# THE MEANING
## OF
# SOIL-EROSION

By
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*The Meaning of Soil-Erosion* is intended for those who, in the course of their advisory work, have to give some thought to the problem of soil-erosion. Important legislation on soil conservation is contemplated in Australia. Much technical knowledge is required and many devices to *cure* soil-erosion will soon be in operation, so it is as well to be clear in our minds just what this erosion is, why there should be soil-erosion, and what practical issues are involved in so-called Soil Conservation.

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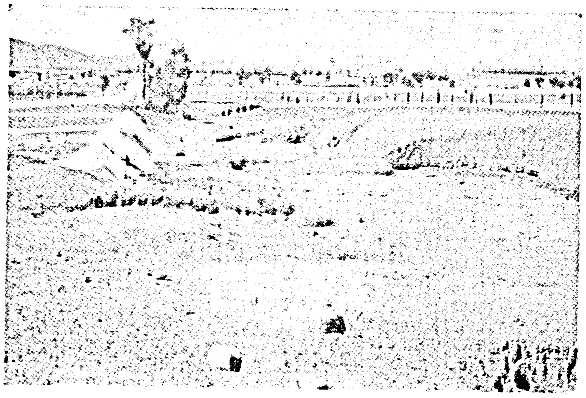
*Plate I*



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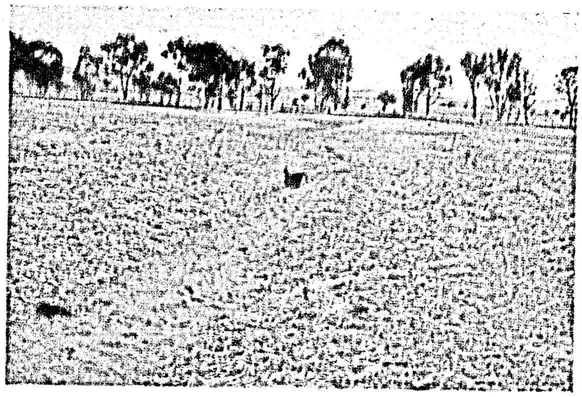

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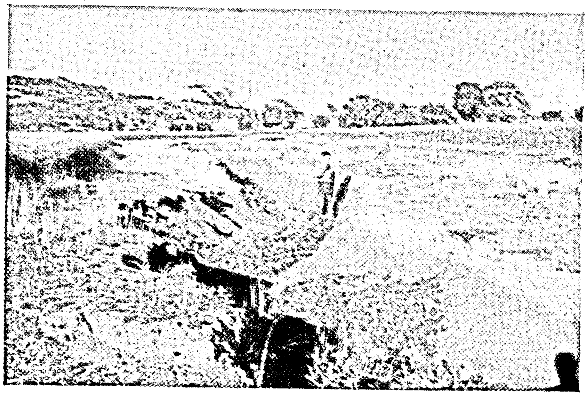

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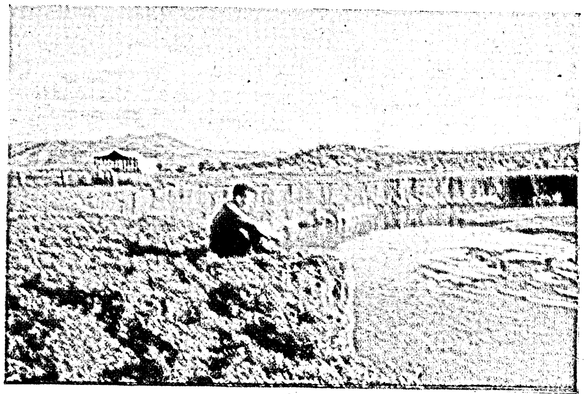

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LANDSCAPES ILLUSTRATIVE OF EROSION BEHAVIOUR (TAMWORTH DISTRICT, NEW SOUTH WALES, AUSTRALIA).

1. The trunk route from Tamworth to Gunnedah (an up-to-date tarred and metalled highway). The road is to the left and the remaining wide area was formerly suitable for travelling stock but it is now an eroded channel. In the early construction of this roadway the top soil from the side was scraped on to the middle —continuous scraping produced a channel way which torrential rain run-off, aided by increased run-off from the good road surface, has transformed into a small valley. This valley developing downwards and outwards requires concrete restraining banks (on the left centre) if the road is not to be carried away. The right bank drains the neighbouring wheat-field and sends out finger gullies which in part are undermining the fence. Erosion here is cataclysmic as the steep right foreground indicates. The road-making processes have altered the natural drainage of this landscape.

2. A "river" of sand (on a fallow field of wheat stubble). Rain wash from the paddocks (fields) above and from the immediate sides has *deposited* a layer of fine sand. All clay has been removed from this material and carried farther away. Renewed ploughing will form in this paddock a soil of greatly increased sandiness, and of more grain uniformity, and less water-retaining capacity. This *deposition* is often the first sign of erosion, a condition easily cured by good property management.

3. Gully erosion is well established, but shows only the "V" form and a readiness to lateral spreading, which if not checked will very quickly radiate to the whole paddock. This picture demonstrates that not only is there a loss of area for wheat growing due to the area of the gully, but a wide region on each side has to be abandoned because of the ramifications of cracks, contributory gullies and the zig-zagging of the gully. The green material in the gully is a crop of weeds indicative of the continuous environmental struggle.

4. Riverine erosion—the "U" form is elaborately developed. One serious flood undermined the bank and removed acres of rich lucerne-growing soil here twelve feet deep (see also text fig. 1). Erosion here is cataclysmic with the maintenance of vertical-walled river banks. Rigorous regional drainage control is the only safeguard for these rich lucerne flats which have a limited distribution and are not being formed on a large scale under present conditions. Figs 3 and 4 from *Proc. Linn. Soc. N.S.W.*, 1937, vol. lxii.

# THE MEANING OF SOIL-EROSION

MACDONALD HOLMES

## PART I

### THE INTRINSIC WORTH OF THE ENVIRONMENT

SOIL-EROSION is ominously obvious to most farmers, graziers, and road-makers. It is especially obvious on that handwork in field and roadway which, heretofore, has made agricultural and pastoral prosperity possible. Soil-erosion is only one aspect of a much larger problem, namely the whole sum and substance of gaining a living from land. Some land surfaces are so exceptionally steep and unstable that no human effort can make them serviceable. On certain of these steep slopes the minimizing of destructive effects is now actually a charge on the State as a whole. *Per contra* other slopes are so ill-drained that human activity is immobilized for several months of the year. Of the 198,000,000 acres of the State of New South Wales only about ten per cent has been found suitable for arable farming.

Inherent in the special problem of soil-erosion lie the problems of the sculpturing of the land surface and the equilibrium of the soil in relation to slope, rock history and climate. Were that all, the problem could be solved in the realm of natural science, but soil is the basis of forest, woodland and grassland, or derivatives of these which give us our food supplies, so agriculture, which can be said to be but the human betterment of natural processes, enters greatly into erosion issues. Further, the soil surface has to be spanned by roads and railways, so that the engineering properties of the soil are as important as those of agriculture.

Now soil-erosion is said to refer only to that acceleration of erosion which accompanies human usage of the land surface, so soil-erosion in this sense is, therefore, a profit and loss business, perfectly straightforward, but of such widespread occurrence and of such gradual operation that in most countries it has passed from an individual to a national issue. The measures necessary to control erosion are creating new individual, new economic, and new political attitudes to land.

#### Land and Its Meaning.

The twentieth century has settled down to putting into ordered sequence the many new discoveries of the nineteenth century, and a fuller, and sometimes new, meaning has to be given to old terms: land usage is not escaping this fashion.

With the nineteenth century expansion of population from European countries, land in the terms of area and space has had a sacredness for itself alone. Nowadays area and space may be costly luxuries unless they can be turned to account and utilized. Whereas in the past little or no use was made of land except where a balanced diet could be obtained direct from the soil by farm husbandry, to-day trade and industry through colonization have sent people out into new country (for example, to the wheat and wool regions) where perhaps only one crop may be obtained, and where a balanced food supply has to be locally imported, so that what was in the eighteenth century area and space becomes, in terms of twentieth century machine civilization and transport, intensively used land.

In the economist's sense, then, land is only significant where it represents a surface of productivity, and the term may include area, soils, the air above as a source of nitrogen and the sub-surface for fuels and metals, so that land becomes synonymous with effective area, and ability to produce, and the study of land resolves itself into **regional resources patterns**. These regional resources patterns involve the turning to account of the geographer's concept of land which sees land in regional entities, each entity having a history and a developing future with laws capable of expression. Land usage must inevitably become aware of and adapt itself to these laws if land economy is to prove successful.

Land usage has accumulated a large body of principles, but a still larger body of what can be termed "lore." The application of lore garnered in small communities, as has characterized Europe until the late nineteenth century, does not lend itself to successful application to the large-scale problems of "new" countries such as Australia: for example, the changes in methods from the two-acre fields of England to the fifty- and hundred-acre wheat paddocks of New South Wales. Nevertheless, new countries have developed sufficiently for them to realize that twentieth century land practice tempers exploitation with conservatism, which alone ensures success for the establishment of resources patterns, and for the political conceptions of Nationhood.

Resources patterns lend themselves to the simple subdivision of agricultural and industrial types, but in reality, in Australia the two are very closely inter-related, since agriculture is greatly dependent upon machinery and transport.

Agriculture, in the wide sense of the term, searches out, turns to account, and improves certain natural regions of the land surface. Its various activities are greatly aided where it finds suitability, though suitability may involve merely acceptance of the natural landscape, as in the wide, ranching character of Queensland, and the Western Division of New South Wales; but suitability may mean a complete transformation of the landscape, as for example, the clearing of the open woodland of the Western Slopes of New South Wales and their conversion to grassland. In this case, permanency of the occupation of the soil by woodland is changed to an equally permanent occupation by grassland, though leaving the landscape more susceptible to soil exposure in the years of scant rainfall. Or again, the search for suitability may mean the entire removal of all vegetation cover, the complete disturbance of the soil by ploughing and its temporary occupation by grain crops for several months of the year, and perhaps not every year in succession. Suitability may seek still further application by ponding back flood waters and using their deposited sediment to raise the land surface and create rich, fertile flats, as for instance in the lucerne-growing districts of the Hunter River district, New South Wales.

Now these agricultural searches and practices require skill and judgment, one might say almost pre-knowledge of circumstances and events, which taken together vouchsafe successful occupation of the soil, and man only courts such success where his agricultural inventiveness and economic skill can be made to give yields that in the social condition of his environment seem to him to be worthwhile. The pastoralist and the forester are equally involved, indeed, more heavily involved in erosion issues, for the reason that their incomes are derived from land on steeper slopes or in climates more arduous than that of the arable farmers. The **fine wool** producers of eastern

Australia have a very strenuous task before them in this connexion.

Since suitability is the key-point in the initial success in agriculture and in general in the use of the land, it naturally follows that those primary factors of the environment, namely climate, topography and soil, which, taken together, produce suitability in the land surface, should be better understood.[1]

We now proceed to the discussion of these primary factors but it will be recognized that land exploitation and development (including the use of the soil) have a history and a sociology which are not yet receiving the intensive study due to them.

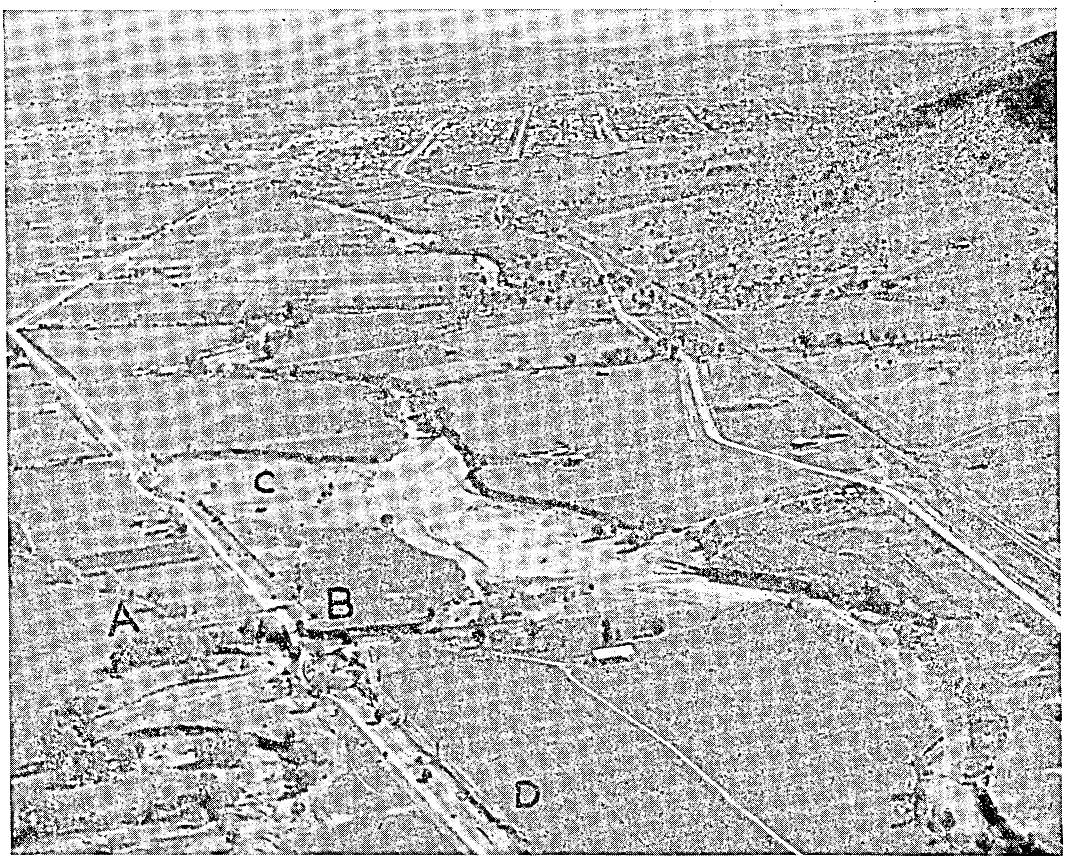


FIG. 1.—THE TAMWORTH PLAIN AT JUNCTION OF PEEL AND COCKBURN RIVERS.
Note the varied suitability in treed upper slope followed down the slope by grazing, wheat and lucerne —extensive riverine erosion—two main roads, railway, and a town of 10,000 people beyond. See later pages.)

[1] Part I of this publication discusses the theory of land surface formation, while Parts II and III apply this theory to soil particularly. The next few sections may be omitted by any one interested only in what is usually termed the more practical side.

## The Theory of Land Surface Formation.

**Early ideas.** The poet and the artist were the first to interpret the extraordinary power which landscape has gained over people's minds. Though this power comes largely from the appreciation of geometric form and the blending of colour, it is not entirely explained in this way. Poetic appreciation of landscape has perpetuated itself in being the chief instrument for giving names to landform. For example, the Blue Mountains of New South Wales have a characteristic blue appearance due to the diffusion of light in their canyon-like valleys. "The still small voice of the level twilight on purple hills."

At the present time, majestic scenery and even the wide open plains are making an appeal as strong as formerly. This appeal is being "capitalized" by tourist bureaux which have governmental support in all countries. One of the most progressive of these Australian tourist organizations (with naïve disregard of any provision for the study of its "goods") has made use of the slogan "Selling Australian Scenery."

Contemporaneous with this poetic appreciation of scenery, but to a great extent divorced from it, has been the application of scientific methods to landform study. Since 1870, and in time to share in the enthusiasm engendered by Darwinism, landform study took on an evolutionary aspect, until to-day landform is looked upon as a product of the great forces within the earth causing crustal movement, and the less spectacular but equally effective forces of climate. Thus great blocks of the earth's crust may be raised into positions which we call mountains, but their majesty and variety of form can be attributed to the climates of the latitudes in which they are found, and in part which they help to bring into being.

Scientific landform study has now attained to a considerable body of knowledge, and several branches of science are helped by geomorphometry as it is sometimes called. Thus the history of the earth as represented by geology looks to surface form for much of its evidence. Again, the irregularities of the surface, when grouped together and reduced to a common base-level, give to geodesy and geophysics evidence of crustal movement and indication of the strength of the forces inherent in the earth. The conception of landscape as a system of straight lines and parabolic curves can be welded (it is true with difficulty) into a system of earth geometry, and the conception of the artist finds itself interpreted by the abstractions of mathematics. Thus the romance which the qualities in landscape bring to the artist is not less significant when formulated in mathematical quantities by the geographer.

From the days of the Romans with their "field measurers" to the highly organized Ordnance Surveys of our times, earth measurement has found landforms a complex study and the relation of landforms to measurement and the solution of its problems has added greatly to the accuracy and beauty of our maps.

Simple as a map may look, no distance on the earth is truly measured until it is related to the Figure of the Earth; and this Figure is the shape the earth has as a whole according to observations of gravity, **measurements of arc** and topographic surveys generally. The internationally accepted Figure of the Earth is Hayford's.

These aspects of the **pure science of landforms** have not been without their application. Thus valleys, which are great grooves in the earth, when measured for volume and for rainfall-catching capacity, become great reservoirs for cities' water supply, also the foremost of our food supplies. The growth of population on marginal lands has necessitated great irrigation schemes, with precise measurements of topography-soil-climate which are the basis of irrigation suitability. So too the transport engineer is evolving a technique for the subjection of the infinite variety of landform. Not least of the many searchers after landform explanation is the pioneer agriculturist who seeks out, as did his predecessors from immemorial time, the simple slopes and "easy-movement" surface for his plough, and for the streets of his cities.

In soil-erosion studies any classification of surface landform would simplify matters. But classification is by no means an easy matter, nor have any classifications so far made met with general acceptance. In this connexion, Passarge's[2] classification merits study.

At the same time, through all efforts at classification there is a persistence of certain ideas which for this reason may claim to be fundamental, especially if examined in a regional way.

**Persistence of ideas.** First of all landform can be considered as a resultant of the play of external forces acting upon the earth, and the reaction of the earth to these as a whole. It would seem that surface sculpture proceeds from a system of irregularity to one of regularity, from a haphazard distribution of slopes and heights towards more ordered and grouped systems of forms. Thus the landscape which appears stupendous and weird may obtain that aspect from the unexpected change of slope and ruggedness of valley, torrential streams and falling rock masses, and the apparent rapidity with which the landscape is changing. At the other end of the scale, that feeling of satisfaction which arises when viewing the well-tilled and cultivated plain, with its parklands and ordered village life, may be attributed to the sequence of gentle slopes and meandering placid streams and the order of interdigited smooth surfaces.

Thus there comes a conflict of emphasis between those schools of thought which see in landform formation a catastrophic action as the first cause, and leave to the function of erosion (denudation) merely small modifications and irregularities of the surface. It were better to see them contemporaneous, the one exceeding in power the other until an equilibrium is reached when the forces proceed very much slower, for erosion of the earth's surface has been accomplished in successive intervals marked off by movements of upheaval.

A further set of ideas in the scientific study of scenery was in time to take part in the evolutionary aspects of science derived from Darwinism. The age-long description of a river as a goddess who had to be propitiated even by human sacrifice was changed to the description of rivers as eroding agents, the torrent having the aspects of youth, the wide navigable streams bearing the burdens of maturity and the placid estuary depositing its sediments and surrendering its burdens until senility and the sea are reached. Advancing that idea further, a **cycle of erosion**[3] can be formulated for the landscape as a whole on the various stages recognized and the degree to which they are likely to evolve. Thus high landscapes, by processes of disintegration and by clearly defined stages, work themselves down to wide extensive plains almost at sea-level, and furthermore, many similar flat surfaces, now the summits of plateaux, are considered to have been once at sea-level, but now lifted by the building-up action of the earth to their present high position.

[2] Mitteilungen des Geog. Gesell. in Hamburg, Heft 2, Bd xxvi.

[3] Davis (*The Cycle of Erosion and the Summit Level of the Alps*: Journ. of Geol., vol. xxxi, No. 1, 1923) discusses Penck's essay on the Summit Level of the Alps. The general principle has been discussed that the height of a ridge crest above a neighbouring floor will be a simple fraction—about one-quarter (according to Penck) of the distance between the valleys (with the exception of the small headwater streams of an uplifted peneplain), provided that the cliffs and ledges on the ridge side are obliterated by the upward or retrogressive extension of graded slopes of fairly uniform declivity; but previous to the attainment of ungraded cliffs and ledges the ridge crest will have heights independent of the spacing of the valleys. It would seem, further, as if a very special, though accidental, relation must exist between rate of upheaval, climate, drainage area and rock resistance in order that good sized streams should maintain a graded flow and that their valleys should maintain graded slopes, even while upheaval is in progress.

Thus land sculpture is conceived as a slow process of evolution, but necessitating cataclysmic forces within the earth so that there may be successive rejuvenations, a repetition amply borne out by the geological table, by beach terraces, and valley-in-valley structure.

Now the development of landforms shows distinctive cycles for the various climatic regions; thus there are normal, arid and glacial cycles. All landscapes, where most of the yearly rainfall total is spread evenly from month to month, differ when compared with those regions where there is a six months' seasonal activity or where there is an almost entire absence of rain, but where wind is the fundamental influence for land sculpture, as in arid lands. Thus landform study envisages the principle of **quality** in landscape which in time will no doubt be expressed in arithmetic **quantities.**

In its application to soil-erosion, this cyclic idea can be very useful, since landscapes may be recognized and classified according to their developmental stage and their erodability—knowledge which must guide pastoral and farm economy. For example, excessively youthful surfaces and excessively senile surfaces prove of equally increasing difficulty—youth because of excessive and rapid drainage, age because of flooding and the absence of drainage.

Thus in landform study in the narrow sense of landscape there arise three schools of thought according as the genetic, catastrophic, and evolutionary aspects of landscape formation are emphasized. There is yet a fourth which has scarcely received any attention, namely purely earth-shape measurement (morphometry). In the literature of civil engineering, this phase of geography meets with great attention because volumes of valleys, run-off of rivers, rates of soil movement, and in general landscape occupation, as in closer settlement and irrigation schemes, invariably necessitate quantitative measurement of land surface form. Thus Penck's[4] mathematical ideas are finding increasing usefulness.

### Australian Regional Landscapes.

And so among the first facts to be explained and the very first thing in the meaning of erosion generally is that the component parts of any landscape have a **consanguinity of behaviour** (so to say), and the very landscape as a whole becomes a living regional entity. It is this **living** quality which distinguishes geographical from geological descriptions of landforms. While the complete specification and explanation of such regional entities for Australia is as yet impossible, the following figures (2, 3) and text make an approximation thereto, and in the absence of precise topographic mapping might suffice. These descriptions are included here because they are indicative of the background upon which erosion thought must work and which must form a basis for regional soil-conservation administration.[5]

**Inland.** In figures 2 and 3 the regions are lettered and numbered rather than named. Regions with the same letter, but a different number have many common characteristics. In figure 2 all those regions grouped under A are characteristically plains; B are upland regions of mature slopes with intervening flat-floored valleys; C are plateaux, for the most part flat on top, but diversified with many very deep canyons, some of those, for example, in the Blue Mountains, extending to a depth of over 1000 feet, though only half a mile wide; group D can be termed mountains, in the sense that their slopes are steep, their summits small in area, and their rock structure very much distorted.

[4] Penck, A.: *Morphologie der Erdoberfläche.* Stuttgart, 1894.

[5] The regions here specified by letters and numbers have been described at considerable length in a cyclostyled memoir prepared in the Department of Geography, University of Sydney. A limited number of copies is available. A bibliography will be found in *The Australian Geographer*, vol. ii, No. 1, 1933, and subsequent numbers to date.

The details of each are now briefly indicated.

**A1.** Coastal riverine plains with flat, fertile valley floors, navigable estuaries, and rugged headwaters.

**A2, 3, 4, 5.** Types of plains with separate characteristics, but all essentially ter rainfall areas these regions are fertile, but in the drier regions, as in Western Australia, the valleys are often sandy and the soil is of poor fertility. In the centre of Australia the plains are found to differ by the characteristic vegetation they carry. To the south of the centre, there

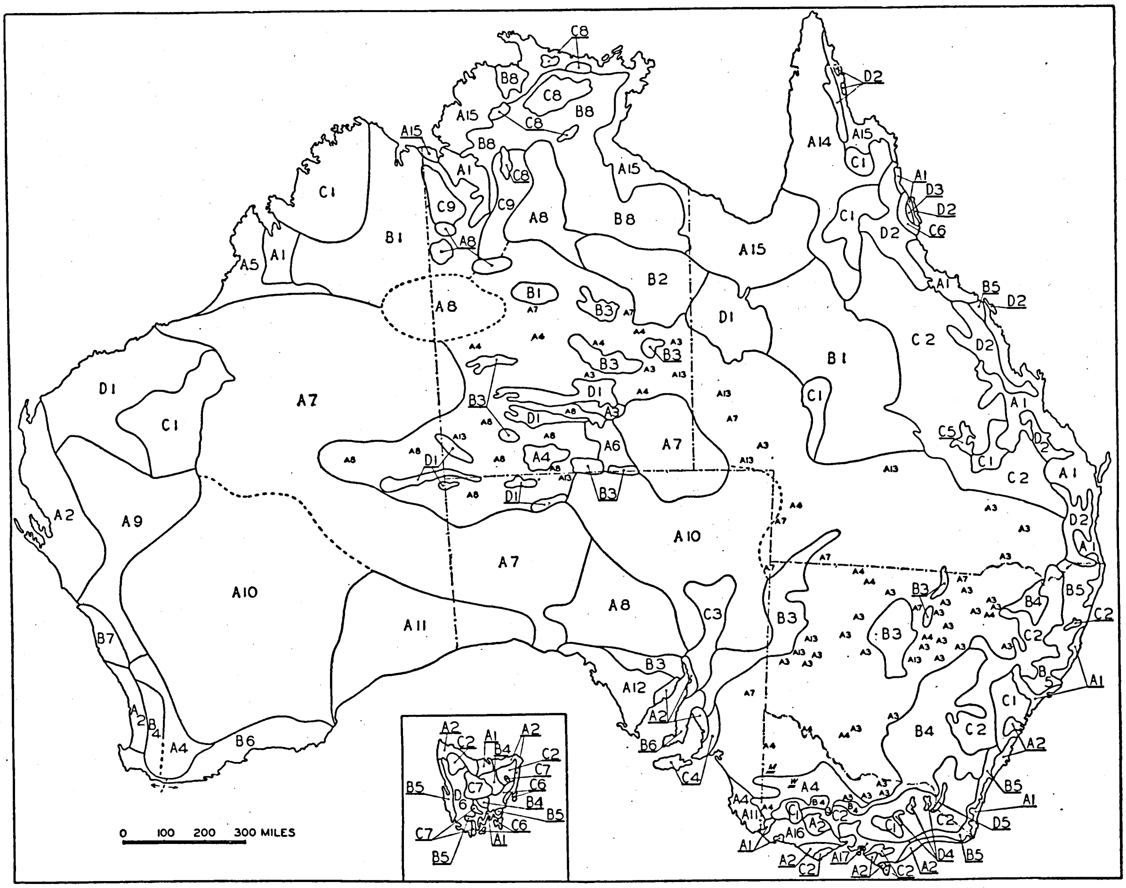


FIG. 2.—AUSTRALIAN REGIONAL LANDSCAPES (INLAND).
Each region is signified by a letter and a number. Where these are underlined they refer to groups of small regions in the neighbourhood. M = Mallee, W = Wimmera.

found inland, surrounded by steeply rising slopes. They differ principally by the characteristics of their soils. Away from the rivers the soils are red and loamy in character, while close to the rivers and in the more gently sloping areas black or grey soils are characteristic. In the better rainfall areas these regions are fertile, are saltbush and cotton-bush flats, with patches of mulga scrub with grass and spinifex. In the north, plain areas are principally mulga flats with spinifex country.

**A7.** An arid land of sand ridges. The ridges are generally parallel, may extend for 200 miles, rise to sixty feet in height, and be separated from each other by distances up to half a mile.

**A10.** Principally sand plain with salt lakes and saltpans, and with low ridges and breakaways.

**A11.** Chiefly a limestone plain almost dead level, without surface drainage, and with limestone caves and underground drainage.

**A14.** A region of sandy ridges and marshy flats, but there is a great frequency of the small, flat-topped plateau bounded by steep cliffs.

**A15.** A gently inclined plain, tilted upwards towards the south at a slope of three feet per mile. The rivers are often dry and sandy, having ill-defined channels, except in the marshy areas near to the coast.

**B1 and B2** are the great uplands of Queensland and the grazing lands of the north.

**B4 and B5** have their principal development in New South Wales where they form the regions of steep slopes (B5) or more gently sloping areas (B4) marginal to the plateaux (C2). They are characteristically picturesque, being tree-covered in great part, or cleared to a park landscape for grazing.

**C1** represents the scenery characteristic of the Blue Mountains of New South Wales, which has had a remarkable in-

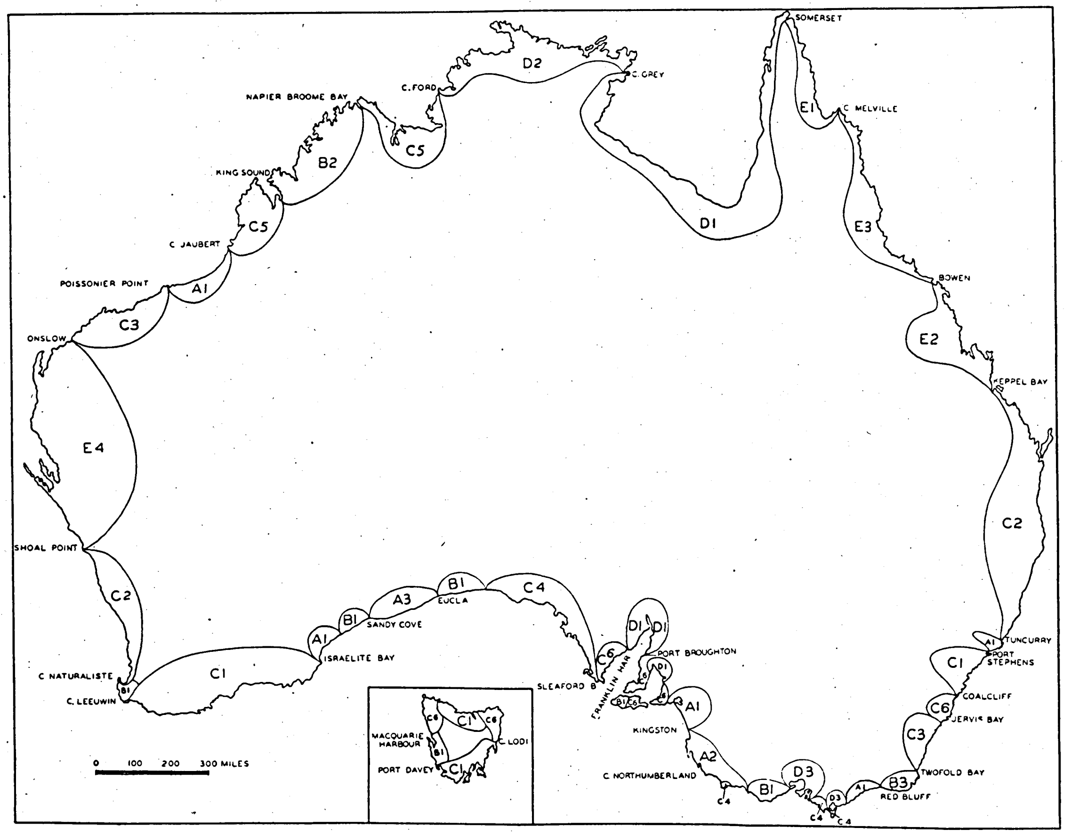


FIG. 3.—AUSTRALIAN REGIONAL LANDSCAPES (COASTAL).
Each region is signified by a letter and a number. Regions marked refer only to the *coastline*.

fluence on the historical development of Australia. These plateaux have a surface level of between three and four thousand feet. Their upper flat surfaces are deeply truncated by precipitous canyon-like gorges. Similar areas are found in north Queensland, but especially in north-western Western Australia.

**C2** are the plateaux of New South Wales and central Queensland. They are great undulating areas with clear streams, and for the most part pastoral country with a healthy and invigorating climate, irrespective of the latitude.

The other numbers under the heading of C are plateau areas, with their own special features.

**D** are small areas of what could be termed true mountains, because of height, steepness of slope, rugged appearance and rock structure, and have been subdivided into six groups because of their individual characteristics.

**Coastal.** In the following description the coasts of Australia are subdivided into four groups according to their appearance. Group A consists of the long sandy beach type; group B, those coasts which have steep cliffs throughout; group C includes those areas where there is an alternation of low flat coastline and cliff headlands; group D are low flat coastlines; and group E in general C type modified by barrier reefs.

Within each of these groups (A, B, C, D and E) considerable variations in coastal form occur, and each group is further subdivided as shown on map (figure 3).

The following paragraphs state briefly their regional characteristics.

**A1.** Coast is almost straight, and backed by fresh or salt water lagoons or swamps. There are very few openings in the coast. **A2** is characterized by projecting headlands, and the coast is fringed with sandhills. **A3** consists of a succession of sandy hummocks, about 150 feet high, partly covered by bushes.

**B1.** Rugged cliffs, general outline simple. No harbours. Cliffs practically vertical, overhanging in places. Numerous small bays and narrow gorges. Sea caves and arches show marine erosion. Islets with vertical cliffs. Talus slopes due to cliff erosion. Narrow beaches with very little sand. Wave-cut platforms at base of cliffs. **B2.** Coastline is extremely broken. Many harbours and islands. Harbours flanked by precipitous sandstone cliffs which rise hundreds of feet—some sounds very deep and landlocked, region being deeply dissected. Ria coastline, tidal phenomena marked. Sounds upwards of forty miles in length, some reaching one hundred miles inland. Mangroves in a few places. An arid coastline. **B3.** The whole coastline is defined by conspicuous mountains and hills. Steep cliffs faced by huge accumulations of sand. A succession of bold promontories and wide valleys. Trend of mountains and strike of rocks at right angles to coast.

**C1.** Deep, narrow arms of the sea with good harbours into which rivers flow. Within the inlets are small, crescent-shaped beaches, usually backed by hills and alternating with long stretches of precipitous cliffs and rocky promontories with rock platforms and many broken rock boulders near the tidal line. Some sand spits and sandy peninsulas and a few small tidal beaches. **C2.** Many rivers enter the sea and sand bars are formed. Cliffs, sometimes fringed with rock platforms, alternate with beaches and low swampy areas. Numerous islands along the coast are sometimes linked together by beaches and sandbars. Beaches and low areas predominate. **C3.** Coastline is broken with an abundance of islands. Tidal phenomena marked. Wide low coastal plains are terminated by practically vertical cliffs which rise to an elevation of between 400 and 1000 feet. Coastal plain fringed by bold, rocky hills which usually form capes and promontories at the head of which are often extensive mangrove swamps covered with salt water at each spring tide. The coast is confronted by rocky ledges which dry at a considerable distance offshore. Coastline is being smoothed by islands tied to the mainland and by the growth of mangroves and by rivers carrying silt to the sea. **C4.** Predominance of headlands—300 feet high and nearly vertical. Steep, high cliffs extend to water's edge, from here coast falls to about 100 feet showing sandhill formation. Between the headlands the land is low, showing a succession of sandhills rising to 100-160 feet. **C5.** The coast is hilly with cliffs skirted by sandy beaches. Headlands 100 to 150 feet. Coast of mangroves with reefs at entrance of bays. Sand and freshwater lagoons are also common. **C6.** Fairly regular coastline—sandy beaches predominate with a few cliffy projections. Low coast backed by sandhills. Low broken cliffs, sandflats and sandspits.

**D1.** A low unvaried coastline, sandy or muddy, often with long stretches of mangroves. Muddy river entrances at right angles to the coast. Smooth, backed inland by low country. Mostly shallow water offshore. **D2.** In general coast much more broken than D1. Very large openings. Large islands off coast. More pronounced headlands. Bays shallow, mud flats. In places the coast is backed by white sandhills. The islands off the coast are steep and cliffed. **D3.** Shallow basin area. Mud flats surround shores of bays. Heads of bays are low and jut out from rocky cliffs. A series of sand hummocks is characteristic of peninsulas. Occasional swamps along the shores of the bays. High cliffs along portions of bay. Coastal headlands rise to nearly 300 feet. Islands in the bay are rugged, irregular, rocky.

**E1.** Like C2, but with low background and with numerous small fringing islands. Alternating low mud and sand plains—low sandhills and undulating country and ranges. **E2.** Low sandy or swampy flats, alternating with hills up to 1800 feet (sometimes rugged). Islands are high and rocky (peaks are drowned ranges). Coastal ranges lofty, often broken by transverse gaps. **E3.** Similar to E2, but more precipitous coast. Alternation of cliffs, mountains high, 1000 to 2500 feet, rugged, steep, very narrow continental shelf. Few islands, gently undulating country, sandhills. **E4.** The chief feature of this area is very large bays flanked by rocky promontories parallel to the coast, allied to the Dalmatian type. Coral reefs occur off the coast.

The Great Barrier Reef may be said to extend for 1000 miles, and follows generally the sinuosities of the coast. The outer edge varies in distance from the coast; at Cape Melville, fifteen miles; at Cape York, eighty miles; at Port Clinton, 145 miles. The reef is almost continuous but has important openings called passages. Cook's Passage, for example, is three-quarters of a mile wide and ten to twenty-five fathoms deep. The Barrier Reef is essentially a coral platform with an outer edge steepening down to over one hundred fathoms and bordered by a crest, not everywhere awash, and having occasionally small reefs outside. On the platform there are regularly distributed reefs at various stages of development. Less frequently there are true rock islands, some of which have taken an alignment parallel to the mainland, e.g. Whitsunday Group. Between reefs and coast is a deep but frequently narrow and tortuous navigable channel, spoken of as the smooth water route when compared with the more boisterous open ocean route.

The landform on the neighbouring mainland is smooth with small amounts of cliffing. There is a frequency of parabolic curves.

### Climate in Relation to Erosion.

The facts to be explained in climate are briefly as follows: Climate is a statistical synthesis of long-term meteorological observations, and not the average of weather conditions as is often stated. Climate deals with abstractions not experience. It is the persistent and sustained climate factors which are important for discussion of wide areas, although for specific problems detailed climatological analysis (micro-climatology) is necessary.

In the absence of initial meteorological observations, the climate of a region can be quite accurately deduced from landscape appearance, and vegetation character, for it is readily understood that the surface appearance of any landscape (the living land surface) is created chiefly by climate and not by geological characteristics. Hard and soft rocks over a wide area may respond alike, and in many

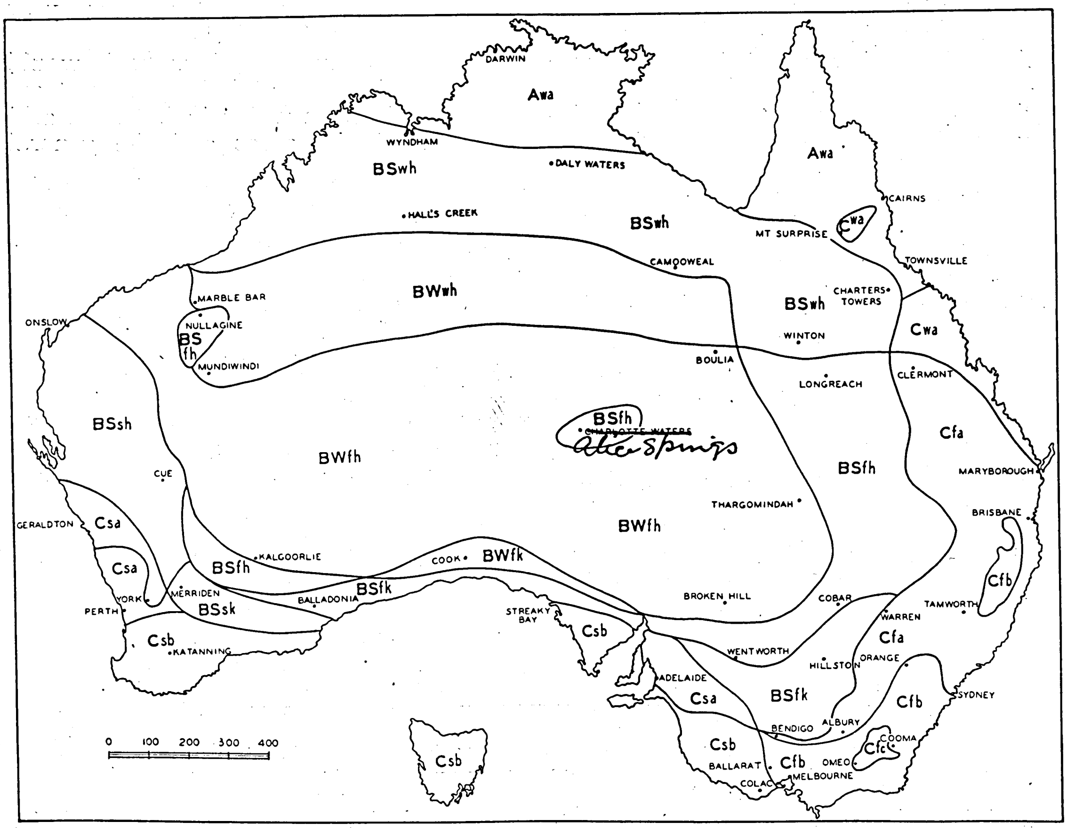


FIG. 4.—THE CLIMATIC REGIONS OF AUSTRALIA BASED ON KOPPEN.
A. Tropical Climates; BS. Semi-Arid (Dry) Climates; BW. Desert Climate.

RAINFALL REGIME.

s = Winter maximum of rainfall. More than 25 per cent of total annual rainfall in the three winter months, June, July, and August.

w = Summer maximum of rainfall. More than 33 per cent of total annual rainfall in the three summer months, December, January, and February, and less than 17 per cent of the total annual rainfall in the three winter months, June, July, and August.

f = Double maximum of rainfall. Less than 25 per cent of the total annual rainfall in the three winter months, June, July, and August, and less than 33 per cent of the total annual rainfall in the three summer months, December, January and February.

TEMPERATURE FACTOR.

a = Average temperature of warmest month more than 22°C. (71·5°F.).

b = Average temperature of warmest month less than 22°C. (71·5°F.) and more than four months with an average temperature of more than 10°C. (50°F.).

c = Average temperature of only one to four months more than 10°C. (50°F.), coldest month more than −36°C.

h = Average annual temperature more than 18°C. (64·4°F.).

k = Average annual temperature less than 18°C. (64·4°F.).

The climatic regions shown in fig. 4 do not differ greatly from Köppen's own maps. The text accompanying the small letters arranges the usual data differently, and adds further modifications to this map. See also footnotes 6 and 8, page 14.

cases are obliterated by great depths of wind-blown sand or covered by glacial or water-carried rock debris to form soil, which bears little or no relation to the underlying rock.

As with landforms, so it is with climate —the regional treatment of large areas (with specific micro-climate studies) indicates wise erosion plans and policies.

limiting of the arid area is also indicated clearly from Andrews's map[7] (fig. 5) on the distribution of arid months per year and from Lawrence's desert year frequency map (fig. 6).[8]

Now to augment such maps it would be well to know the wind and rain **storm tracks** and **storm nodes** in both the arid and the pluvial areas and the general

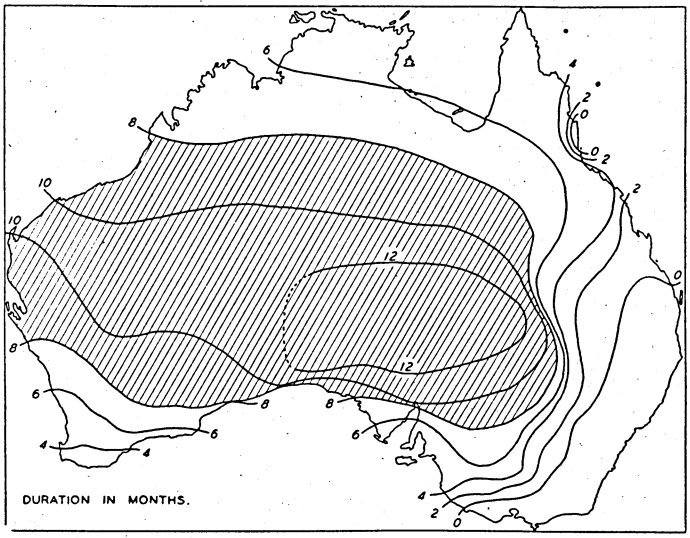


FIG. 5.—LINES OF MONTHLY CLIMATIC ARIDITY.
Shaded portion has over eight months "arid" and can be said to represent arid Australia.

## The Chief Climatic Regions of Australia.

Perhaps the most successful regional climatic maps of Australia are based on Köppen's world classification of climate.[6]

Fig. 4 and accompanying text sets out the various climatic regions of Australia on general terms. The regions are self-explanatory and certain well defined climatic régimes are delimited. For example, the inland regions of Australia experience arid erosion chiefly, while the coast experiences pluvial erosion, and there are many subdivisions within these. The detrends of the prevailing strong winds, while on the coastal area, the distribution of thunderstorms which bring torrential rain narrows the erosion issue within the climatic field.

Though not all thunderstorms bring torrential rain, there are on the north coast of New South Wales, in the neighbourhood of Brisbane, between thirty and sixty important thunderstorms in the year. In the wheat belt of New South Wales fifteen is a common frequency and in the Western Division up to fifteen is common.

[6] Köppen and Geiger: *Klimakarte der Erde*, 1928. D. A. Herbert (A.N.Z.A.A.S. Report, vol. xxii, 1935) prefers Thornthwaite's classification. Both systems are equally meritorious and adequate on present Australian meteorological data. See also *The Australian Geographer*, vol. iii, No. 3, 1937.
[7] This we have treated more fully in Publication 2 of this series. See also Report A.N.Z.A.A.S., Melbourne, 1935, "Content of Geographical Study."
[8] *The Australian Geographer*, 1937, vol. iii, No. 3.

In any national erosion project these general climatic regions must be of service, but in addition special details of climate (not now available) over short periods and small regions will be necessary. Such climates are called micro-climates, and their investigation is dependent upon research projects rather than the standard meteorological services of a State; for example, rainfall (precipitation) is required by the fall and not by the 24 hours, and what is called the first and last **killing frost date** should be known in all wheat and wool-shearing districts.

The critical incidence of precipitation, wind and temperature are more important than arithmetical averages in specific erosion cases. For example, the coincidence of summer thunderstorms (December) and bare soil fallow in the Tamworth district, New South Wales, makes the prediction of storm-rain frequency invaluable in soil conservation treatment.

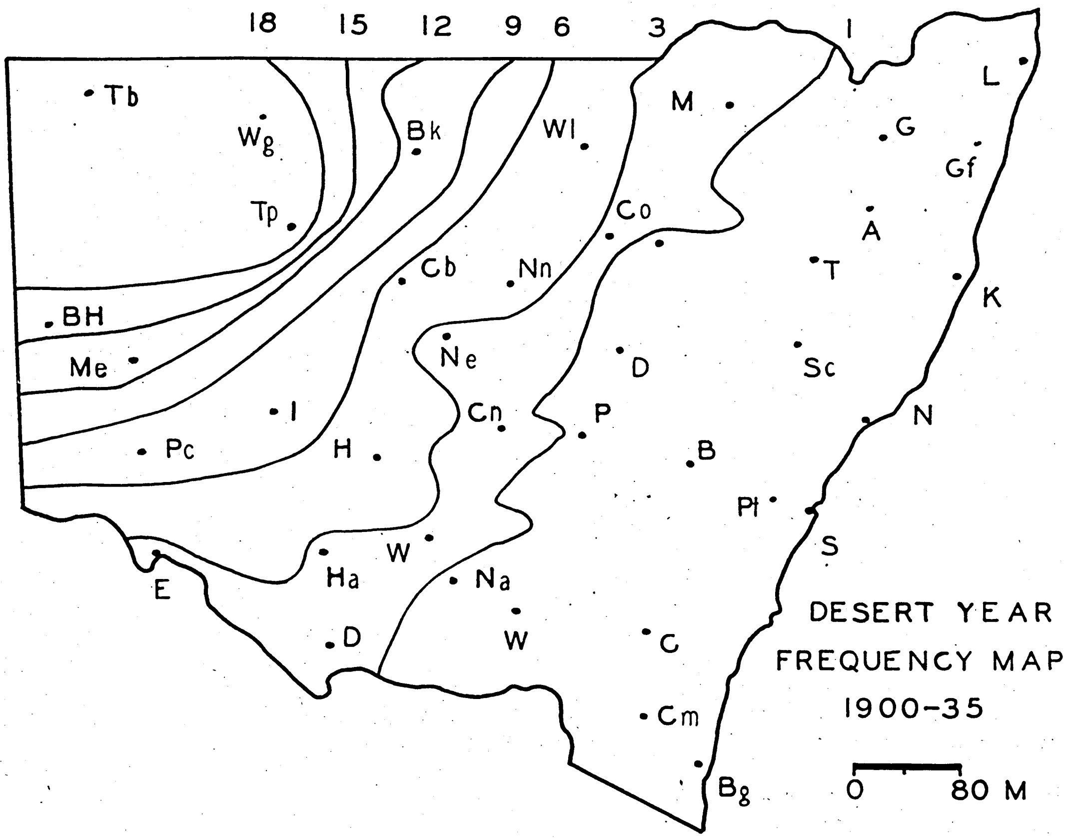


FIG. 6.—DESERT YEAR FREQUENCY IN NEW SOUTH WALES.
The western portion of the State has eighteen out of thirty-six years *desert*, while the eastern third has thirty out of thirty-six years *humid*.

### The Geological Factor in Erosion.

In erosion issues those factors of solid geology to which most attention is usually given by geologists are not so significant as at first sight would appear. The reasons for this are obvious, since geological structure and surface form are invariably greatly discordant, that is to say rarely are flat plains underlain by horizontal rocks. Nevertheless, adequate geological mapping is very pressing in this erosion work, since it is desirable to know the character and ages of rocks so as to determine erosion history.

The present-day surface of Australia began early in geological history, experienced several catastrophic changes, but has probably been exposed to atmospheric agencies since Palaeozoic times, and for this reason extensive areas are overlain with deep deposits of unconsolidated material, the top surface only of which is now labelled soil. Further, over large areas, drainage patterns (a very significant erosion study) traverse many rock types and structural forms, and soil deposits associated with them show a complex history. What is called a **drift map** (that is superficial deposits rather than solid geology) would be invaluable for erosion purposes, and field geologists ought to give more attention to this in their work, their reports, and their maps. Some aspects of soil-erosion are almost unintelligible without knowledge of this past soil history if one may so call it.

Now practically all of Australia has been land since the end of Cretaceous time while since Carboniferous times there have been great changes in the general level and hence the slope and erosion rate of the Australian land surface, and many unconsolidated deposits, now forming soil, owe their characteristics to these changes. Further, there is geological evidence in Australia for great climatic changes in Pleistocene times, that is to say about the time when mankind was first on the earth, and such climatic change means many changes in erosion and deposition. The evidence for this climatic change will be found, for example, in the Kosciusko glaciation, the deep mining leads in Victoria and New South Wales (e.g. Hanging Rock, Nundle, and Wollomumbi, New England) and the variety of eastern Australian soils.[9]

It will be sufficient to give one or two examples here of the significance in the erosion issue of the long period of landform development, past geological history and climatic change.

Slope has a remarkable influence on rate and character of erosion, and a long erosion period with several tectonic changes in surface levels has produced over Australia very extensive plains and gentle slopes. The frequent changing character of the rock, especially in eastern Australia, in the best agricultural and pastoral lands has induced frequent **breaks of slope** with what could be termed "oversteepening" of the lower middle slope, while the climatic change has produced valley-in-valley structure. The very ease with which water dams in eastern Australia can be constructed, but likewise the difficulties of silting, can be attributed to this cause. Again, since soil is to a great extent rock debris, the character of the underlying rock has an important bearing on the type of soil formed, but the variety of rock type and structures and the long erosion history in eastern Australia demand caution in attributing to soil qualities borrowed from the associated rocks. So it is the discordance between geological structure and slope, and between rock character and soil type, that are so illuminating in erosion problems.

### The Vegetation Factor in Erosion.

As is almost everywhere obvious, the landscape is covered either with trees, grass or crops. By a variety of ways, such as adaptation, colonization and succession, have the present societies of trees

[9] See also: E. C. Andrews: *The Geology of the Broken Hill District.* Memoirs of the Geol. Surv. of N.S.W., Geol. No. 8, 1922. J. Macdonald Holmes: *The Growth of Soil on Slopes.* Procs. Linn. Soc., N.S.W., vol. lxii, 1937. W. R. Browne and H. G. Raggatt: *Notes on the Buried Rivers of Eastern Australia. Aust. Geog.*, vol. ii, No. 6.

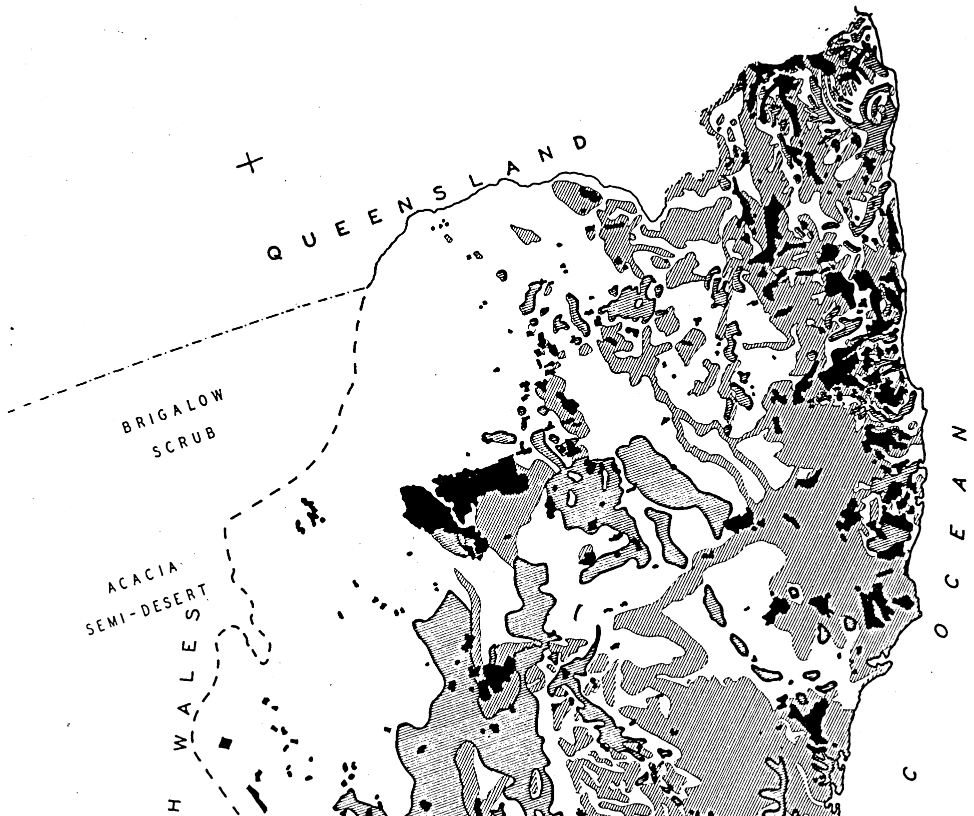


FIG. 7.—LAND OCCUPATION, NEW SOUTH WALES (EASTERN).

This map shows the way nature and man's activities have occupied the soil. Red = cropland; diagonal = treedland; black = State forest; white = grassland. The word "treedland" is used for areas not forests but often partly cleared for grazing purposes. This map shows that the greater part of the eastern area of the State has been changed from its pristine appearance, e.g. 87 per cent now grassland.

come to their present co-ordinated efforts and location, for trees and grasses are societies and their erosion effectiveness only obtains according as they remain societies.

Generally, except in the very far west, the chief covering in Australia has been trees, either in the form of rain forest, woodland or scrub (mallee or mulga), though in the middle west of the State there has been an even mixture of grass and trees (savannah). The effect of agricultural and pastoral development, especially in the last fifty years, has been to remove extensively the tree covering and to replace it by grass pasturage, though large areas have been replaced by crops, especially wheat and lucerne, which of course means bare fallow land for at least several months of the year.

The general appearance of this State and the changes which have taken place may be seen from the land use map of New South Wales (fig. 7). This map should be of further service in the determining of regional erosion policies throughout the State. It will be seen that in the coastal regions the areas under agriculture are comparatively small, widely distributed and closely related to valley floors. Fur-

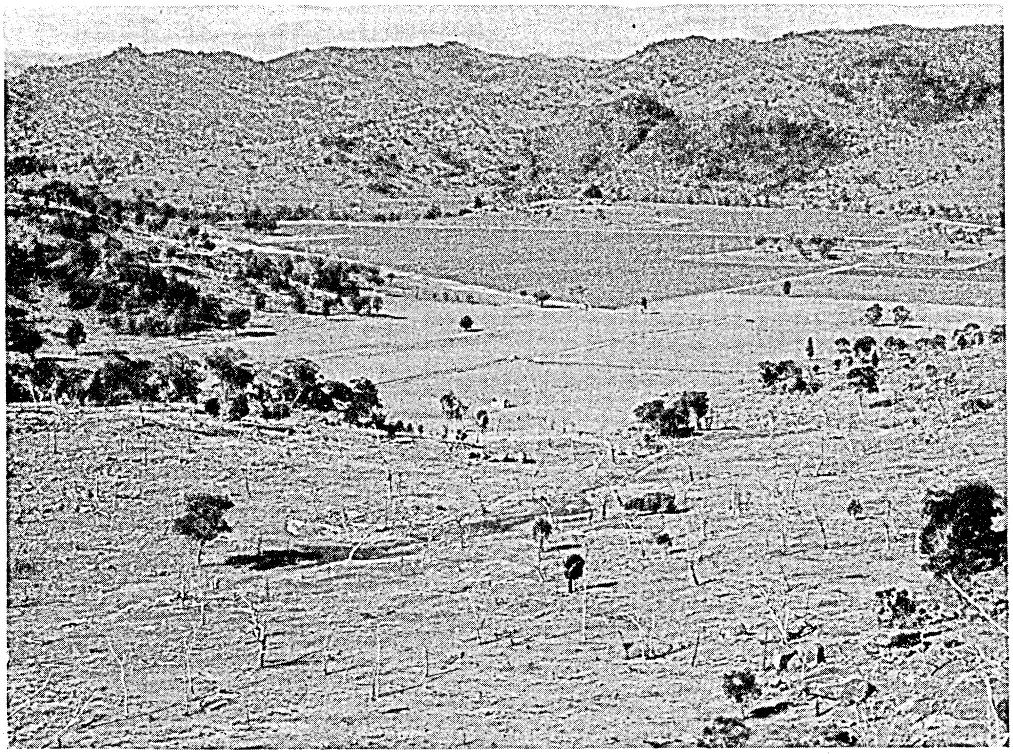

FIG. 8.—RICH ALLUVIAL VALLEY FLOOR SURROUNDED BY STEEP HILLS TYPICAL OF THE MARGIN OF NEW ENGLAND PLATEAU.

Ruthless clearing of hill-sides (foreground), aided by increased run-off, is destroying the lower slopes and will ultimately affect the deeper soils of the valley floor. Note the extensive detreeing of the steep slopes in this cauldron-shaped valley. There is great need for a plan in this valley such as contour tree-preservation, the break-of-slope tree-planting, the creation of heavy pasturage and a smaller subdivision of paddocks for crop rotation.

ther, that these good agricultural soil areas are in close proximity to steep slopes, usually grassed, and very steep slopes on the edges of the plateaux, usually tree covered. The maintenance of this pattern, i.e., lower slope agriculture, middle slope grass, and upper slope trees, is absolutely imperative if the rich agricultural flats are to remain. Further, the very limited agricultural suitability has to be preserved from cataclysmic forces engendered by flood on the forested (or frequently deforested) ranges (fig. 8).

Again, soil-erosion has often been considered most disastrous in arable land, but it will be clear from this map (fig. 7) that the greater part of the State is grassland. Grassland soil-erosion is seldom as obvious as arable land erosion and yet much of the degeneration of pasturage is directly due to the removal of the clay content of the soil by erosion which makes an absence of the necessary seed bed for reseeding of grasses and for the establishment of new and tender growth. Two tendencies are apparent: one, the establishment of hard, woody tissues in grasses, and the other the decay of the soft and more nutrient grass types, leaving the environment to the harder grasses. This deterioration of pastures has often been attributed to the selective feeding habits of stock, but that alone, we are prepared to state, is not the chief cause of pasture deterioration.

From the position of the chief arable areas of the State and the fact that wheat is the chief crop, a crop usually grown inland and often marginal to agricultural conditions, wind erosion is likely to be as disastrous as water erosion. The relative frequency of appeals by western farmers due to crop losses can be as closely related to soil-erosion as to climatic vagaries.

Greater attention requires to be given to the type of vegetation (including grasses) suitable as fodder rather than as fertilizers, and the preservation of the soil slope from slumping and the differential development of sandiness and grain uniformity. The critical points about vegetation cover are that:

(1) No matter what **density** of vegetation exists, there must always be some erosion—for vegetation is an eroding agent—direct physically and indirect by chemical changes from plant growth and decay.

(2) Farming and cropping, and even forestry, necessitate practices, such as burning, scarifying and ploughing, which for short and sometimes long periods bare the ground. The efficacy of these processes depends on opening, loosening and exposing the soil.

(3) The **cultural landscape** (as it has been called) need not have in its economy any greater amount of erosion than its dispossessed **natural landscape.**

In eastern Australia rarely is the ground one hundred per cent covered all the year round by the natural growth of vegetation. Controversy has arisen between the value of grasses versus trees as a stabilizer of erosion. In the first place if trees are already established, changing to grass means cutting out trees, disturbing the soil even to some depth, and logs which have been burned out as they lie up and down the slope frequently leave a very erodable layer of loose soil. There is always a time lag between the destruction of the tree cover and the establishment of the grass cover. This can be accentuated in unexpected dry spells of weather. Sufficient erosion damage is often done during this time lag to prevent the establishment of a good grass cover. Should, however, a good grass cover become established erosion is less. In the present economic scheme, where wool is more valuable than poor timber, grass may pay better too.

We have noted in many widely separated areas in the coastal ranges of New South Wales slopes of 40° being cleared with devastating results (fig. 9).

I am indebted to Mr W. H. Maze for the measurements for fig. 28 and for fig. 9. Also to Miss E. F. Lawrence for figs. 13, 14, 15, 19, 20, 21, 24, and for the measurements for fig. 27.

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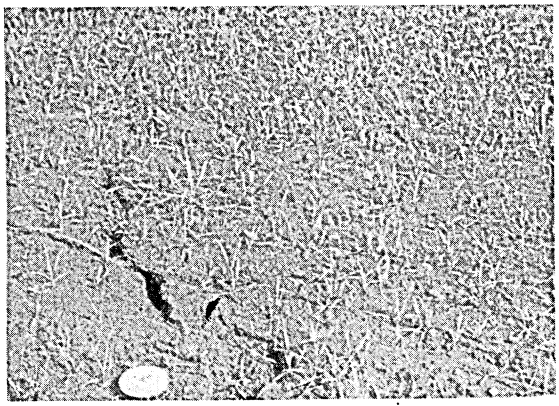

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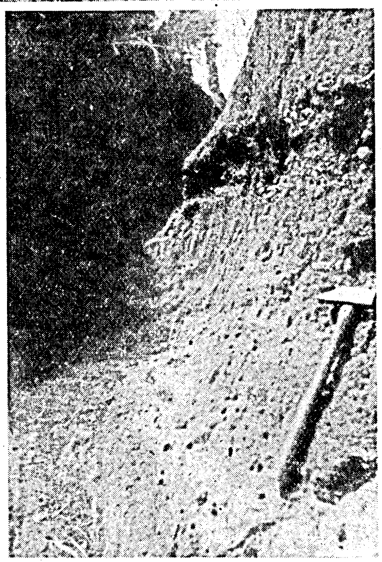

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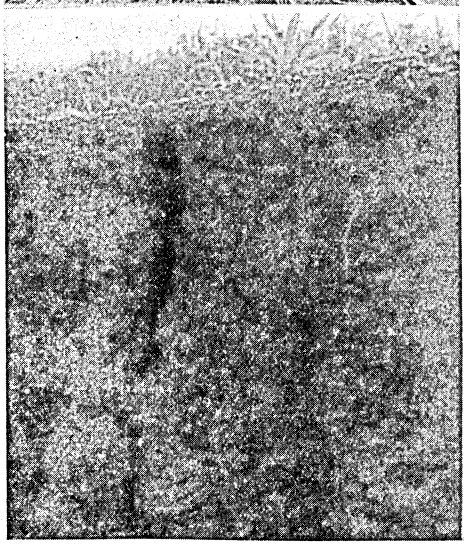

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FIG. 9.—GULLIES THREE FEET DEEP ON HILL-SIDE AFTER TREE CLEARING.
This can be obviated by less ruthless clearing, leaving strips on the contours. Even an occasional log dropped across the slope will preserve much of the soil.

FIGS. 13 AND 14.—SOIL CRACKING AND THE BEGINNING OF DOWNSLOPE MIGRATION.

FIG. 15.—THE HARDENED SUBSOIL LAYER.
This layer erodes by collapsing in large cakes—it presents difficulties in grading gullies. Note the graded slope from beneath the hard layer. Soil moisture is often greatest just below the hard layer.

FIG. 19.—GRAVEL ZONE IN SOIL PROFILE (FALSE C HORIZON).
The hammer indicates the position of the clay zone.

**The Intrinsic Worth of the Environment.**

In any consideration of final ends, the intrinsic worth of the environment must be given due consideration. The preceding sections of this publication merit the recognition that regional landscapes are living entities, not mere dead inert matter awaiting man's will, and further that agriculturally and pastorally developed landscapes are not likely to "stay put." The ancient psalmist realized that virtue comes from the hills, but did not contemplate the loss to the hills. "Stones grow" is an old Scottish proverb, which in essence means that the finer soils are removed by the process of weathering and cultivation, and, that in course of time, only the inert fractions (especially common to soils in formerly glaciated areas) remain. Landscapes, if left entirely alone by mankind, will change, for the present aspect is the triumph of aeons of time and of earth forces still waging major wars.

In some parts of landscape there is wastage and erosion, in others deposition. Loss and gain are the compensating factors of nature's economy. The very forces that make soil also destroy soil, and the whole soil-erosion question is how far man's economy can be made to fit and coincide with those soil-building, rather than those soil-destroying, forces. The soil-erosion problem has arisen as a national issue because forest, pastoral and agricultural economy have accelerated the soil-destroying forces beyond the individual property owner's power to retard their ravages while remedies are becoming exceedingly arduous and costly.

The chief value of our large scale discussion of erosion rests in explaining why there are soil-erosion problems. Its further value lies in this that any erosion policy must take cognizance of (1) the intrinsic worth of the environment; (2) the regional basis of land sculpture and also of land usage; (3) the establishment of general principles as to the sequence of experiments likely to be most effective in each region; and (4) that erosion reclamation is not work for an expert trained only in one aspect of land, but for co-operative effort by several kinds of land experts. The creation of a new type of expert at this stage in the development of ideas and practices will not clarify the position. For example, the Murray River is administered as a region by a Commission with representatives of three States. In the same way a Western Erosion Council should be established for the western lands of Queensland, New South Wales, and South Australia to handle broad problems of marginal pastoral activity in the effective areas of inland eastern Australia.

As has been shown, landscape results from Nature's objectives to develop drainage patterns in ordered form and by sequence of events, and designed for flood levels and usually the maximum load. Cataclysmic action on a large scale is rare, but in minor phase common. Australia is not alone in finding that a period of landscape rejuvenation can be so readily accelerated because it had just become established before the advent of the aborigines.

The particular worth of the **soil environment** can be illustrated by figs. 10 and 12. Fig. 10b illustrates soil succession with slope, (1) immature stony soil, (2) red loams, (3) river silts, (4) black heavy clay, (5) light grey clay loam. These types have been brought into being because of past erosion history. The present erosion tends to expand (1), and erode (2) so as to obliterate (3), (4) and (5). The section across the slope (fig. 10a) shows how former deep valleys have been filled in, almost creating an extensive level plain. The soil at A may be 15 to 20 feet deep, while at B it may only be 5 inches. B is obviously an area suited to permanent pasture or tree belts, while A is typical wheat land. The border zone between A and B is a very hazardous erosion area. Figure 11 illustrates photographically a steeper example of an area similar to drawings in figures 10a and 10b.

Figure 12 is an example from the **fine wool** pasture areas of New England. Much erosion has gone on in the past and filled in a wide strath in two main stages. The soils on the slopes (about 16 inches deep when cleared) lend them-

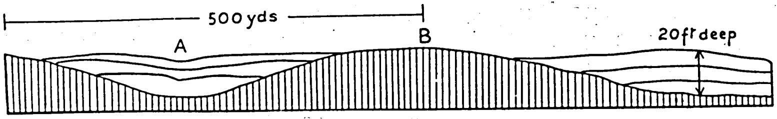



FIG. 10A.—SOIL PATTERN ACROSS SLOPE.

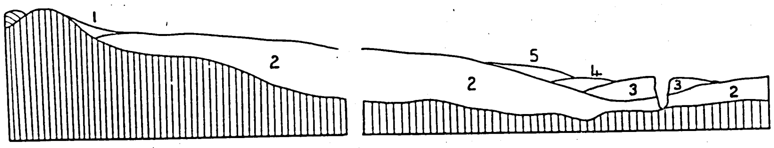



FIG. 10B.—SOIL SUCCESSION DOWN SLOPE.

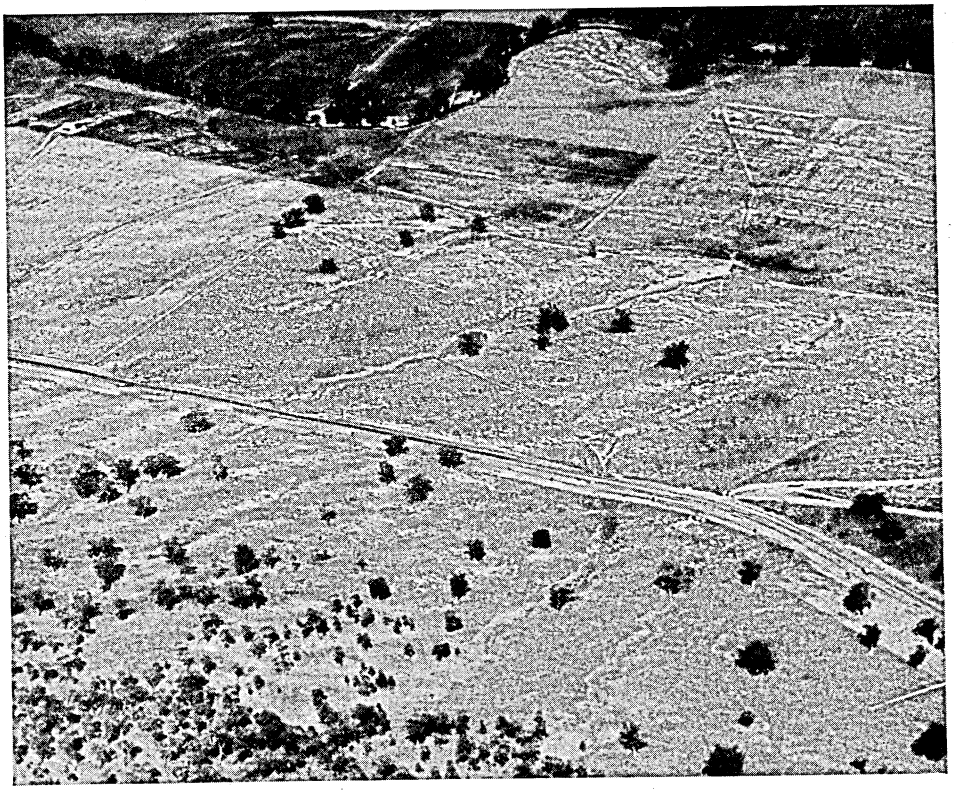


FIG. 11.—CHANGES IN SOIL WITH SLOPE.

Foreground, steep hill-side almost cleared of trees; middle distance, badly eroded land formerly ploughed; these two being separated by a main road with bridges over the gullies; background, Peel River surrounded by lucerne flats. Note the sharp boundary between red loams (middle) and lucerne soils (background). The severity of run-off is shown by the drainage pattern.

selves to comparatively poor pasturage, tending towards decreasing value. The middle zone of gentle slopes lends itself to intensive pasture improvement, but also to intensive erosion for it is a fifteen-feet-deep soil area with **deposit repetition.** Two major gullies are present twelve feet in depth, and show a finger-like pattern, so that erosion will proceed with rapidity and in the end will remove the whole of the best pasturage.

X 72—84 in. Black clay zone, semi-columnar, soft.
Y 84—108 in. Light brown, iron-stained, granitic gravel, increasing in coarseness towards the base.

The zone of greatest moisture is between seventy-two inches and eighty-four inches. This causes the gullies to maintain steep sides by collapse. Some believe

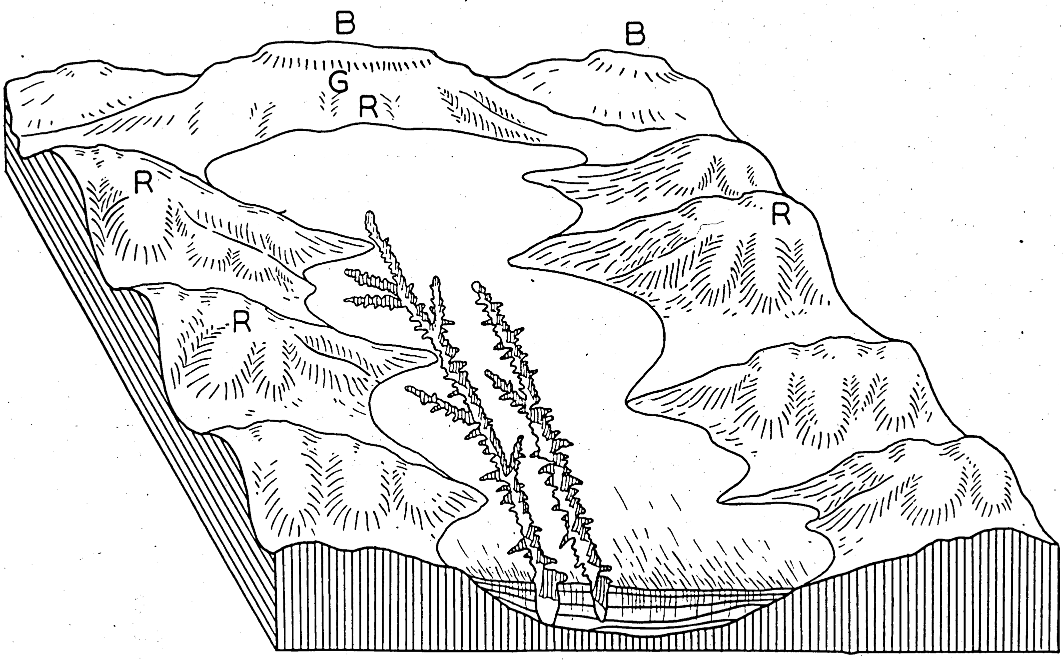



FIG. 12.—TYPICAL SECTION OF NEW ENGLAND PLATEAU.
Note the wide infilled valley system and the smoothed-off granite (R) hill-sides, some of which are capped by horizontal basalt (B), itself underlain by ancient river gravel (G). The deep soil areas are truncated by two major gullies. The deep soil areas are strictly limited and impose upon pasture improvements similar strict limitations. This section represents five square miles.

The soil profile is as follows, and shows repetition (so to say):

A 0—6 in. Dark grey-brown loam.
B1 6—12 in. Light grey, brittle, sandy loam.
B2 12—48 in. Dark, gravelly loam, hard even for a crow-bar, columnar.
Cp 48—72 in. Gravelly soil, iron-stained, easily cut, coarse gravel at base.

a cure for gullies is to grade their sides, but in this case, as in many others, the sides refuse to grade due to lack of homogeneity. The real cure must be applied where the run-off from the hills soaks into the middle clay zone, i.e. at the boundary shown on fig. 12.

In these examples the regional effectiveness of vegetation cover is perhaps the most vital factor in **erosion retardation.** It is obvious that rejuvenation of erosion has proceeded some way and is being further accelerated by choice of crop type.

It is equally obvious that if the present crops are to be maintained counteraction must be taken on the upper slopes and soil type margins; such works may not prove remunerative but are an insurance, for augmented crop yields can be obtained if erosion be looked upon, and treated, with as much respect as is given to other environmental factors.

The whole crux of the soil-erosion problem lies in **environmental appreciation.** Few realize that soil is a product of erosion which never ceases and can rise to a crescendo of destruction, and that even the trees and grasses themselves battle for soil changes as opposed to soil exhaustion and stagnation. Human endeavour makes tremendous demands on soil as on other factors of environment. Environment's intrinsic worth merits this fuller recognition, that any landscape can be given a place in the erosion sequence, and its full history and **behaviour** estabished. For example, the area shown in fig. 12 is in its third rejuvenation stage in which soil wastage is greater than soil accumulation.

Part I of this publication set out to recognize the inevitable and almost the inexplicable in soil-erosion, and having recognized also the regional aspect, we now proceed to analyse the problem further, especially in regard to soil, the **medium** in which erosion practice must work.

## PART II

## THE WAYS OF SOIL-EROSION[10]

The ways of soil-erosion are fundamentally the ways of erosion generally. Soils decay, but also grow by the process of erosion, and any application of erosion to soil, and soil to the production of a food supply must recognize that soil is a continuous system of changing physical and chemical quantities, involving air spaces, grain size, lime, iron, and phosphorus, but retaining its position on a slope only by a balance of frictional forces.

Now soil is formed chiefly as a process of disintegration from rock wastage and the rate of formation bears a relation to the nature of the rock and the slope of the land surface. A balance of forces means accumulated deposits since upper slopes are, in any scheme of things, likely soil losers. Any change in the balance means unstable deposits which suffer from seasonal and even continuous downslope migration of finely weathered particles. Stabilized deposits soon develop a surface layer with characteristics of its own which differ from the underlying rocks and even from the accumulated deposit of which it is a part. Of recent years soil science has considered its work to lie only in these surface layers which are bounded by the downward limit of atmospheric and biological influences. Before proceeding to the further sections of this paper it is necessary to examine this new concept of soil though the nature and behaviour of deposits must also be known for erosion purposes, and because they are the **first causes** of soil.

### The Characteristics of Soil.

Now the chief consideration of the new concept is that soils must be described and classified from features within themselves rather than with reference to externals such as geological origin or climatological criteria. Nevertheless, soils can usually be grouped into **lime-forming** (pedocals) and **non-lime forming** (pedalfer) types, which are features related to two major climatic regions (semi-arid and pluvial) B and C types generally, on fig. 4. Perhaps the chief feature of the new method is the recognition of changes with depth, known as the **profile,** and the naming of its subdivisions. The topmost zone is a zone of leaching and is defined as the **A horizon,** the intermediate layer, which is a zone of deposition, is known as the **B horizon** and finally the **C horizon.** Soils with well-established A and B horizons are called "mature" and show little relation to any parent material. Soils without profile are called "immature," and show evidence of their rocky origin.

We have noted in addition that there are great areas of less mature soil, but which have the beginnings, at least, of a profile. These ought not to be classified with those **soils without normal profile** which are so classified because of some continuous erosion feature or of some high ground water standing through a large part of the year. These intermediate soils we speak of represent much of the great wheat belt of eastern Australia,

[10] Arid soil-erosion discussion has been left to Publication No. 2 of this series.

and so are an important subdivision. We have called them the **less mature** group (using the customary nomenclature). (Proceedings, Linnean Society, N.S.W., 1937, vol. lxii, Parts 3-4.) Such soils are being formed as part of a deposit which came into being quite recently in geological history, and are not disintegrations from rock lying directly underneath. Again, normal soils heavily eroded will show a **truncated profile.**

Soils in the newer aspects have now been examined widely in the field and the laboratory and are classified chiefly according to colour, texture, structure, chemical composition and biological features. Colour charts have been prepared so as to get uniformity in a nation's soil surveys, and, in the terms of the new Soil Science, a soil is known when it possesses a geographical name, setting out most of the soil characteristics of any region, and a texture name, which is the characteristic of the surface layer (e.g. Tamworth loam). It is important to strive for national and even world uniformity in soil classification and description.

Soil chemistry has played a major part, and especially that aspect of chemistry known as Colloidal Chemistry, because much of the material of soils is in a colloidal state, and probably must be in such a state before it is serviceable to plant life. The chief aspects of soil are colloidal character, soil acidity; reaction "constant," and "buffering"; chemical condition; the physical structure of the soil, its water-holding capacity, its permeability, and its reaction to evaporation; and soil dispersion.

### Soil Properties and Eroding Propensities.

The modern description of soils gives little or no indication of their soil-eroding propensities, though certain factors usually measured by soil analysis are of value in deducing soil erodability. The chief internal factors are those of structure and content (chemical and mechanical), while the external factors of precipitation (including rainfall, snow and frost) and temperature, have known reactions on soils.

Now soil is considered mechanically subdivided when the percentages of coarse sand, sand, silt and clay are known.

| Name of fraction | Range of diameter |
|---|---|
| Clay | Less than ·002 mm. |
| Silt | ·02-·002 mm. |
| Fine sand | ·2-·02 mm. |
| Coarse sand | 2·0-0·2 mm. |

The chief soil classes are determinable by this means:—

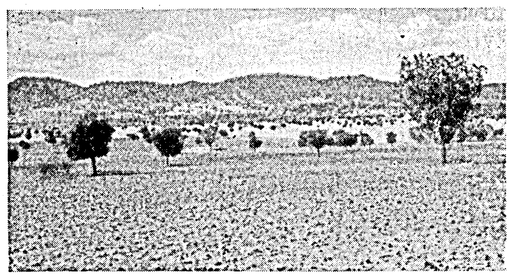
| | |
|---|---|
| Coarse barren sand .. .. .. .. | 5% clay |
| Light sandy loam .. .. .. .. | 10% „ |
| Light loam .. .. .. .. .. .. | 12% „ |
| Heavy sandy loam .. .. .. .. | 14% „ |
| Heavy loam .. .. .. .. .. | 18% „ |
| Clay .. .. .. .. .. .. .. | 28% „ |
| Very stiff clay .. .. .. .. .. | 42% „ |

Now it will be seen that the percentage of the soil above what will pass through a 2-mm. sieve receives little critical examination, the reason being that the finer soil particles are the most important types in colloidal soil chemistry upon which so much direct crop growing depends. From the erosion angle, however, that fraction which will not pass through a 2-mm. sieve (sometimes spoken of as the inert fraction) plays a very important part, for it cannot be ignored in soil structure, packing, and grain size uniformity, three very important factors in erodability. Strange as it may seem, many of the New South Wales Western Slopes wheat soils have a very high inert fraction (10 per cent to 30 per cent in the field matrix).

But the finer fraction, especially the clay content, which is most significant in the chemical analysis of a soil, has also an important bearing on erosion. The effect of the clay content is its solubility, its elasticity, and its water-absorbing capacity. A factor of **stickiness and lubrication** is measurable from the above qualities. Soil movement rate varies with the size, uniformity and rotundity of the soil grains, but it also varies with the size of the soil particles, and of the interstitial air spaces: these latter are usually known as soil structure, the many varieties of which are associated with clay contents.

Open structures, whether natural or artificially loosened by the plough, break down and move under the influence of wetting and drying such as accompanies light rainfall. Under the normal sequence of events there is a **vertical soil movement** and **soil creep.** Under torrential rain conditions soils may be extensively removed, resorted and widely transported. If soils be loose at the surface and hard underneath, due to excessive drying or to agricultural working, torrential rain may cause erosion down to the top of the hard layer, i.e. the removal of almost the entire tillage. The subsequent cracking of the hard layer becomes a special problem in the rehabilitation of the paddock. Heavy clays show movement by cracking, sometimes several feet in depth, but since heavy clay soils are usually found at low levels on gentle slopes, they are not very greatly sluiced or eroded (figs. 13, 14, 15). They are more likely to be destroyed by deposits placed on top of them, followed by interpenetration. Non-uniform soils, such as the stony soils of the Tamworth wheat belt, pack remarkably, and are not extensively eroded, because of the splitting up of the water movement into very many small channels and the ponding back behind each large stone (fig. 16).

Further, grain size is not so important as the frequency of rotundity in grains, and in some cases the specific gravity. (The effect of uniformity is shown in the high frequency of skidding on piled-up gravel on road corners. Most of such gravel has been through a mesh at the quarry previously, and in this way obtained its uniformity.) Soils of uniform grain size erode more rapidly than non-uniform soils, especially where the commonest ingredient is quartz sand. The changes in interstitial air spaces between



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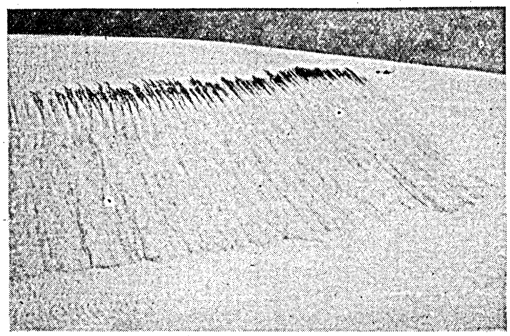

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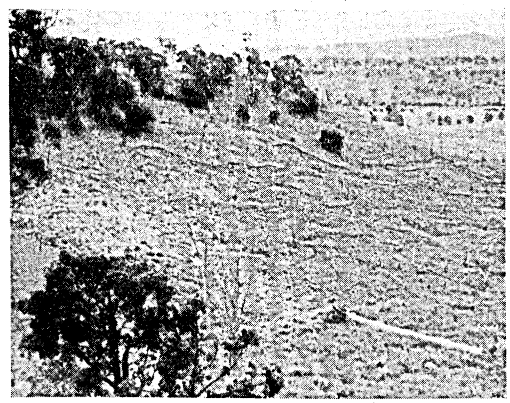

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FIG. 16.—THE TAMWORTH STONY SOILS IN READINESS FOR WHEAT GROWING.

They show little erosion as yet. The trees are chiefly kurrajongs and have been planted to give shade. Their foliage is used as fodder for sheep in times of drought.

FIG. 17.—COLLAPSE ON EDGE OF SANDHILL.

Gravity migration and development of gully pattern. Eventually the top will be lowered and the base extended. This is due principally to *drying out.*

FIG. 18.—GENERAL SOIL COLLAPSE DUE TO EXCESSIVE CLEARING ON TOO STEEP SLOPES.

Formerly a smooth slope, it is now unstable and hummocked.

soil particles and the influence of moisture and temperature in changing these are powerful factors in erosion studies. When soil is detreed greatly increased packing ensues, in some cases with an obvious slumping of the surface. Soil, to be agriculturally productive, must have air spaces, and the relationship of temperature to expansion and contraction of the air space ratio is a fundamental measurement. In the same way frost action changes the air space ratio and the water space ratio in the topmost soil layers. A severe frost and a heavy thaw can leave behind innumerable finger gullies.

Thus, whether from changes in temperature or from removal by waterlogging of clay, differential collapsing of the surface is an early feature in erosion; subsequent rainfall finds its path made easy. A similar type of collapse takes place greatly once gullies have been established (and plough furrows down a slope are but small gullies) and may have an effect many yards away from the gully itself (figs. 17 and 18).

When grassland is changed to ploughed land the topmost layer is loosened, but the intermediate layer is often greatly hardened and compacted. Rainfall will invariably loosen and expand the soil, excessive drought will harden and compact it. The nature of these "induced" soil structures becomes a primary study in the cures for soil-erosion.

Soils are being continually acted upon by external forces, the chief of which are slope and climate, including temperature, rainfall, frost and snow.

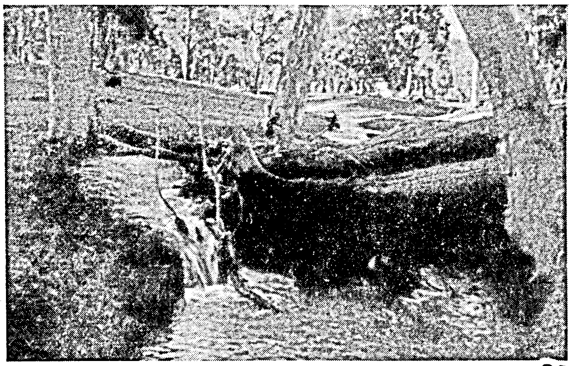
To a great extent the climatic factor influences:—

(1) The rate and kind of mineral weathering.
(2) The rate and kind of decomposition of organic matter and the accumulation and distribution of humus in various horizons.
(3) The transfer of substances from one layer to another and the removal of substances from the soil.

Every slope is continuously acquiring and almost continually losing weathered material. Soil in the absence of a protective vegetation cover is continually sluiced by rain water, so that only a certain depth may be formed. The function of soil has been considered chiefly as a food for plants; but it is also a supporting medium for them, and it is furthermore a protection for the land surface against further denudation. Under a protective vegetation cover, the depth may be increased, but in general great accumulations of soil do not take place unless a slope of less grade is in proximity to one of steeper grade. The determining factor is **break of slope,** whether abrupt or gradual.

It is well known that soil losses increase with change in slope, but also with the length of the slope. Long slopes of even grade lose more soil per unit of area than short slopes. Our observations in the Western Slopes of New South Wales indicate that there is only slight loss of soil on bare slopes up to 1° but on slopes from 2° to 6° (measured with Abney level) there is a considerable increase in the rate of erosion, which may have a **carry over,** on to the more gentle slopes, and every small increase in slope thereafter greatly increases the rate of erosion. A very frequent micro-relief feature in New South Wales is a short steep slope just beyond the junction of the deeper soils with the upper-slope shallow soils. Arable farmers have recognized it in fixing the position of fences. It is significant in fixing the point of gullying.

Again, according to the laws of velocity, if the land slope is increased four times the velocity of water flowing over it is about doubled; if the velocity is doubled the erosive capacity is increased four times. If the velocity is doubled the quantity of material of a given size carried is increased about thirty-two times, and if the velocity is doubled, the size of a particle transported is increased sixty-four times. When water flows in definite channels, there is a reduction in



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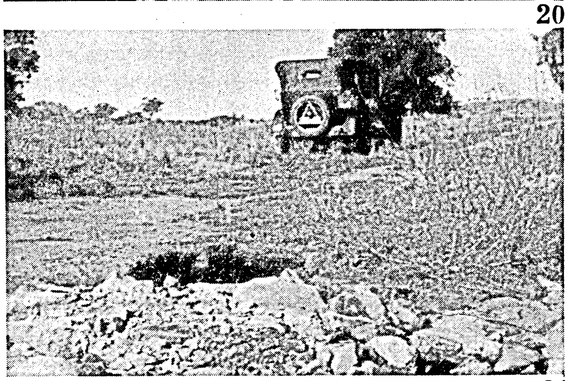

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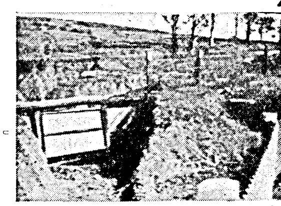

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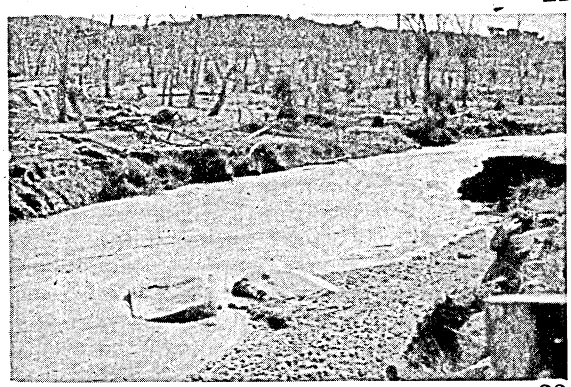

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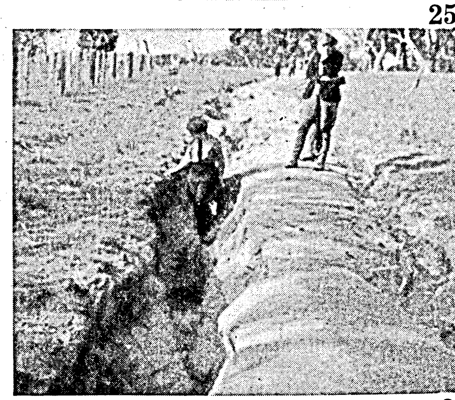

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FIG. 20.—A SMALL GULLY BLOCKED BY FALLEN LOGS.
Note the filling up and the movement of the stream around the end of the logs. In time the stream will have eroded a course for itself around the logs.

FIG. 23.—INFILLED STREAM OF CLEAN SAND DUE TO RAIN WASH FROM NEIGHBOURING CLEARED AREAS.

FIG. 24.—*EXPULSION* GULLY DUE TO EXCESSIVE LOOSENING OF TOP LAYER BY DOWN-SLOPE PLOUGHING.

FIG. 25.—A TRAP PREVENTS EXCESSIVE AMOUNTS OF DEBRIS FROM DESPOILING THE NEIGHBOURING ROAD.

FIG. 26.—EDGES OF ACCESS ROADWAY FORM DRAINAGE GULLIES WITH THE CONSEQUENT DESTRUCTION OF THE ROADWAY.

friction, and a still greater increase in velocity. Other variables such as obstructions and irregularities which act with a churning effect alter these figures, but they are an indication of what is to be expected.

The nature of the deposit in relation to the top soil surface is important in soil-erosion work; in "The Growth of Soil on Slopes" (Procs. Linn. Soc., N.S.W., vol. lxii, Parts 3 and 4, 1937) we have shown that many soils throughout the State have a profile repetition and that the clay content increases with depth, then decreases and may increase again, and that in many soil areas there is a **false C** horizon (fig. 19). This lower clay zone often contains much more moisture than the layer above and below it, and we have shown that at this zone in the soil profile erosion may be initiated.

Soil propensities for erosion also vary greatly with the slope position of the soil. Hill-tops have shallow and unstable soils, while middle slopes initiate aggregation and differentiation, and flood plains stabilize silt. Long gentle concave slopes favour an increasing clay content. Perhaps the most fundamental factor in soil-erosion in New South Wales and probably elsewhere is the relation of the deeper **soil deposits** to the **soil surface,** a relation which establishes the fact that the cause of erosion at any point is likely to be found some distance from where the damage is visible. The place where running water forms gullies is not a haphazard accident, but a predictable event in the local environment. Erosion propensity in soil and soil deposits is a measurable quantity, though not easy of arithmetical statement. The cure of erosion, therefore, necessitates some general precautionary or "prophylactic" treatment, as well as constructive work on the "injured" area, and further, the localization of a precise cure may involve several paddocks or properties. It is only necessary to mention here the failures of netting across gullies (fig. 20), and the stone reinforcing of small runnels (figs. 21 and 22). And so soil has eroding propensities of its own and independent of land utilization methods.

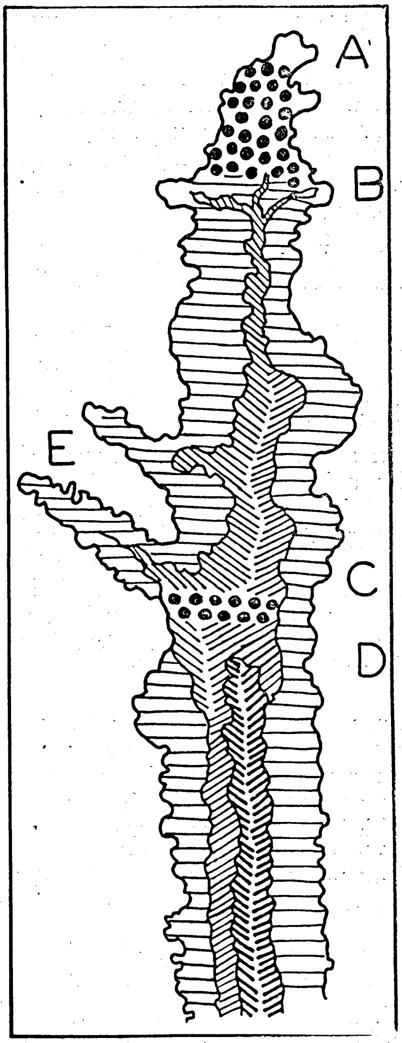



FIG. 22.—SHOWS ATTEMPT TO BLOCK HEADS OF GULLIES BY STONE PACKING.

This is effective for a time and then gullying undermines the stones by head water erosion. At the point A an area of six square feet has eroded beyond the stones (shown photographically, fig. 21, above). The stones are causing lateral spreading. At C a bank of stones is acting as a waterfall and re-deepening at the point D.

**Land Usage and Its Eroding Effect on Soil.**

Is it true that every farming practice means a degradation of the natural soil profile? It can be true, but need not be more true than Shakespeare's statement: "Most subject are the fattest soils to weeds." We have shown in our previous section that the first problem in any erosion project is to determine the erosion character of the soil in relation to slope, climate, and the soil itself before considering the induced changes brought about by forestry, pastoral, agricultural and road-making practices. The effect of these changes is now discussed.

Man and animals make many changes in the soil, and probably about 30 per cent of the earth's surface has its top soil and vegetation controlled by man and animals. In Australia, in order to allow agriculture to proceed, most of the suitable areas had to be cleared of vegetation, and where not actually coming under the plough, the land has been cleared for grazing, so over large areas there has been a change from forest and woodland to ploughed land and grassland; even now there may be burning of the grass annually to make way for fresh grass, so that the chief factors are, burning, clearing, ploughing (tillage), tramping, over-grazing, and in addition there is the action by rabbits and other smaller animals in digging and transporting soil. The making of developmental, feeder and access roads and trunk highways makes great inroads in soil.

The chief actions of grazing on the surface are:—

(1) The withdrawal of large quantities of plant matter.

(2) Mechanical harm to plants by grazing, gnawing, brushing against, and trampling.

(3) Selective destruction by pastoral animals. Desired plants are at a disadvantage or entirely destroyed or the undesirable ones increase abundantly.

(4) Disappearance of dung-avoiding species from much-frequented feeding places and the introduction of strong nitro-phillus communities.

(5) Direct effect upon soil formation by stirring up soil particles and changing the micro-relief—the factor of tramping is extraordinarily important.

As far as mankind is concerned, his most destructive agent is fire. Most forest fires are caused by man either wilfully or accidentally. Great changes in the forest succession take place because of fire, but forest burning may have occurred only once when first cleared, while grass burning is often of yearly occurrence as a form of farm economy. Many important changes take place, chiefly in the reduction of the top layer of soil to a uniformly very fine grain which will move on some of these steep slopes almost by its own volition (fig. 23).

The selective cutting of timber alters the ratio of the types of plants in any formation, and may cause entirely new plants to come up and others to die. Perhaps the greatest changes in soil and soil formation occur from ploughing, fertilization, and irrigation, all of which are necessary if we are to obtain our grain food supply.

The effect of arable agriculture in relation to soil-erosion is:—

(1) To expose partially or wholly to the full vigour of the atmospheric agencies the soil surface, loosen the topmost layer and frequently harden the intermediate layer (fig. 24).

(2) To change the chemical content of soils by addition and subtraction and to alter the humus or organic content.

(3) To change the soil moisture content both in space and in time by the preparation of seed beds and subsequent operations.

The effect of road making on soil-erosion is chiefly to alter the natural drainage patterns by systems of collection from hard road surfaces and from road gutters and redispersion by getaway channels (figs. 25 and 26). A road network could mean very effective drainage control and the road maker will require to consider this factor of the **induced drainage network** even to the extent of carrying his constructive work a considerable distance farther from his road than at present.

As already stated, most soils are deposits resting on rock slopes, and the surface of the deposit has taken up an angle of repose which gives the deposit a stability. The erosion factor requiring most measurement is under what conditions any humanly induced agricultural, pastoral, forestry or road-making process will cause the angle of repose to be changed. It is necessary to measure for all soils a **coefficient of cohesion** and to experiment with summing up the **totality of factors** in any erosion situation.

Now it will be realized that soils are held together by static friction, and move under the influence of kinetic friction. The force necessary to change static friction to kinetic friction is considerably greater than the force necessary to maintain kinetic friction, or in other words it requires a very small force to maintain erosion, but a considerably greater force to start it. Most observers will have noticed the suddenness and the rapidity of gully expansion once gullies begin to appear. The problem to determine is when any farming practice will be sufficient to overcome the natural tendency for soil to "remain put" and to build up farming practices which will retard the forces making for increased soil movement once it has started. For example, the making of a seed bed by opening and loosening the soil and conserving moisture right through the period of summer rain in the northern wheat belt of New South Wales makes for the initiation of erosion, whereas, especially if carried out on what can be considered slopes beginning to be too steep for tractor ploughing, the rising temperatures of late summer conditions after harvesting favour compacting and hardening and, therefore, the reduction of erosion. A reduction in the period of summer fallow is necessary.

On bare soil heavy rainfall has a hammering effect which may be sufficient to overcome static friction. Water collected on an upper concave slope and forced to abut against a middle convex slope, is sufficient to overcome static friction in a soil deposit and produce small gullies and throughout the agricultural areas the very frequent distribution of small gullies on the middle slope can be attributed to this force.

Middle slope erosion is often aggravated by the upper limit to which ploughing is carried on. Now this upper limit has heretofore been determined to a great extent by the ability of the machinery to carry out the work, and the favourable price level of wheat, encouraging the farmer to get as much area as possible under the plough. This upper arable limit will, therefore, always be higher than the limit deemed desirable from the erosion aspect.

To maintain continuous cropping on the middle slope it is necessary to protect the **upper** and **upper middle** slopes. Alternatively the middle slope can be maintained as an intensive pasture or even forest belt. The development of **strip farming** is a positive recommendation in such cases. The alternative to strip farming is the creation of **control channels** and a still further disturbance of the soil by making what are sometimes called **contour drains** or **broad base terraces.** Both these are sometimes necessary and effective if scientifically carried out, but it is essential to determine the critical rate (i.e. the maximum volume per unit of time) of water for which it is economically feasible to provide in the control channels. This in itself necessitates an effective measurement of **rain expectation** and the meaning of **critical rainfall.** Thus the selection of areas for the production of crops, i.e. the pattern of land usage in areas liable to erosion, or already badly eroded, may involve a complete change from the present crop and pasture distribution.

It has always been considered advisable in Australia, and indeed it has only been necessary to have very shallow ploughing, and disk ploughs have had their advantage. Our observations go to show that, partly from this cause, the subsoil layer—a few inches from the surface—is greatly hardened. The effect of erosion on the topmost few inches has been to remove the clay content and give an ever-increasing grain and texture uniformity. Paradoxical as it may seem, the breaking of the harder layer by deeper ploughing and the reduction thereby of sand concentration is an effective erosion preventive. Thus, the estimation of suitability of an area for cropping, pasturage, and forestry is not only determined by the plants themselves or the market price level of the crop but must also make provision for soil husbandry.

The way in which erosion changes the face of a paddock is shown in figure 27. This is a paddock of nine acres and shows an assemblage of erosion forms. At points C, D, E bare patches form areas of hardness. The solid black lines are gullies up to three feet deep. These are often surrounded by much bare ground (dotted). The angular pattern of the whole system is evidence of its immaturity. Much of this paddock should not have been ploughed and certainly not down the slope. Nevertheless erosion has not yet gone beyond the reclamation stage. For example, if a boundary were drawn across the paddock above the point C, and the upper half maintained in permanent pasture, then the lower half would re-establish itself if kept in pasture for a few years, or, if regraded, would be useful for wheat growing.

In figure 28 an erosion series is depicted covering about 511 acres. Involved in this series are several properties; although the main damage is within what is now one property. Formerly part of

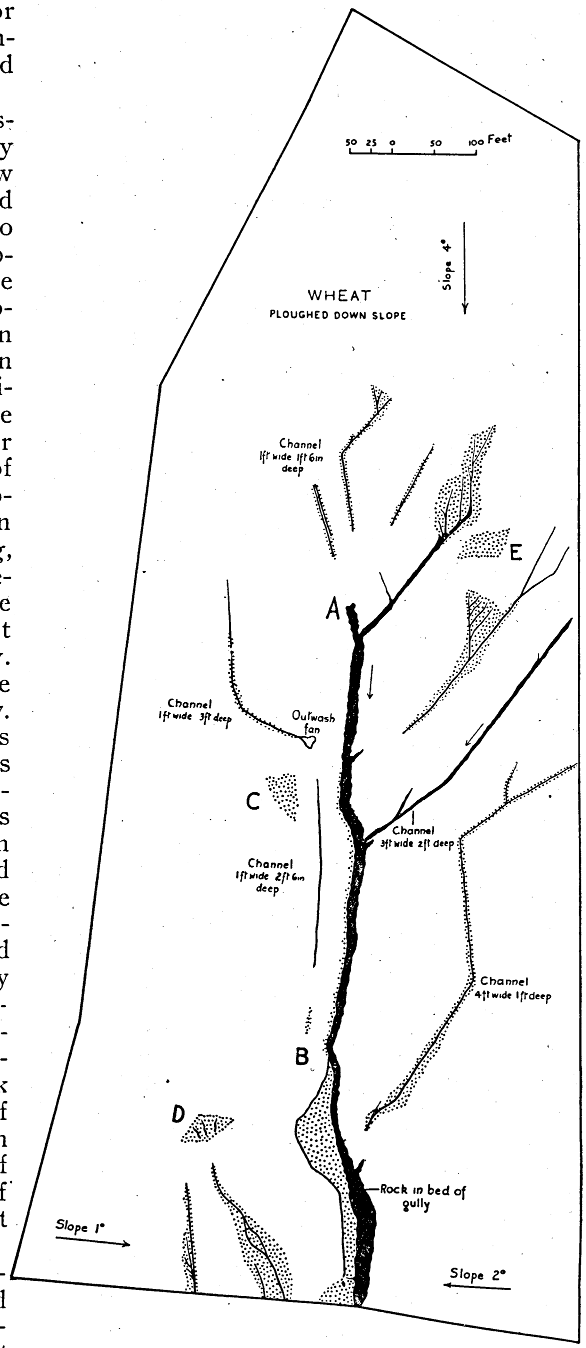



FIG. 27.—A BADLY ERODED WHEAT PADDOCK OF NINE ACRES.

the area here shown was divided into four separate properties, two of which were forty acres, and two of sixty acres. The present extensive erosion was probably initiated then. The whole district has been a pastoral run for one hundred years and in small farms for about fifty years. A main road passes through this unit, and, being forced to take a right angle, has altered considerably the natural drainage area above the road at the point X, where soil building up has gone on. There has also been building up at points marked (b). Figure shows the boundary (dotted line) of two soil deposit types. Inside the line are deep rich red loams suitable for wheat growing, which represent an accumulation such as has been previously described. Outside the line are hill-top shallow directly disintegrating soils. The watershed is shown by broken line.

The whole unit requires redesigning, including the roadway, which is in a most awkward position for any replanning scheme. The present rectangular pattern of the paddocks is wasteful and the diagonal nature of the gullies across the paddocks means that machinery cannot be got into them. Ploughing and fallowing of the upper paddocks is disastrous on the lower paddocks. Contour strip farming with a complete reorientation of the paddocks is essential. The small bridge across the corner of the road across a gully seven feet deep and six feet wide has already been carried away, and will be again shortly. Figure 28 shows that there are several zones of deposition throughout this property, a feature which can be used, as described later, to rehabilitate the property.

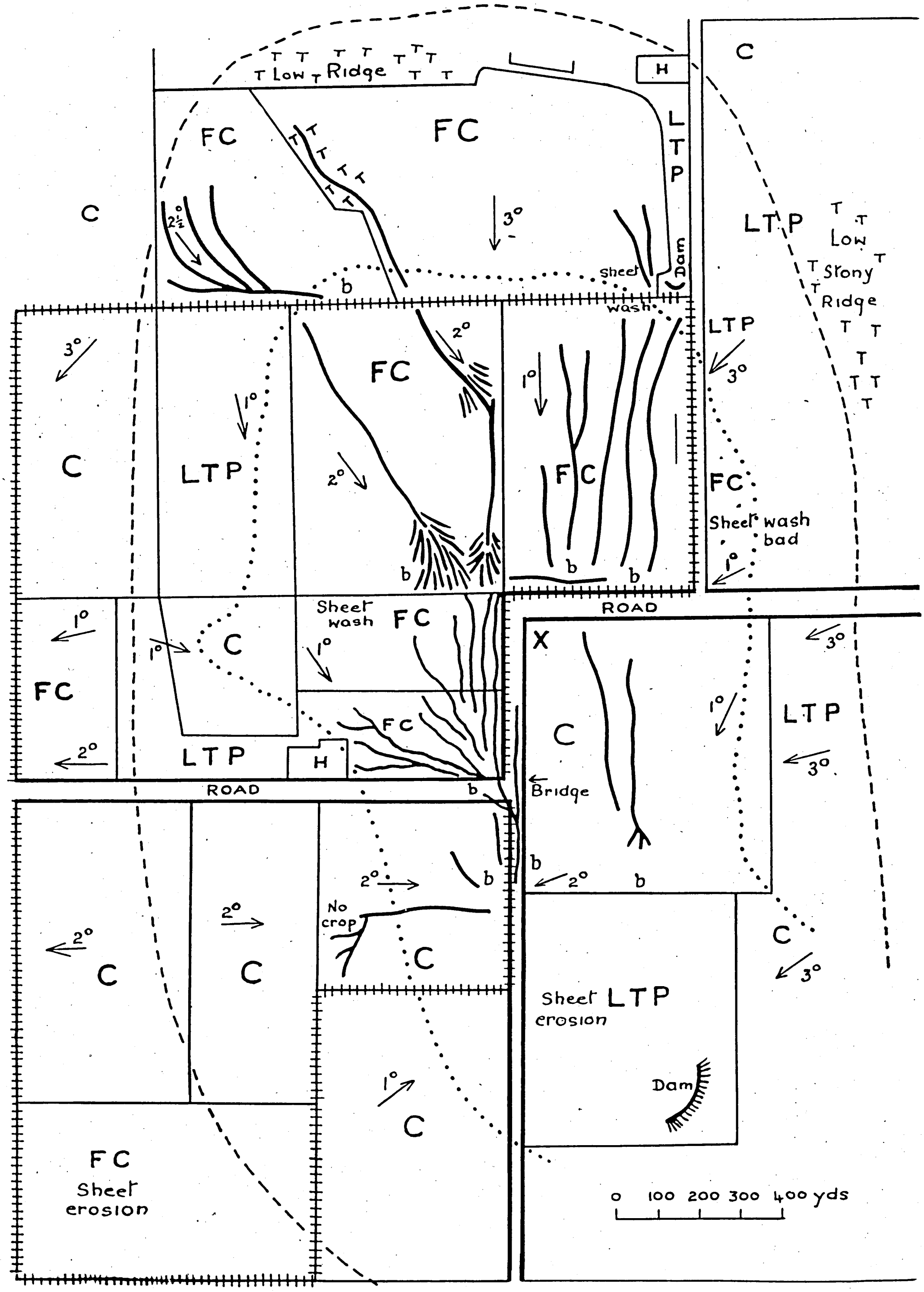



FIG. 28.—A BADLY ERODED ARABLE FARMING PROPERTY OF 511 ACRES.
Inside the dotted line are deep red loams—the broken line shows the position of watershed—boundary of property shown by crossed line. FC = formerly cultivated. LTP = lightly treed pasture. C = cultivated. T = trees. H = household area. Paddock fences are shown by plain lines.

## PART III

## THE CURE OF SOIL-EROSION

SOIL-EROSION is only recognized when its results have become disastrous to farm economy, but the forces which waste soil often make soil, so any cure involves a shift in the point of attack from the valuable on to the less valuable soil, in other words to use erosion against erosion by taking advantage of the end point of the erosion sequence which is deposition and soil building.

Since there must always be some erosion, it is well to recognize this sequence: that firstly there is—**rock and soil disintegration**; followed by **removal and transportation of the material,** and finally **deposition.** Now the stages of destruction brought about by disintegration and transportation are (figs. 29, 30, 31, 32):

(1) Wetting and drying; solution and clay removal; hardening and compacting; ending in collapse by gravitation;

(2) Sheet wash in which films of the soil are removed successively by water coursing down the slopes in unbroken sheets;

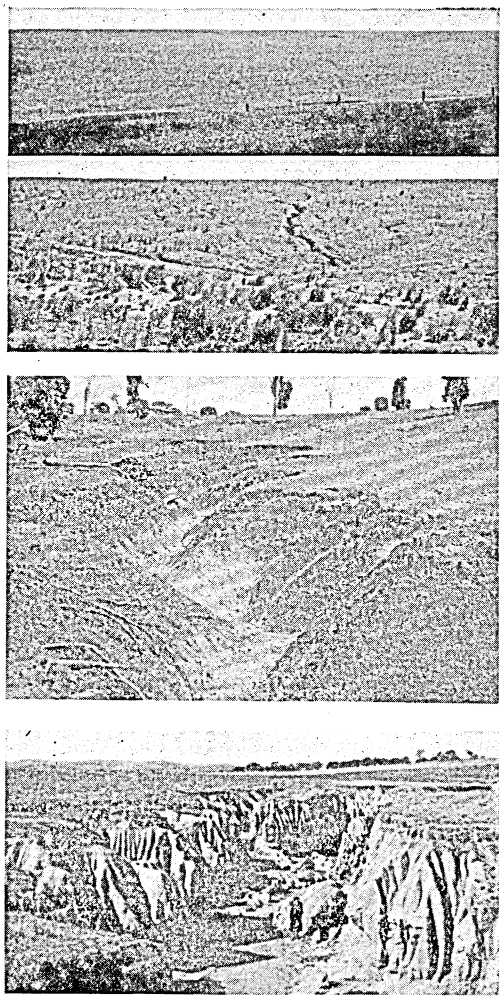
(3) Rill wash when soil removal is acquiring linear concentration;

(4) Gullying.

Now the final aspect of erosion, namely deposition, is seldom considered in erosion studies, but is the most important in any cure. Though deposition is a constructive force, it can also destroy by superimposing a layer of sand and gravel on to a lower slope of rich clay loam or flood silt. We have noticed land worth £20 to £40 per acre converted to land worth about £5 per acre in this way. (Figure 11 shows a somewhat similar example.) And so while soil erosion in farm economy can be looked upon as a disease and treated as such, it must be remembered that erosion is a natural mechanism and economy. Were it not so there could hardly be any cure.

The "disease" of erosion must first be **diagnosed** by recognizing the liability of any paddock to erode. A determination of soil erodability is equally necessary with that of soil fertility before a crop is sown. Secondly erosion can be prevented or at least kept well within farm costs by good farm and property management and so after diagnosis comes **general prophylaxis.** The basis of this precautionary treatment is sound educational information disseminated by all officers of governmental departments dealing with land. For example, very often all that is required is a change in the final ploughing direction from down the slope (fig. 24) to around the slope, and to avoid **extensive** long-continued summer fallow. Again, it may be possible to rearrange the areas in sown pastures and cropped land, or as already indicated to organize the whole property on a system of **strip farming.**

The disease of soil-erosion may have gone sufficiently far to require **surgical treatment.** Here is a dilemma. Will it pay to spend tens of pounds per acre on a property only worth a few pounds per acre or, as in some grazing properties, only a few shillings per acre? There is often no alternative to heavy expenditure but abandonment, which is the reason why soil-erosion has become a regional and even a State responsibility. Some



FIGS. 29, 30, 31 AND 32.—THESE FOUR FIGURES SHOW A SEQUENCE BEGINNING WITH SHEET WASH AND ALMOST IMPERCEPTIBLE ON THE SURFACE, PROCEEDING TO RILL WASH (NOTE THE POOR PASTURAGE ASSOCIATED WITH RILL WASH). HEAD WATER GULLYING (FIG. 31) SHOWS THE TYPICAL OVERLAPPING SPURS AND THE EXPOSURE OF A C HORIZON. FIG. 32 SHOWS AN EXTENDED GULLY WITH PRECIPITOUS AND COLLAPSING SIDES AND FLAT FLOOR—THE BEGINNINGS OF BAD LAND TOPOGRAPHY.

countries and some Australian States have advocated the abandonment of badly eroded areas and made provision for the dispossessed farmer elsewhere.

Agricultural engineers have now devised a goodly number of new farm implements and devices to conduct erosion surgery.[11] All of them are based on the principle of collecting excessive rain run-off from where it is not wanted and dispersing it to channels where it can do the least harm. Erosion cure makes no pretence of stopping great volumes of running water, but so arranges **soil-slope, vegetation cover,** and **run-off channels** that least harm may be done. For example, if running water can be slowed down or stilled for even sixty seconds, it will have dropped most of its load of sand and silt, while prevention of volume increase (by retardation traps and pockets on hill-sides) over a few hours will save the fine silt and much of the clay. The comparatively small amounts of erosion remaining may even have a beneficial effect. "Surgery" means great soil disturbances by filling in gullies and regrading the paddocks. When is it wise to disturb the soil to this extent?

After surgery there comes **convalescence.** The paddocks and pastures must be nursed back to health. Repeated cropping or over-stocking to get a return on the increased outlay will produce a condition worse than in the beginning.

The cure of soil-erosion, therefore, means some or all of the following according as the case presents itself:—

1. Reafforestation.
2. Intensive pasture improvement.
3. Changed and probably new farming practices, and property economy.
4. Increased productivity per property; and
5. Ultimately smaller properties.

This latter aspect is in contradiction to the statement often heard that more land is necessary per property before any erosion project can be carried out. We make bold to suggest that the view expressed at the beginning of this publication is the correct one, namely that first quality produce and good land husbandry are more likely to be forthcoming from smaller than from larger areas. This may

[11] The practices to date are thoroughly and fully explained in Q. C. Ayres: "Soil-erosion and its Control."

be unpalatable to some, but history shows that it is the chief trend of our times. Since erosion takes so many different forms in any one region the **cure of erosion must lie in successful land planning** even to the extent of elaborate resubdivision. In one part it may be sheet wash, in another gullying, while in a third it may be destruction of a rich lucerne bank by the swing of a river. All these erosion forms are invariably interconnected, since if there was not a quick run-off from the hills there would probably be less gullying and a more regular and measurable flow in the river. Any State organization must **cure erosion regionally** and by the co-operation of all departments dealing with land rather than by expensive reconstruction work at a point. For example, the cure for river-bank erosion is not at the river, but on the hills and catchment area as a whole, for any hydraulic engineer will build a structure to stop **erosion at a point** though invariably the river will break away at a fresh point. Figure 1 illustrates this point, and also the difficulty of controlling river erosion. The foreground shows the unstable junction of the Peel and Cockburn Rivers. The Peel formerly went off to the left (A). Later it turned in at the bridge (B). The increased power given to the river eroded a new area to form the loop (C). A further diversion of the Peel comes in to the right of the road at (D). Note the destruction of the main road at two points and the removal of acres of rich alluvium usually sown with lucerne.

A somewhat similar situation is found again nearer the town.

Devising an economy to cure soil-erosion requires caution, for many of the devices at present being tried are doomed to failure to the detriment of the whole educational attitude which is so valuable in land planning schemes. For example, packing head water gullies with stones has been considered effective. Figure 22 shows a common result. At the same time the situation depicted in figure 1 is not going to be cured by timidity. Therefore, the first recommendation to any property owner must be to try every farming practice known to build up soil and every form of pasturage protection before proceeding with expensive outlays on machinery and structures.

Of course, the whole erosion technique on a property must carry the peak load, i.e. the torrential thunderstorm and flood. So some erosion projects on a farm could be considered as an insurance.

This publication does not purport to give **case records** or technical instruction, but to "give some thought to the matter" of erosion, and these three points stand out:—

(1) That by a wise system of property management suited to the environment, serious erosion damage can be avoided.

(2) That insurance against erosion must govern the future policy of the combined users of the land.

(3) That erosion damage which has become well established will require costly remedies, for this reason **erosion cures** must be based on land valuations.

**A Soil Conservation Policy.**

So universal has soil-erosion become that parliamentary legislation is contemplated in New South Wales. For the same reason of universality any national enactment must contain compelling clauses of a far-reaching character involving considerable private and public funds. At the same time the very nature of the issues described in these pages warrant, in any Act, appeal clauses and a humanitarian outlook in the administration.

At this stage in the history of erosion in all countries a national policy is worth formulating. We have shown that the erosion issue is not a responsibility of any one department, but necessitates heads **of all departments dealing with land** to be continually in consultation. Their deliberations in New South Wales could be based on a map of the Land

Board districts of the State subdivided into (a) areas where the soil-erosion problem need not be considered at all; (b) areas where soil-erosion cure is too costly to do anything about; (c) areas where erosion is likely, but not yet present; (d) areas where erosion is worth-while attempting to cure at once. These are the necessary facts, without which expenditure can be colossal and in great part futile.

As we have shown earlier, the Department of Main Roads, and shire authorities, and pastoralists are even more implicated than are arable farmers. Coordinated land activities by governmental departments, and by neighbouring property owners must be the keynote of any erosion policy. Further, the whole spirit of any policy or project must be scientific, and case records maintained. Laboratory experimentation should precede extensive field expenditure.

The basis of any policy therefore must be:—

(1) A measurement of the precise worth of the local environment, and the regional nature of erosion, the formation of regional councils with advisory officers.

(2) (a) Examination and measurement of erosion propensities of soils.

(b) Examination of present farming and pastoral methods in their relation to soil-erosion.

(c) Laboratory experimentation and regional sampling—the placing of the issues on a scientific foundation that the facts of soil maintenance may be truly ascertained.

(3) (a) Land valuation. Some erosion cures, soil conservation, and water catchment preservation schemes can be considered purely as an insurance, and lands can be valued accordingly. Soil-erosion insurance can be considered a charge on the State as a whole.

(b) Many detailed cures on individual properties must be based on the value of the land both before and after treatment.

## UNIVERSITY OF SYDNEY PUBLICATIONS IN GEOGRAPHY

No. 1. The Meaning of Soil-Erosion, pp. 38, coloured plate 1, figures in text 32.

No. 2. The Erosion-Pastoral Problem of the Western Division of New South Wales, Australia. (In the Press.)

No. 3. (In preparation.)

No. 4. Land Utilization Regions of Tasmania, by A. G. Lowndes, M.Sc., and W. H. Maze, M.Sc., pp. 1-29, plates 1-5, map 1 (coloured), figures in text 14, published in 1937.

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