SOIL GROUPS OF NEW ZEALAND

Part 3

GLEY SOILS

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Edited by W.C. Rijkse

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PREFACE

Gley soils occupy some 4% of the total area of New Zealand. They are scattered throughout coastal plains and river valleys, and when artificially drained are high-producing soils. Because of these features, most soil scientists will have encountered gley soils, yet few will have an intimate knowledge of or interest in them.

It is hoped that this volume might contribute to the understanding and, in some cases, better use of this important group of soils. In the section on Gley Soils in the original volume "Soil Groups of New Zealand", produced in 1964 and reprinted in 1971, a series of short papers were gathered together as a record of discussion and "as a possible source of ideas for future work". In the present volume this collection is extended and supplemented by new information in many areas. However, in regard to their soil processes and land use potential, the gley soils still offer wide and comparatively little-explored fields of research.

One of the objectives of this volume is to define gley soils as a group and to present information which might help in deciding the relative taxonomic positions of such soils as acid sulphate soils, saline gley soils, alpine gley soils, gleyed recent soils and gley podzols. The authors have individually expressed current thinking, in particular in respect of soil-forming processes and soil utilisation.

I would like to thank all of the authors for their willing contributions, in particular Dr J.A. Pollok for his valuable contributions at short notice and Dr D.L. Dent for his contribution in the relatively new (to New Zealand) field of acid sulphate soils, also Mr D.I. Kinloch for his help in the final preparation of this volume.

W.C. Rijkse

Soil Bureau, D.S.I.R., Rotorua

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**1 INTRODUCTION**

CLASSIFICATION

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In the early bench mark soil surveys of New Zealand (Hughes et al. 1939 and Grange et al. 1939) the gley soils were classified on the map legends as meadow soils. The soils had a high water table at a depth of 30 to 60 cm in the late spring and the subsoils were flecked or mottled with brown iron oxide staining. Other properties, including peaty topsoils and an iron oxide pan at a depth of 30 to 60 cm, were regarded as diagnostic of this group of soils.

The classification of soils of the North Island was set out in a brief mimeographed statement on 12 December 1940 and the meadow soils are classed as poorly drained soils older than the recent soils and showing meadow characteristics. The group is subdivided as follows:

(a) Better drained division; rushes; a brownish colour.
(b) True meadow; grey and flecked.
(c) Peaty phase; shallow; 30 cm peaty loam on surface.

The classification was published in the "General survey of the soils of North Island, New Zealand" (N.Z. Soil Bureau, 1954) in which the meadow group is designated as meadow (gley) soils. The principal profile characteristic is the presence of a grey layer, commonly mottled with rust colours, and known as the "gley" horizon. Other features include brown to grey topsoils and iron and iron-manganese concretions and pans in the subsoil. The meadow soils are subdivided on the basis of site and natural drainage: (a) moderate drainage on terraces where ground water is perched temporarily during wet periods, and (b) poor drainage on lower-lying land where the water table tends to be permanently high. Topsoils at the latter site may also be peaty. Saline soils were considered to be gley soils as well.

Meadow soils are designated gley soils by Wright et al. 1952. In gley soils the profile development is largely controlled by the water table which lies more or less permanently in the upper part of the subsoil. If the ground water rises into the topsoil, subsoils become strongly mottled. Locally, topsoils may become peaty through the accumulation of organic matter derived from plants growing in situ. The class saline gley also appears and refers to gley soils that have been modified by a high initial salt content in the estuarine mud and that have a salty or brackish ground water. Sandy gley soils occur at the coast where wind-blown sand is accumulating in shallow depressions occupied by gley, saline gley and thin organic soils.
In Pohlen et al. 1947, meadow soils are referred to as having a grey subsoil because of high water table conditions. They occur on terraces above flood level. Included in the group is a recent meadow soil which may be subject to flooding.

The legend on the Soil Map of New Zealand 1948 (N.Z. Soil Bureau 1948) (also in Taylor et al. 1959) classifies gley soils and saline gley soils as intrazonal soils. In an explanatory statement to this map Taylor & Cox (1956) say that gley soils owe their distinctive characteristics to ground water at or near the surface for prolonged periods during the year. This causes the formation of a gley subsoil commonly mottled with rust colours. Meadow soils are also mentioned but not discussed.

In the first of the detailed soil surveys after World War II, "Soils of the Lower Clutha Plains" (Cutler et al. 1957), the term gleyed recent soils makes its appearance. These soils have bluish subsoils and occur under a swamp vegetation with ground water near the surface. Some soils are formed on recently deposited alluvium and others on older alluvium. The dominant environmental criterion is the high water table.

Gleyed yellow-brown sands and gleyed recent soils make their first appearance in a pedological classification in Cowie & Smith (1958). In very weakly gleyed sand soils, reddish mottling is confined to the lower part of the subsoil, whereas in other weakly gleyed soils the subsoils are greyer in colour with a few mottles in the upper part, the number increasing with depth. In moderately gleyed soils, mottling enters the topsoil and is more concentrated in the upper part of the subsoil. In strongly gleyed soils, mottles and concretions are abundant in the topsoil with few in the subsoil. The colour of the latter horizon is bluish grey. In gleyed recent soils the subsoils are grey coloured with reddish mottles. Periodic accumulation of fresh alluvium from flooding, however, is still the dominant process.

In the "General survey of the soils of South Island, New Zealand" (N.Z. Soil Bureau 1966a) the profile features of gley soils are given in some detail. Topsoils are very dark greyish brown to black and contain much organic matter and raw humus; the subsoils (B horizons) are sticky and plastic with concretionary accumulation of sesquioxides, and they have a coarse prismatic structure; underneath is the gley horizon without sesquioxide accumulation and having distinctive greyish, bluish or greenish colours. The site for gley soils is low-lying swampy land where the soils are moistened with rain water as well as with ground water. Two classes, gley recent and saline gley recent are introduced. The qualifier gley is used in the present tense rather than in the past tense, to indicate that the gley process is still continuing.

In the publication "Soils of New Zealand" (N.Z. Soil Bureau 1966b), gley soils are classified as central and northern gley soils and saline gley recent soils as a central association.

In the "New Zealand Atlas", Leamy & Fieldes (1976) spell out clearly, for the first time, the meaning of soils and climatic zones. Gley soils are included in both the intrazonal group and the zonal group.
DEFINITION OF THE GLEY GROUP

W.C. Rijkse, with contributions from R.B. Miller, J.D. Cowie, D. Dent, G. Mew & E. Griffiths
N.Z. Soil Bureau, D.S.I.R.

Gley soils form a fairly restricted group, defined as those soils with groundwater at or near the surface for prolonged periods. It does not include soils with perched water tables, which are classed as gleyed members of the appropriate zonal group, nor soils which are actively accumulating. For the purpose of this discussion, the range of soils has been extended to include other intrazonal or azonal soils with high groundwater tables - gleyed recent soils, saline gley soils, acid sulphate soils and others.

GLEY SOILS

These soils often occur in alluvial depressions, and on the lower parts of fans where there is seepage from higher ground. Features are:

- a high groundwater table for all or part of the year,
- occur in low-lying areas,
- are independent of climate,
- are not accumulating,
- are undergoing reduction, particularly in subsoils, which may be expressed by colours of chroma less than /2 and hues 2.5Y to 5Y and 5B,
- may have pale (2.5Y to 5Y) horizons with mottles ranging in hue from 5YR to 5Y (e.g. dark reddish brown, strong brown, yellowish brown, olive brown and olive),
- may contain iron or manganese concretions,
- have high organic matter levels, high total nitrogen and, with the exception of those derived from wind-blown sand or pumice, have adequate potassium levels.

GLEYED RECENT SOILS

These are often similar in appearance to gley soils. However, they are subject to accumulation and are not really independent of climate since flooding may be seen as a result of climate. Furthermore, these recent soils may have different degrees of gleying, often being described as weakly, moderately or strongly gleyed, and the degree can be modified by artificial drainage.

Features are:

- occur in low-lying parts of, or depressions in, alluvial plains,
- flood frequently or infrequently, with subsequent accumulation of fresh alluvium,
OTHER GLEY SOILS

Small areas of other gley soils are formed from coarse-textured materials such as wind-blown sand and volcanic ash (e.g. sandy gley soils and gley soils from pumice alluvium).

Features are:
- occur in low-lying areas,
- have high groundwater tables for all or part of the year,
- are undergoing reduction, particularly in the subsoil, which may be expressed in colours of chroma less than /2 and hues 2.5Y to 5Y and 5R,
- may have mottles ranging in hue from 5YR to 5Y,
- may contain iron and manganese concretions or concentrations,
- have high organic matter contents and high to medium total nitrogen.

Little is known about other members of the gley group, such as subalpine gley soils and alpine gley soils. These soils occur mostly at high altitudes and tend to have deep to very deep organic topsols.

DISTRIBUTION. (1) NORTH ISLAND

W.C. Rijkse
N.Z. Soil Bureau, D.S.I.R., Rotorua

Gley soils occur throughout New Zealand, predominantly on alluvial plains, in valleys and swamps, and on terrace lands. It is estimated that in the North Island they occupy about 242,000 ha (of which 22,000 ha are saline gley soils (S.M. Jarman, pers. comm.). This is 2% of the total area of the island. Although gley soils occur relatively small areas, they are important, for if artificially drained they are amongst the most productive soils in the country.

An account of the distribution of gley soils, district by district, is given below for the North Island. This description does not claim to be complete as further detailed surveys of river plains and valleys reveal more pockets of gley soils.

North Auckland

Isolated pockets of gley soils and gleyed recent soils occur on wider flood plains and in swampland near Kaiatala bordering the Waioa and in swampland near Kaitala bordering the Waiaroa and in swampland near Kaitala bordering the Waiaroa and in swampland near Kaitala bordering the Waiaroa. Generally, River, near Dargaville and Ruwai, and near Whangaroa, Kaipara and Manonui Harbour. Saline gley soils occur around Whangaroa, Kaipara and Manonui Harbour.

South Auckland

Flood plains and swamps are extensive in the Hauraki Plains and in the lower Waikato Valley. Gley soils of the Hauraki Plains are shown in cross-sections of that area (Figures 1a and b). In the lower Waikato Valley, gley soils (Topehahae-Kaipo soils) occur west of Hamilton, east of Ngatiawahi, and around Te Awamutu and Otorehanga (Orbell 1974); they are derived from pumice alluvium.

Taranaki

Gley soils on terraces derived from volcanic alluvium (Glen silty loam, Awatuna silty loam) occur extensively in South Taranaki (Campbell & Wilde 1970). Soils derived from volcanic ash that receive considerable amounts of seepage from higher areas are Egmont black loam, strongly mottled phase and Egmont brown loam, strongly mottled phase.

Bay of Plenty

Soils in depressions and on lower parts of the Rangitaika Plains are derived from thin layers of volcanic ash, pumice alluvium and peat (Pullar in prep., Rijkse in prep.). Examples are shown on the idealised cross section of that area given in Figure 2. After artificial drainage, the soils are generally suitable for dairying, fattening and limited cropping.

East Coast - Poverty Bay

Gley soils occur on former back-swamps of river terraces in Waipau Valley, and on Gisborne and Tolga Bay Plains (Figure 3). The soil pattern in these areas can be compared with that of flood plains in the Manawatu District, also shown in Figure 3. On river terraces, often a well drained soil occurs nearest to the edge of the terrace and a gley or gleyed soil towards the back of the terrace (Pullar 1962, Rijkse & Pullar in press, Rijkse & Kennedy in prep.). In many places, however, the soil pattern is more complex because alluvial fans overlie the terraces or because parts of the sequence are missing.

Hawkes Bay

A large area of saline gley soils occurs in the Old Ahuriri Lagoon (Ahuriri series) (N.Z. Soil Bureau 1968b, Part 3). Gley soils and gleyed recent soils occur in small pockets throughout Hawkes Bay District (Kaiapo series, Raumati series, Awamate series) (Pohlen et al. 1947, Pullar & Ayson 1963) and similar soil patterns as occur in Manawatu District (Figure 3) also occur in eastern Hawkes Bay (Rijkse 1974).

Manawatu

Gley soils on alluvial plains are shown in Figure 3. They occur along the Manawatu, Rangitikei, Orua and Pohangina Rivers (Cowie 1972, Rijkse 1975b). Sandy gley soils are extensive in the Manawatu-Rangitikei
Ke - Keroone silt loam; yellow-brown loam from Holocene to late Pleist. rhyolitic volcanic ash
Wh - Waihou silt loam; yellow-brown loam from Holocene volcanic ash (airfall or waterlaid) on rhyolitic alluvium; well drained and occurs on levees of present and former stream
TP - Te Punainga silt loam; intergrade between gley and yellow-brown loam from ash [Waihou] over rhyolitic alluvium; imperfectly drained; mottled subsoil; occurs on lower slopes of levees and very low rises associated with present and past drainage patterns
Wt - Waitoa silt loam and sandy loam; gley soil from rhyolitic alluvium; on flats between levees. On low points of these flats, once peat covered (and occasional small patches left), these are Hungahunga soils; peaty gleys from shallow peat on rhyolitic alluvium
Sb - Shaftesbury clay loam; gley soil from andesitic alluvium; on lower slopes of Kaimai fans
Gd - Gordon silt loam and stoney silt loam; yellow-brown loam from andesitic alluvium and a shallow volcanic ash cover; on mid and upper fan sectors
TT - Te Tui silt loam, ash on andesite, a yellow-brown loam on Kaimai foothills

Figure 1(a) Cross-section showing gley soils of the upper Hauraki Plains. (Along Diagonal Road, from west of Ngara to footslopes of Kaimai Range)

Figure 1(b) Cross-section showing gley soils of the lower Hauraki Plains
Organic soil, poorly drained, derived from fibrous sedge peat covered with 5-10 cm Tarawera Ash and alluvium from Whakatane River.

Gley soil, poorly drained, derived from shallow Tarawera Ash, on layers of peat or peaty loam, on pumice alluvium.

Recent soil, well drained, derived from 14 cm Tarawera Ash on alluvial sands. River terrace levee.

Gleyed recent soil, moderately well drained, derived from shallow Tarawera Ash, Kaharoa Ash, on peat or pumice alluvium.

Gleyed recent soil, poorly drained, derived from shallow Tarawera Ash, shallow Kaharoa alluvium, on Kaharoa Ash, on peat. Shallow depression on river terrace.

Gleyed recent soil, well drained, derived from alluvium, on Tarawera Ash, Kaharoa Ash, on alluvium from Kaharoa Ash, on Kaharoa Ash, on peat. Frequent flooding.

Recent soil, excessively drained, derived from alluvium from greywacke and volcanic ash. Frequent flooding. A-C profile.

Recent soil, well drained, derived from alluvium from greywacke and volcanic ash. Infrequent flooding. A-(B)-C profiles.

Gleyed recent soil, imperfectly drained, derived from Tarawera Ash, Kaharoa Ash, on peat and Taupo Pumice alluvium.

Awakaponga silt loam
Rangitaiki sand
Opouriao fine sandy loam
Awakeri loamy sand

Pongakawa peaty sand
Otakiri sand
Awaiti loamy sand
Paroa loamy sand
Paroa silt loam

Recent soil, excessively drained, derived from alluvium from greywacke and volcanic ash. Frequent flooding. A-C profile.

Recent soils, frequent flooding, excessively to well drained, A-C profiles
Gleyed recent soils, frequent flooding, imperfectly to poorly drained, A-C profiles
Recent soils, infrequent flooding, well drained; A-(B)-C profiles
Gleyed recent soils, infrequent flooding, imperfectly to poorly drained, A-B-C profiles
Recent soils (intergrading to yellow-brown earths), non-flooding, well drained to somewhat excessively drained, A-(B)-C profiles
Gley soils, non-flooding, imperfectly to poorly drained

Recent soils, frequent flooding, excessively to well drained, A-C profiles
Gleyed recent soils, frequent flooding, imperfectly to poorly drained, A-C profiles
Gleyed recent soils, frequent flooding, imperfectly to poorly drained, A-C profiles
Recent soils, infrequent flooding, well drained; A-(B)-C profiles
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Recent soils (intergrading to yellow-brown earths), non-flooding, well drained to somewhat excessively drained, A-(B)-C profiles
Gley soils, non-flooding, imperfectly to poorly drained

Gley soils, non-flooding, imperfectly to poorly drained

Figure 2 Idealised cross-section of Rangitaiki Plains, Bay of Plenty, showing gley soils

Figure 3 Idealised cross-sections of river terraces, showing gley soils
sand country (Pukepuke series, Carnarvon series and some of Hokio series) (Cowie et al. 1967).

Wairarapa - Wellington

Gley soils (Horora silt loam) and gleyed recent soils (Muhunoa series, Otukura series, Ahikouka series) have been mapped on alluvial plains near Greytown (Cowie 1966) and they also occur extensively around Lake Wairarapa. On valley floors in the Wellington District, gley soils (Gollans silt loam) occur locally (Grant-Taylor et al. 1974).

DISTRIBUTION, (II) SOUTH ISLAND

J.G. Bruce
Soil Bureau, D.S.I.R., Gore

The occurrence of gley soils is governed by local environmental factors, particularly high ground water. As a consequence, their extent and distribution are largely predictable. In general they do not cover large areas and in many instances it is not possible to indicate their presence on a soil map because of limitations of scale. Their distribution, broadly, includes any valley, flood plain or depression which has a high water table or poor drainage conditions, including coastal or estuarine depressions that are inundated by tidal waters. However, in the South Island there are certain regions where environmental factors favouring the development of gley soils are locally abundant, and it is on these areas that this discussion of gley soil distribution is based.

According to Long (1966) the area of gley soils (including gleyed recent and saline gleyed recent soils) in the South Island is approximately 340 000 ha. Of this area, 114 000 ha (33.5%) are true gley soils, 209 000 ha (61.5%) are gleyed recent soils, and 17 000 ha (5%) are saline gleyed recent soils. Though the soils cover a relatively small area, their distribution is widespread, particularly in the lower-lying coastal and near-coastal regions, and in inland plains and basins.

The distribution of the three groups of gley soils will be described individually even though, in some areas (especially near Lake Ellesmere and the Wairau River delta), soils of the three groups occur in close association. In many places too, especially South Canterbury, parts of Otago, and Southland, the gley soils are closely associated with organic soils, both low moor and high moor.

Soil names used in this account are those of the soil sets used in the "General survey of the soils of South Island" (N.Z. Soil Bureau 1968a). In many cases, following more detailed surveys in later years, new soil series names with local attachments have been established. However, as it is the regional pattern rather than the local pattern that is being described, those new names will not be used.

GLEY SOILS

The distribution of gley soils can be divided into three broad regions, largely according to the provenance of the rock types on which the soils are developed. The regions are:

1. The Nelson Region, towards the head of Tasman Bay,
2. The East Coast Region, extending from the Wairau River to the Waitaki River,
3. The Southern Region, including Otago south of Dunedin, and Southland.

Nelson Region (5000 ha)

Gley soils in the Nelson Region cover only a small area and include the Braeburn and Richmond soils. Braeburn soils occur in the Moutere district where they are developed on alluvium derived from weathered greywacke gravels, eroded largely from the adjacent Moutere Hills. Richmond soils, developed on alluvium derived from basic igneous and ultrabasic rocks and shale which crop out in ranges to the east of Nelson, are distributed along the eastern shore of Tasman Bay, mainly between the Waima and Waitaki Rivers.

East Coast Region (59 000 ha)

In the east coast region, gley soils are developed largely in alluvium of greywacke origin derived from the denudation of the main axial ranges. The soils are widely spread throughout the region, and the majority are referred to the Temuka soil set.

In the northern part of this region the distribution is sparse, the only sizeable areas being near Blenheim and in the district surrounding Havelock.

Large contiguous areas of gley soils occur in the central part of the region in the Kalapai district, the Lincoln-Leeston district adjacent to the western shores of Lake Ellesmere, and the coastal districts between Tinwald and Hinds south of the Ashburton River. Associated with the Temuka soils in the last two districts are the somewhat shallower and stony Waterton soils, occupying some 14 000 ha. Smaller areas are located near Oxford and Glentunnel and, as well as Temuka soils, these include Coopers Creek soils (2600 ha) developed on loess colluvium eroded from the adjacent downlands, and greywacke alluvium.

In the southern part of the region the distribution is somewhat scattered, with localised occurrences near Geraldine, Temuka and Washdyke, in the coastal district between the Otaio and Waiau River mouths, and in depressions along the back of low terraces of the Waitaki River northwest of Glenavy. Gley soils in these southern districts are all referred to Temuka soils.

Southern Region (50 000 ha)

The distribution of gley soils in the southern region, unlike that in the other two regions, is more inland than coastal and the individual
occurrences have a marked dendritic pattern. The region is mainly a broad area of low-relief downlands and plains, and the geomorphic dissection pattern includes many underfit rivers and streams.

In the eastern part of this region the gley soils are referred to the Taiieri soil set and are developed on alluvium derived from schist and greywacke with an abundance of quartz. Occurrences are somewhat scattered, the largest areas being in the Milton district on the flood plain of the Tokomairiro River, at Lovells Flat, and surrounding Lake Tuakitoto.

Between Balclutha and Gore, in the valley floors of the many small streams draining across the downlands from the northern flanks of the Kaikuku Ranges, and in the adjacent downlands of West Otago near Waikoikoi and Heriot, Taiieri soils form a closely spaced pattern though individual areas are small and narrow. There are localised occurrences near Waitahuna and Lawrence, on broad reaches of the Waitahuna and Tuapeka Rivers respectively.

Dacre soils, developed on alluvium derived from tuffaceous greywacke loess over quartz gravels, are widespread on the gently sloping Southland Plains in the central part of the region. The dendritic pattern on the Southland Plains is very marked, with the soils occupying the valley floors of most drainage channels including the Waihopai River, the Titipua and Waikii Streams, the Waimatua and Waituna Creeks, and tributary streams. Smaller patches are located in the west, particularly in the Otautau District in stream valleys draining downlands within the Aparima River catchment.

In the north-western part of the region, gley soils are distributed along inter-moraine depressions and parts of glacial outwash plains of the Te Anau - Manapouri Basin. These, the Manapouri soils, are developed on alluvium derived from diorite, granite and tuffaceous greywacke originating from the Fiordland region and deposited by glacial action. Manapouri soils cover about 10 000 ha. The dendritic pattern of distribution is not so strongly marked here as in other parts of the southern region.

Stewart Island

In addition to the gley soils of the South Island, some 6400 ha have been mapped on Stewart Island (Leamy 1974). They include Freshwater and Scott Burn soils which occur largely in Freshwater Valley and adjacent valleys. These soils are developed on alluvium derived mainly from diorite but also including some schist and granite.

GLEYED RECENT SOILS

Gleyed recent soils cover a much greater area in the South Island than do the gley soils. Their distribution can be divided into five broad regions; however, more than 75% of the area of these soils occurs in two of them.

The five regions are:
1. The West Coast Region, from Whanganui Inlet to Big Bay,
2. The East Coast region, extending from the Wairau River to the Waitaki River,
3. The Inland Regions of Canterbury and adjacent North Otago,
4. The Otago Region,
5. The Southland Region.

West Coast Region (92 000 ha)

Gleyed recent soils are extensive on the broad flood plains of all rivers on the West Coast, particularly between the Grey and Cascade Rivers. Smaller, more isolated areas are located in Whanganui Inlet, in coastal districts north of both Westport and Greymouth, and at Big Bay in the south. The soils include Harihari and Karangarua soils.

Harihari soils, which occur largely in the central part of the region, are developed on schist alluvium derived from the adjacent steeplands of the Southern Alps. Karangarua soils, developed on alluvium derived from schist, greywacke and granitic rocks, are closely associated with Harihari soils in most areas but north of Greymouth they are the only soil unit separated.

East Coast Region (23 000 ha)

Taitapu soils are the main gleyed recent soils of the east coast region and are developed largely on alluvium derived from greywacke. Their distribution is somewhat similar to that of the gley soils but they do not cover such a large area.

In the northern part of the region, Taitapu soils are associated with Temuka soils on the Wairau River flood plain near Blenheim. There are also some small localised patches along the Kaikoura coast and at Cheviot.

The major occurrence of gleyed recent soils in the East Coast region is in the vicinity of Banks Peninsula and Lake Ellesmere. Here the Taitapu soils form an almost continuous irregular band from the Ashley River mouth to the southern shores of Lake Ellesmere. In many places they are situated in depressions behind beach ridges. Near Kaikoura and at Lake Ellesmere the gleyed recent soils are closely associated with large areas of gley soils. Much of Christchurch is located on these soils.

In the southern part of the region, Taitapu soils are mapped on the flood plain of the Opar River near Temuka, with a few other small isolated areas on the flood plain of the Waitaki River.

Inland Region (12 000 ha)

Gleyed recent soils of the inland region of Canterbury and adjacent north Otago are, like those of the coastal region, developed on greywacke alluvium, but are referred to the Dobson soil set. They occur in somewhat isolated patches on flood plains of the upper reaches
of the Ashley, Rakata and Rangitata Rivers, on localised flood plains of the smaller rivers in the Mackenzie Basin, and on lake head deltas of Lakes Tekapo, Pukaki, Ohau, and Wanaka.

Otago Region (13 000 ha)

In the Otago region, gleyed recent soils are developed on fine alluvium from schist and include the Paerau and Koau soils. Paerau soils occur in the inland regions of Otago, including parts of Central Otago, at elevations above 550 m. They are located mainly on the flood plain of the upper reaches of the Taieri River near Waipiate, where they are associated with recent (Fraser) soils. Koau soils occur in the lowland regions of Otago. They are extensive on the Taieri Plain south of Mosgiel, and on the lower Clutha Plains near Balclutha.

Southland Region (69 000 ha)

Gleyed recent soils are extensive on the flood plains of the majority of Southland rivers, particularly in central, western and northern districts. Makarewa soils, which are developed on alluvium from greywacke and tuffaceous greywacke, predominate. They are widespread in the central district, mainly on the flood plain of the Makarewa River, its principal tributaries the Otapiri and Hedgehope Streams, and on low lying back-bottoms of the Oreti River flood plain between Winton and Dipton. Distribution is more scattered in the western district where they are confined largely to the flood plains of tributary streams of the swift-flowing Waiau River, and to other localities near Otautau, west of Riverton, and along Crombie Stream in coastal Fiordland. In northern districts, Makarewa soils occur south of Mossburn within the Aparima River catchment, and on the flood plain of the Waimaia stream traversing the Waimaia Plain. They also occur in the south-eastern coastal districts between Waimahaka and Niagara, on streams draining the local uplands.

In the coastal reaches of the Oreti and Mataura Rivers, Oporo soils (8000 ha) are extensive and merge with the Makarewa soils of the local catchment areas. Oporo soils are developed on fine alluvium from greywacke and schist derived from the headwater catchments of these through-flowing rivers. Oswald soils (6000 ha), developed on alluvium from greywacke and schist derived from local catchments in the northern district, have formed on the Five Rivers Plain near Lumsden, and on the lower part of the Waimaia Plain near Riversdale. In many places, particularly near Riversdale, these soils are somewhat shallow and stony.

**SALINE GLEYED RECENT SOILS**

Saline gleyed recent soils are developed largely on alluvium of fine texture in estuarine or tidal conditions. The alluvial parent material is predominantly of greywacke origin but in some localities sediments of local origin form the parent material. In the South Island, saline gleyed recent soils occupy about 17 000 ha and all are referred to the Motukarara soil set.

They are thinly distributed in coastal or near-coastal situations from Waiapu to the Ashley, Rakata and Rangitata Rivers, on localised flood plains of the smaller rivers in the Mackenzie Basin, and on lake head deltas of Lakes Tekapo, Pukaki, Ohau, and Wanaka.

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The major occurrence, covering an area of about 9500 ha, is at Motukarara soils are closely associated with both gley and gleyed recent some 3000 ha in the Wairau River Estuary near Blenheim. Here, also, Other localities in the north are at Greymouth Harbour on Durville Island, Pelorus River and Havelock at the head of Kenepuru Sound, on the shores of Lake Grassmere, and at Waiapu as mentioned above.

The alluvial parent material is predominantly of greywacke origin but in some localities sediments of local origin form the parent material. In the South Island, saline gleyed recent soils occupy about 17 000 ha and all are referred to the Motukarara soil set.

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U.S.D.A. CLASSIFICATION

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RECOGNITION OF GLEY SOILS

The term "gley" is not found in the U.S.D.A. Soil Taxonomy (Soil Survey Staff 1975) but soils with characteristics associated with wetness, with a defined Aquic moisture regime, are recognised at the second level (i.e. suborder category) of the classification. "The aquic moisture regime implies a reducing regime that is virtually free of dissolved oxygen because the soil is saturated by groundwater or by water of the capillary fringe". The absence of dissolved oxygen is implicit in the concept. Consequently, the duration of saturation must be at least a few days and the soil temperature must be above biologic zero (5°C) at some time while the soil or the horizon is saturated.

NOMENCLATURE

Names are constructed by adding the prefix Aqu to the formative element of the order name. The following aquic suborders have been recognised (order names in brackets):

- Aquents (Entisols)
- Aquepts (Inceptisols)
- Aqualfs (Alfisols)
- Aquolls (Mollisols)
- Aquox (Oxisols)
- Aquods (Spodosols)
- Aquults (Ultisols)

Aqu- suborders are not currently recognised in the Aridisol, Histosol and Vertisol orders.

DIAGNOSTIC CRITERIA

The primary diagnostic criterion defining Aqu- suborders is the presence of low-chroma colours.

The diagnostic criteria in the definition of Aquepts are:

1. Have an SAR (Sodium adsorption ratio) that is > 13 (or sodium saturation that is 15 percent or more) in half or more of the upper 50 cm that decreases with depth below 50 cm and the soils are saturated with water at some time of year within a depth of 1 m; or

2. Have artificial drainage or an aquic moisture regime and have one of the following:
   (a) A histic epipedon composed of mineral soil materials;
   (b) A mollic or umbric epipedon that is underlain immediately or at a depth < 50 cm below the mineral soil surface by a horizon that has dominant color, moist, on ped faces, or in the matrix if peds are absent, as follows:
      (i) If there is mottling, chroma of 2 or less;
      (ii) If there is no mottling, chroma of 1 or less;
   (c) A histic epipedon composed of organic soil materials or an ochric epipedon that is underlain at a depth < 50 cm below the mineral soil surface by a cambic horizon or a subhorizon above a fragipan that has dominant color, moist, on ped faces or in the matrix if peds are absent, that meets the requirements of 2b(i) or 2b(ii);
   (d) A sulphuric horizon that has its upper boundary within 50 cm of the soil surface."

Additional criteria used in definitions of other suborders include:

- presence of sulphidic materials; change in colour with exposure to air; and presence of diagnostic horizons associated with wetness causing perching, e.g. calcic or petrocalcic horizons or continuous plinthite.

Where these diagnostic criteria do not fully apply, soils are placed in other suborders, and at subgroup level aberrant gley features may be recognised as intergrades to Aqu- suborders by forming a subgroup name with the adjective aquic or epiaquic, e.g. Aquic Ustochrept (a typic Ustochrept intergrading to an Aquept).

A gley soil in New Zealand may be classified as an Aquent where the marks of any major set of soil forming processes are lacking, or the soil is salty, sulphurous or comprised of low strength materials; an Aquox where a cambic, umbric, placic, calcic or sulphuric horizon, plaggan epipedon, fragipan or duripan is present; an Aquod where an argillic or natric horizon is present and the base saturation is 35 to 50 percent; an Aquult where an argillic or natric horizon is present and the base saturation is less than 35 percent.

Yellow-grey and yellow-brown soils and related intrazonal soils exhibiting gley features may be classified into the Aquept, Aqualf, Aquoll or Aquult suborders. Aquods may be recognised among the gley podzols. The Aquox are likely to be uncommon in New Zealand.

Some examples of New Zealand soil series classified to Great Group level are:

- Paretai series (gley recent soil): Hydralquent
- Temuka series (gley soil): Ochraqualf
- Tokomaru series (moderately gleyed central yellow-grey earth): Fragiaqualf
- Okarito series (gley podzol): Haplaquod
- Taitapu series (gley recent soil): Haplaquoll
- Taieri series (gley soil): Haplaquent
F.A.O. CLASSIFICATION

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INTRODUCTION

In the legend to the FAO-UNESCO Soil Map of the World, New Zealand Gley Soils fall generally and not unexpectedly into the Gleysols, although some go into the Fluvisols.

In the key (F.A.O. 1974), Gleysols are defined after the elimination of Histosols (organic soils), Lithosols (less than 10 cm to hard coherent rock), Vertisols (cracking clays), Fluvisols (recent soils on alluvium) and Solonchaks (salty soils).

Thus soils, even though gleyed, with an H horizon of 40 cm or more (60 cm or more if mainly sphagnum or moss or if the bulk density is less than 0.1; less if the organic matter merges with stones) go into the Histosols, not the Gleysols.

Similarly, soils on recent alluvial deposits, whether gleyed or not, are placed with the Fluvisols so long as they do not have diagnostic horizons other than an ochric A, umbric A, H, or a sulphuric horizon.

GLEY Soils

Definition

Gleysols are:

"Soils formed from unconsolidated materials exclusive of recent alluvial deposits", showing hydromorphic properties within 50 cm of the surface; having no diagnostic horizons other than (unless buried by 50 cm or more new material) an A horizon, a histic H horizon, a cambic B horizon, a calcic or a gypsic horizon; lacking the characteristics which are diagnostic for Vertisols; lacking high salinity; lacking bleached coatings on structural ped surfaces when a molic A horizon is present which has a chroma of 2 or less to a depth of at least 15 cm."

As used in this definition, recent alluvial deposits are fluviatile, marine, lacustrine, or colluvial sediments characterized by one or more of the following properties:

(a) having an organic matter content that decreases irregularly with depth or that remains above 0.35 percent to a depth of 125 cm (thin strata of sand may have less organic matter if the finer sediment below meets the requirements);
(b) receiving fresh material at regular intervals and/or showing fine stratification;
(c) having sulfidic material within 125 cm of the surface.

Soils showing these characteristics are grouped with Gleyic Greyzems.

Suborders of Gleysols

The Gleysols are divided into 7 suborders as follows:

- Gleysols having permafrost within 200 cm of the surface
- Other Gleysols having plinthite within 125 cm of the surface
- Other Gleysols having a mollic A horizon or a eutric histic H horizon
- Other Gleysols having an umbric A horizon or a dystric histic H horizon
- Other Gleysols having one or more of the following: a calcic horizon or a gypsic horizon within 125 cm of the surface, or are calcareous at least between 20 and 50 cm from the surface
- Other Gleysols having a base saturation (by NH₄OAc) of less than 50 percent, at least in some part of the soil between 20 and 50 cm from the surface
- Other Gleysols

Hydromorphic properties

Hydromorphic properties are defined as follows (F.A.O. 1974, pp. 29-30):

"A distinction is made between soils which are strongly influenced by groundwater, the Gleysols, and the soils of which only the lower horizons are influenced by groundwater or which have a seasonally perched watertable within the profile, the "gleyic" groups. The Gleysols have a reducing moisture regime virtually free of dissolved oxygen due to saturation by groundwater or its capillary fringe. Since hydromorphic processes are dominant, the occurrence of argillitic, natric, spodic and oxic B horizons is excluded from Gleysols by definition.

The morphological characteristics which reflect waterlogging differ widely in relation to other soil properties. For the sake of brevity, the expression "hydromorphic properties" is used in the definition of Gleysols and gleyic groups. This term refers to one or more of the following properties:

1. Saturation by groundwater, that is, when water stands in a deep unlined boresole at such a depth that the capillary fringe reaches the soil surface; the water in the bore hole is stagnant and remains coloured when a dye is added to it.
2. Occurrence of a histic H horizon.
3. Dominant hues that are neutral N, or bluer than 10Y.
4. Saturation with water at some period of the year, or artificially drained, with evidence of reduction processes or of reduction and segregation of iron reflected by:

4.1 in soils having a spodic B horizon, one or more of the following:

(a) mottling in an albic E horizon or in the top of the spodic B horizon;
(b) a duripan in the albic E horizon;
(c) if free iron and manganese are lacking, or if moist colour values are less than 4 in the upper part of the spodic B horizon, either:
   (i) no coatings of iron oxides on the individual grains of silt and sand in the materials in or immediately below the spodic horizon wherever the moist values are 4 or more and, unless an Ap horizon rests directly on the spodic horizon, there is a transition between the albic E and spodic B horizons at least 1 cm in thickness, or
   (ii) fine or medium mottles of iron or manganese in the materials immediately below the spodic B horizon;
(d) a thin iron pan that rests on a fragipan or on a spodic B horizon, or occurs in an albic E horizon underlain by a spodic B horizon.

4.2 in soils having a mollic A horizon

If the lower part of the mollic A horizon has chromas of 1 or less, either:

(a) distinct or prominent mottles in the lower mollic A horizon; or
(b) colours immediately below the mollic A horizon or within 75 cm of the surface if a calcic horizon intervenes, with one of the following:
   (i) if hues are 10YR or redder and there are mottles, chromas of less than 1.5 on ped surfaces or in the matrix; if there are no mottles, chromas of less than 1 (if hues are redder than 10YR because of parent materials that remain red after citrate-dithionite extraction, the requirement for low chromas is waived)
   (ii) if the hue is nearest to 2.5Y and there are distinct or prominent mottles, chromas of 2 or less on ped surfaces or in the matrix; if there are no mottles, chromas of 1 or less

(iii) if the nearest hue is 5Y or yellower and there are distinct or prominent mottles, chromas of 3 or less on ped surfaces or in the matrix; and if there are no mottles, chromas of 2 or less
(iv) hues bluer than 10Y
(v) any colour if the colour results from uncoated mineral grains
(vi) colours neutral N.

If the lower part of the mollic A horizon has chromas of more than 1 but not exceeding 2, either:

(a) distinct or prominent mottles in the lower mollic A horizon; or
(b) base colours immediately below the mollic A horizon that have one or more of:
   (i) values of 4 and chromas of 2 accompanied by some mottles with values of 4 or more and chromas of less than 2
   (ii) values of 4 and chromas of less than 2
   (iii) values of 5 or more and chromas of 2 or less accompanied by mottles with high chroma.

4.3 in soils having an argillic B horizon immediately below the plough layer or an A horizon that has moist colour values of less than 8.6 when rubbed, one or more of the following:

(a) moist chromas of 2 or less;
(b) mottles due to segregation of iron;
(c) iron-manganese concretions larger than 2 mm, and combined with one or more of the following:
   (i) dominant moist chromas of 2 or less in coatings on the surface of peds accompanied by mottles within the peds, or dominant moist chromas of 2 or less in the matrix of the argillic B horizon accompanied by mottles of higher chromas (if hues are redder than 10YR because of parent materials that remain red after citrate-dithionite extraction, the requirement for low chromas is waived)
   (ii) moist chromas of 1 or less on surfaces of peds or in the matrix of the argillic B horizon
   (iii) dominant hues of 2.5Y or 5Y in the matrix of the argillic B horizon accompanied by distinct or prominent mottles.

4.4 in soils having an oxic B horizon:

(a) plinthite that forms a continuous phase within 30 cm;
which this might be approached.

and grades of gley and gleyed soils in New Zealand are associated with Regosols in the Manawatu sand country. Gleysols occur as inclusions with Podzols near North Cape and associated with Cambisols in the West Coast of the South Island.

DISTRIBUTION OF GLEYSOIS IN NEW ZEALAND

Using these definitions and applying them to the 1:5 000 000 scale of the Soil Map of the World, Gleysols are found in 6 New Zealand associations. Humic Gleysols are dominant in a Gleysol/Histosol/Acrisol association in the Hauraki lowlands and occur associated with Fluvisols in the Waikato and as inclusions in Acrisols in Northland. Dystric Gleysols occur as inclusions with Podzols near North Cape and associated with Cambisols on the West Coast of the South Island. Eutric Gleysols are associated with Regosols in the Manawatu sand country.

It has proved difficult in the past to define the various kinds and grades of gley and gleyed soils in New Zealand. Their widespread distribution and their importance in land use now make it necessary to develop a precise classification. The notes above indicate one way in which this might be approached.

4.5 in other soils:

(a) in horizons with textures finer than loamy fine sand:

(i) if there is mottling, chromas of 2 or less;

(ii) if there is no mottling and values are less than 4, chromas of less than 1; or if values are 4 or more, chromas of 1 or less;

(b) in horizons with textures of loamy fine sand or coarser:

(i) if hues are as red as or redder than 10YR and there is mottling, chromas of 2 or less; if there is no mottling and values are less than 4, chromas of less than 1; or if values are 4 or more, chromas of 1 or less;

(ii) if hues are between 10YR and 10Y and there is distinct or prominent mottling, chromas of 3 or less; if there is no mottling, chromas of 1 or less.

CLASSIFICATION IN THE FEDERAL REPUBLIC OF GERMANY

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The classification of gley soils in the Federal Republic of Germany is based essentially on the ideas of Mückenhausen (1962), as adopted by the Arbeitsgemeinschaft Bodenkunde (Soil Science Working Party) (1971). Some minor modifications may have been introduced by Professor Mückenhausen in his new book "Bodenkunde" (Soil Science) published this year, but these are unlikely to have changed the fundamental classification. The key unit of soil classification in the German system is the Bodentyp (European soil type, equivalent to the genetic group). Each Bodentyp has its characteristic sequence of soil horizons resulting from the soil forming processes responsible for its genesis. The Bodentyp is classified upwards, first into classes and then into one of three major divisions; Terrestrial Soils, Semi-terrestrial Soils and Subaqueous Soils; after the manner of Kubiena (1953). Deviations from the normal Bodentyp are recognised, as are intergrades between Bodentypen. Lower categories in the classification are the variety, subvariety and form, the latter as influenced by parent material and texture.

In the German classification an important distinction is made between groundwater gleys and perched water gleys. The former constitute a class within the Semi-terrestrial Soils, the latter a class within the Terrestrial Soils.

Three main Bodentypen are recognised within the class of groundwater gleys. These are:

1. Gley (normal gley)
   Characterised by an A horizon overlying a mottled horizon which, in its turn, overlies a reduced horizon.

2. Nassgley (wet gley)
   Characterised by groundwater close to the surface, giving essentially an A horizon overlying a reduced horizon.

3. Anmoorgley (humus enriched gley)
   Characterised by groundwater close to the surface and an A horizon with 15-30 percent organic matter, overlying a reduced mineral horizon.

Various deviations from the central concept, various intergrades, and various subtypes related to these main Bodentypen are recognised.

It is interesting to note that the Germans recognise another class of semi-terrestrial soils known as Auenboden (from die Aue - a fertile plain or meadow). Soils within this class are periodically subject to flooding and the deposition of sediment (of either rock or soil origin)
and experience fluctuations of groundwater level in sympathy with the rise and fall of river levels. A Bodentyp within this class of interest to New Zealanders is the Auengley, a soil formed in relatively young sediment with an A horizon overlying a mottled horizon which in turn overlies a reduced horizon. This Bodentyp corresponds almost exactly to our gley-recent soils.

Turning now to the perched water gleys: these fall within a class of the terrestrial soils with the impressive German name of Staunasseböden; literally, dammed up or internally blocked wet soils.

Two Bodentypen are recognised within the class:

(a) Pseudogley
(b) Stagnogley

In both Bodentypen an impervious horizon or layer within the soil profile blocks or dams up precipitation water percolating down from the surface.

Pseudogleys are subdivided into the categories primary and secondary, according to whether the impervious layer is of geological or pedological origin. The former includes instances where geological strata are close to the surface, such as occur in New Zealand, for example, where a relatively thin coating of volcanic ash overlies laharc breccia at receiving (as opposed to shedding) sites. Secondary Pseudogleys embrace impervious soil horizons arising, for example, from a clay shift or, alternatively, from close packing as in fragipans. The impervious horizon is appropriately referred to in German as a Sohle (sole). The horizon above it shows the characteristic mottling and ironstone concretionary development associated with seasonal oxidation and reduction, the pale grey reduction colours becoming increasingly predominant with increase in duration of waterlogging. Soils such as the Tokomaru silt loam, at the wet end of the yellow-grey earth genetic group in New Zealand, would be classified as secondary Pseudogleys in the Federal Republic. Secondary only in the technical sense of the origin of the impervious horizon, they are absolutely first class Pseudogleys!

The Stagnogley represents the extreme case where perched water remains in position for the greater part of the year and a predominantly grey-coloured horizon develops above the sole. It equates with the popular conception of a Planosol.

In both secondary Pseudogleys and Stagnogleys the impervious horizon is mottled with a mixture of pale grey and orange-brown colours.

The distinction between groundwater and perched water is not new. Reference is made to it in Robinson (1949). It is clear from Mückenhausen (1962) and Kubiena (1953) that the Europeans have been aware of a discernible difference in soil properties since the turn of the century. Although both classes of soils experience the common property of wetness, it has been found worthwhile to distinguish them. They are wet, as it were, for a different reason, and often occur at different elevations.

The question remains whether it would be profitable to make this distinction in the New Zealand system of soil classification.

3 PEDOLOGY

PROCESSES OF GLEYING

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INTRODUCTION

Processes of gleying can only be meaningfully discussed in the context of the soils in which they are presumed to occur. Such soils are commonly referred to as gleys. Gleys, as a genetic group, have been retained in many national surveys, for instance those of England and Wales (Avery 1973) and Germany (Mückenhausen 1962; Arbeitsgemeinschaft Bodenkunde, Soil Science Working Party 1971), as well as in the Soil Map of the World (FAO 1974). The group is presently extant in surveys in New Zealand but has disappeared from the U.S. Soil Taxonomy (Soil Survey Staff 1960, 1975), where its place has effectively been taken by Aquic suborders in seven out of the ten orders of the system.

In Germany and in the Soil Survey of England and Wales a distinction has been drawn between groundwater gleys and perched or surface water gleys. Fitzpatrick (1971) follows a similar line. No such distinction has been made in New Zealand. Translating into the U.S. Soil Taxonomy, most Aquents, Aqueps, Aquolls and Aquox correspond to the groundwater grouping, whereas most Aquafs and Aquults are wet from perched water. Aquods may be saturated from either above or below, a point of interest to New Zealanders.

In any account of gleying processes it is necessary to stipulate which of the two circumstances is involved as the processes are not identical in each. Note, however, that in some special circumstances both kinds of processes may be operative within the one soil profile.

PERCHED OR SURFACE WATER GLEYING

The processes operating in surface water gleys have been documented in Schlüchting & Schwertmann (1973). The principal ones are pseudogleying (Mückenhausen 1962) and ferrugmentation (Brinkman 1970, Dudal 1973). A brief description of these processes as they affect German soils with clay illuvial horizons and New Zealand yellow-grey earths is given in Pollok (1975).

In the account which follows, attention is focussed on the processes operating in groundwater gleys.

GROUND WATER GLEYING

Historically, the word gleys or glei was a Russian folk term referring simply to a mucky or mirey soil mass (Mückenhausen 1962, FAO 1974). Vuisotski (1905) and Zavalishin (1928), as reported in
Joffe (1936), give descriptions of gley horizons formed under the influence of high groundwater. Both authors place emphasis on the blue-grey colour of the gley horizon. According to Crompton (pers. comm.), Vuisotski acknowledged that the gley horizon could sometimes be overlain by an ochreous pan. Zavalishin observed that usually the grey-blue background is mottled with large red spots and veins, but commented that "when gleing is very strong, the material is of a homogenous grey-blue colouration without any spots or veins".

**INTENSITY OF GLEYING**

This last quotation opens up the whole question of the intensity of gleing. Bloomfield (1959) takes the view that the fundamental aspect of the gleing process is the formation of grey-coloured material, with ochreous mottling as but a secondary and counteracting process. The debate as to whether the gley horizon should be restricted to homogenous grey, grey-blue or grey-green coloured soil material, or whether it should also include ochreous mottlings, has continued for over half a century. Strzemieni (1959) reported that the Russians, French, New Zealanders and (prior to 1960) Americans have emphasised the grey-blue criterion, while the English, Germans, Spanish, Portuguese, Italians and Dutch have stressed the importance of ochreous mottling in association with the grey-blue colour.

Such generalisations, however, should be treated with caution. Within the class of groundwater gleys, the Germans recognise three types: Gley, Nassgley and Anmoorgley; as reported elsewhere in this issue (Pollok 1978, p31). The Gley (normal gley) has an Ah-Go-Gr sequence of horizons, but the Nassgley (wet gley) has an Ah-Gr and the Anmoorgley (peaty gley) an Aa-Gr sequence. In the German system of horizon designation, Go stands for a partially oxidised (i.e. ochreous mottled) horizon in the zone of fluctuating groundwater, and Gr for a reduced (i.e. blue-grey) horizon in the region of the permanent water table. Ah represents a humus-rich A horizon, Aa an amoor or peaty horizon. Clearly there is recognition here of differences in intensity of gleing, after the sense of Zavalishin (1928). Similar recognition is afforded in the recent English definitions for gleyed horizons (Avery 1975). *Intensely gleyed horizons* (containing sufficient iron to redden on ignition) are required to have "a dominant chroma of 1 or less in yellowish, greenish or bluish hues, that change on exposure to air". *Other gleyed horizons* (i.e. less intensely gleyed ones, with or without ferruginous cortices) are normally required to have chromas less than 3. Gley soils as a major group are required to have one such gleyed horizon (intense or less intense) starting at a depth of less than 40 cm from the surface. Where the gleyed horizon lies deeper, but within 60-70 cm of the surface, the gleyed character is recognised at a lower level in the classification.

In order to explore the idea of intensity of gleing further, it is of interest to make a traverse along any sand plain in the Manawatu sand country, from open water lagoon at the foot to dune soil at the head. In Table 1 the soil types as reported by Cowie & Smith (1958) and Cowie, Fitzgerald & Owers (1967) along such a traverse in the Motuiti Dune-Phase (Cowie 1965) have been listed. In the adjoining columns, horizon designations for the soils according to the FAO/UNESCO/ISSS and German systems are given. These are to a first approximation, based on Cowie's original profile descriptions. Where B horizons are recorded in this example they are in the most rudimentary stages of development.

### TABLE 1  
FAO/UNESCO/ISSS and German horizon designations for soils of the sand plain and apical dune of the Motuiti Dune Phase, Manawatu sand country

<table>
<thead>
<tr>
<th>Soil type</th>
<th>FAO/UNESCO/ISSS</th>
<th>German</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open water lagoon</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Omanuka peaty sandy loam</td>
<td>Hg-Cr</td>
<td>Aa-Gr</td>
</tr>
<tr>
<td>Omanuka peaty sandy loam (shallow phase)</td>
<td>Hg-Cgr</td>
<td>Aa-Gor</td>
</tr>
<tr>
<td>Pukepuke black sand with concretions</td>
<td>Acs-Bgc-Cr</td>
<td>GoAh-Go-Gr</td>
</tr>
<tr>
<td>Pukepuke black sand</td>
<td>Ah-Bg-Cr</td>
<td>Ah-Go-Gr</td>
</tr>
<tr>
<td>Himatangi sand</td>
<td>Ah-Bg-Cg</td>
<td>Ah-Go-G02</td>
</tr>
<tr>
<td>Himatangi weakly mottled sand</td>
<td>Ah-Bw-Cg</td>
<td>Ah-Bv-G0</td>
</tr>
<tr>
<td>Motuiti sand (formerly Foxton dark grey sand)</td>
<td>Ah-Bw-C</td>
<td>Ah-Bv-C</td>
</tr>
</tbody>
</table>

The result is illuminating. A continuous sequence of soils ranging from horizons of maximum gleing intensity at the foot of the sand plain to horizons of minimum gleing intensity towards the head is revealed. Cowie has expressed the same idea graphically in Soil Bureau Bulletins 16 and 29 (Cowie & Smith 1958; Cowie, Fitzgerald & Owers 1967).

Any attempt to classify the soils of such a continuum into gleys and non-gleys is dependent solely upon our mental concept of what constitutes a groundwater gley. This is nicely illustrated in Table 2, where an attempt has been made to classify the soils of the sequence according to the German system and the New Zealand systems of Taylor & Cox (1956) and Taylor & Pohnlen (1970). The idea of the New Zealand comparison stems from Cowie (1968).

From the table it is clear that the different classifications cut the continuous soil sequence at different points. The classification classes are artificial individuals (Knox 1965). It would therefore seem wise to discuss gleing processes in the context of any arbitrarily selected soil class. Rather, it would appear more profitable to consider the processes as they operate across the continuum, where the complete spectrum of intensity of gleing lies revealed.

### MECHANISMS

If Zavalishin's observation is accepted, that where gleing is strongest, homogenous grey-blue colours prevail without any spots or veins, this implies that the mechanism is one of complete reduction under the influence of a permanent water table. The level of the permanent water table must reach at least as far up as the bottom of the A or H horizon. Waterlogging per se, however, is insufficient cause. If the water perchance is oxygenated, an ochreous mottled horizon, instead of an homogenous grey-blue one, will result.
In this connection it is of interest to note a requirement laid down for the Aquic moisture regime by the U.S. Soil Taxonomy (Soil Survey Staff 1975), which stipulates that the soil temperature should be above the biological zero of $5^\circ C$ at some time while the soil or horizon is saturated. This is because dissolved oxygen is removed from groundwater by the respiration of micro-organisms, roots and soil fauna. The Aquic moisture regime is required to be a reducing one.

**REDOX REACTIONS**

It could be imagined that, given a soil completely saturated with deoxygenated water, the operation of redox potential alone, under the prevailing conditions of $pH$, would be sufficient to account for the formation of an homogenous blue-grey horizon. Elements capable of valency change would all end up in the reduced state. By way of illustration and expressing it at its simplest, the following reactions for iron and manganese would be driven hard to the right.

$$\begin{align*}
\text{Fe}_2\text{O}_3 + 6\text{H}^+ + 2e^- & \rightarrow 2\text{Fe}^{2+} + 3\text{H}_2\text{O} \\
\text{MnO}_2 + 4\text{H}^+ + 2e^- & \rightarrow \text{Mn}^{2+} + 2\text{H}_2\text{O}
\end{align*}$$

The net result would be that iron and manganese, rendered soluble in the reduced state, would be distributed uniformly throughout the soil mass.

However, for the above reactions to be driven to the right an input of electrons is required on the left. Organic matter is the most potent source of electrons in the soil system. Once organic matter is introduced, however, the argument is no longer a purely physicochemical one.

**ORGANIC EFFECTS**

Bloomfield (1951) demonstrated that the anaerobic fermentation products of plant remains are very potent complexing and reducing agents. Another English author, Bromfield (1954), obtained evidence of the presence of iron-reducing bacteria in gleyed clay at a depth of 2 feet (60 cm), but not in gleyed clay at 10 feet (3 m). This led him to suggest that in the shallower layers of soil, where there is organic matter available to micro-organisms, the micro-organisms are able to supplement the gleying action of plant-reducing substances. Bloomfield (1959), for his part, adduced from the apparent absence of iron-reducing organisms at depth, as reported by Bromfield, that the gleying at 10 feet was a product of the purely chemical action of soluble organic compounds derived from the upper horizons. A modern and elegant account of the reduction reactions that can take place in soils in the (simultaneous) presence of organic matter, absence of an oxygen supply, and presence of anaerobic micro-organisms, is given by van Breeman & Brinkman (1976).

**FERROUS SALTS**

Traditionally, the grey, blue-grey or blue-green colour of intensely gleyed horizons has been attributed to the presence of various
ferrous salts, such as ferrous sulphide (FeS) or ferrous phosphate (vivianite, Fe₃P₂O₆·8H₂O). However, Bloomfield (1959) notes that while such compounds may be formed in waterlogged soils, they certainly are not invariably present. In his experience, the formation of vivianite is a rare occurrence. This observation, however, need not necessarily be true in New Zealand, and vivianite is known to occur in soils of the Pohangina Valley and Opiki regions of the Manawatu. Bloomfield acknowledges that the reduction of sulphate to sulphide occurs in some gleys. However, since such soils, when drained and thereby oxidised, give rise to acid sulphate soils with extremely low pH, he prefers to treat them as a special group on their own, if only to simplify the problem of the discussion of the more general class of gleys.

RESIDUAL IRON

Bloomfield (1950) attributed the grey or nearly white (low chroma) colour of clay at the end of his gleying experiments to the removal of the masking effect of amorphous ferric compounds originally present in the clay. However, it later (Bloomfield 1959) reached the conclusion that there was more to the gleying process than just this. Part of the iron, in a form other than ferric oxide, is retained by the clay in a manner that prevents its removal by water. A requirement of intensely gleyed horizons, after the system of Avery (1973), is that they should contain sufficient iron to redden on ignition, even though their normal chromas are one or less. However, Bloomfield (1959) would prefer the grey colour of gleyed soils to remain stable to atmospheric oxidation, whereas in the system outlined by Avery the pale yellowish-greenish or bluish hues of the intensely gleyed horizon are required to change colour on exposure to the air. No such colour change is specified for less intensely gleyed horizons.

It thus remains an open question how much ferrous iron or, for that matter, any other reduced element remains in the soil as a result of the gleying process. Bloomfield has noted that iron is sometimes lost from waterlogged soils, as evidenced by the chalybeate film occasionally encountered on the surface of ditch water. In other situations (for example, confined basins) there may be little opportunity for dissolved iron to move out. In fact the reverse may be true and the soil may become a sink for the receipt of ferrous iron from the surrounding terrain. The whole question of the relationship between groundwater flows and gleying processes remains open for investigation. An interesting lead in the case of the movement of soluble salts with the pattern of groundwater flow has been given in a recent paper by MacLean & Pawluk (1975).

That some reduced iron and manganese is normally present in most groundwater gleys is attested by the fact that the blue-grey mottling, a close association with ochreous mottling and possible concretionary development is inevitable. Soils occupying the middle position, where both reducing and oxidising conditions prevail, are more extensive than those confined to environments where reducing conditions alone predominate.

THE GLEYING SPECTRUM

It is precisely at this point that a challenge should be presented to the view, current in many quarters, that consideration of the gleying process should be restricted to conditions where reduction is complete and only blue-grey colours prevail. Such a narrow concept confines the phenomenon of gleying to very restricted areas. Yet the chance of ochreous mottlings popping up to blot the blue-grey copy-book is ever present. Even from the beginning, Vuisotzkii and Zavalishin noted the possibility. Likewise, in the definition given by Avery for gleyed horizons other than intensely gleyed, the subtle phrase "with or without mottles" creeps in. In the definitions of Aquic suborders in the U.S. Soil Taxonomy the specifications for chroma vary according to the standard phrases "if there is mottling" or "if there is no mottling". From a chemical point of view it seems unduly restrictive to limit the range of redox reactions in water-logged soils to the equilibrium position where only reduction prevails. Clearly, in the example of soils on the Motuiiti sand plain given earlier, the redox equilibrium is swinging both ways once the middle ground between complete reduction and complete oxidation is reached.

It is also necessary, at a time when attention is being focussed upon individual diagnostic horizons, to be reminded of the genetic connection between horizons. At the turn of the century it was regarded as a major advance in pedological thought when P.E. Müller established such a connection for the eluvial and illuvial horizons of podzols. In the case of gleys, as soon as the condition of complete reduction is left behind, one of intermittent waterlogging is encountered, most typically in that region of the pedon where the level of the water table fluctuates between winter and summer limits. It may possibly come as a surprise to many readers that it is in such a circumstance that the Germans find their typical or normal gley (Mückenhoven 1962, Arbeitsgemeinschaft Bodenkunde 1971). The same circumstance, exactly, prevails in the Papakura brown sand and many other soils in New Zealand. As indicated in Table 1, the designated horizon sequence for such soils, expressed in simplest form, is Ah-Go-Cr in the German system and Ah-Bg-Cr in the FAO/UNESCO/ISSS one. A clear genetic connection exists, between the two lower horizons in particular, through the seasonal rise and fall of the water table. The reduced iron, manganese and other elements borne upwards when the water table rises in winter are precipitated, oxidised and left behind when it falls in summer.

CONCLUSION

In conclusion then, groundwater gleying processes involve redox reactions aided and abetted by the decomposition products of organic matter. Despite modern concentration of attention on the reduction end of the redox spectrum, a close association with ochreous mottling and possible concretionary development is inevitable. Soils occupying the middle position, where both reducing and oxidising conditions prevail, are more extensive than those confined to environments where reducing conditions alone predominate.
GISBORNE REVISITED - FIELD OBSERVATIONS ON GLEYED RECENT AND GLEY SOILS

W.A. Pullar
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After a lapse of 20 years I have re-examined my unpublished notes on hydromorphic soils of the Gisborne Plains. (For a general account of the soils of this area, see Pullar 1962). The following comments are still valid:

1. Despite artificial drainage for 50 years the groundwater level fluctuates widely, from 30 cm below the surface in winter to 150 cm below in summer. The duration of seasonal high groundwater level has, however, been shortened by artificial drainage.

2. The Taupo Pumice marker bed occurs within a metre of the surface. It is part of the solum in gleyed recent soils (Makaraka clay loam) but occurs below the solum in gley soils (Kaiti clay loam). It is more important as an aquifer in the former group of soils and is therefore involved in the flushing process.

3. Gleyed recent soils are weakly accumulative; gley soils have been non-accumulative for about 500 years.

4. A feature of the gleyed recent soils is that the A1 horizon is gradually being added to at the surface while at the same time it is being gleyed underneath. They are, thus, A-gleyed soils in which buried A horizons have low % organic C values, but well developed nut structure. Also the A1 horizon becomes more rapidly melanised than in well drained luvisolic soils.

In the gley soils, however, the thickness of the A1 horizon in its natural state is no more than 5 to 10 cm, but after artificial drainage the thickness increases to 18 to 23 cm. The increase reflects a higher level of biologic activity.

5. Horizon designations for classification purposes include sa1, A1, 1A, for gleyed recent soils and A1, A1g, Bg for gley soils.

6. The colour of the buried A horizon in gleyed recent soils is SGY 4/1 and that in the A1 horizon of the gley soils is SY 3/2. The Bg horizon of both classes of soil is SGY 6/1.

Hydromorphic soils are difficult to classify in the field as man has so interfered with them that they are partly anthropic. Are we making observations in the "here and now" or are we effecting, unconsciously, a constructed universal of what the soils should have been in their natural state, before the advent of man and particularly before European settlement? While I like to think that the field is an important arbiter in classification I consider that, in this class of soils, field observations should get more support from the laboratory.
In the middle 1960s I was much impressed by the work of Fieldes et al. (1965) in developing a tentative soil classification based on the constitution of the soil exchange complex. They attempted, also, to isolate the effect of dominant constitution on fundamental properties such as the pH/base saturation relationship. According to these authors, soil constitution classes have specific curves when plotted on a graph with pH and % base saturation values as co-ordinates. Furthermore, there is no overlapping of regions except at high base saturation values of illosols and montosols. Gleyed recent and gley soils are included in the illosols constitution class.

This classification was tested for the Gisborne hydromorphic soils but the exercise was not a success. The high % base saturation values of 100 caused overlapping in the region between the illosol and montosol curves (Figure 1). Much better results were obtained with the gley soil Kaiti silt loam, containing Taupo Pumice and Waikihia ash in the Bg horizon. It would seem that the parent material effect (montmorillonite) is still too strong for the gley process and that, according to my interpretation of classification by soil constitution, there are no true madytic or gley soils present on Gisborne Plains.

**GLEYING INDUCED BY IRRIGATION IN TWO CENTRAL OTAGO SOILS**

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During two recent soil surveys in Central Otago, evidence of gleying induced by irrigation was found. The soils concerned were:

(i) Duffers silt loam*, in the Bannockburn Valley
(ii) Manuhirikia fine sandy loam, in the Cromwell Gorge

Both soils have received water every summer by wild flooding irrigation since between 1900 and 1910.

**Duffers silt loam**

Duffers silt loam is classified as a brown-grey earth. It is developed on in oitū and slope colluvial tertiary clays with an admixture of loess in its A horizon. The landform is gently to moderately sloping and ryegrass-clover association is the dominant pasture.

Inefficient water distribution caused by wild flooding irrigation has induced a perched water table at, or more commonly above, the tertiary clay contact. Even moderate slopes (up to 12°) display gley features where excessive water is applied. Excessive water and subsoil impediments cause significant changes in profile morphology. These are:

(i) An increase in the clay fraction of the topsoil, i.e. non-irrigated silt loam becomes a heavy silt loam under irrigation.

* Tentatively correlated with the Becks series.

(ii) The B horizons of non-irrigated soils have colour values of 5 or less and chromas of 3 or more, while the B horizons of irrigated soils have values of 4 or more and chromas of 2 or less.

(iii) Coarse prismatic structure is a feature of both soils but the structure in the gley soil is more strongly developed and extends from the A to the C horizon.

(iv) Gleyed subsoil horizons contain white dendritic accumulations approximately 1 to 2 cm in length (they are non-calcareous as they do not react with HCl). Prominent concentrations usually occur in the Bg horizons.

(v) Non-gleyed profiles had no mottles but Fe and Mn mottles and concretions increased in abundance, size and prominence with progressive gleying.

**Manuhirikia fine sandy loam**

Man-induced gley features are not confined to fine-textured soils. Manuhirikia fine sandy loam is derived from loess resting on terrace or fan gravels. The overall drainage classification is well drained. Paint mottles were observed in the B and C horizons where the soil was irrigated by wild flooding irrigation.

**Discussion**

Gleying in the above soils has been recorded 50 to 60 years after irrigation commenced. In view of the significant increase in irrigated lands in New Zealand there is a need to investigate and characterise the environmental, chemical and physical changes that could take place in irrigated soils, especially where gley features are induced by subsurface impediments. Such changes could significantly alter the concept of a soil's mapping and taxonomic units.

The question arises, when classifying induced gley soils, at what taxonomic level they should be defined. A factor to be considered is the extent to which the gley process is reversible, should irrigation be discontinued. If the soil re-assumes its original morphological features, classification would be at phase level. If, however, gleying is irreversible, will the natural environmental conditions return the soil to neo-sitic status or will the imprint of gley development remain in the soil requiring the soil's reclassification to perhaps paleomadenti-sitic, or a silt-madytic or madentic soil?

Research should be directed at understanding what pedological changes take place in irrigated soils, what time periods are involved and the effects these changes have on land use.
THE SIGNIFICANCE OF COLOUR IN THE DEVELOPMENT OF GLEY SOILS IN THE Rotorua Basin

N.M. Kennedy
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Rotomahana Mud is a hydrothermally altered material, deposited as a near-continuous layer on the eastern side of Lake Rotorua during the Tarawera eruption of 1886. It constitutes the parent material of some well drained recent soils (Rotomahana shallow sandy loam, Rotoiti sandy loam) and some gley soils (Nganguru shallow peaty loam, Hinemoa silt loam).

The colour of the Rotomahana Mud in the well-drained recent soils is greyish brown (2.5Y 5/2 to 10YR 5/2), but in the gley soils with a constantly high water table it ranges from grey to bluish grey (N 6/ to SB 5/1). On sites where the water table fluctuates, the colour of the Mud grades from greyish brown (2.5Y 5/2) near the surface to bluish grey (SB 5/1) near its base. Strong brown (7.5YR 5/6) mottling is usually more pronounced but concretions are either very few or absent.

Conclusions are:
1. Since the parent material is no more than 90 years old, the nature of the site is considered to be more important than the passage of time in the development of gley soils;
2. Where the Rotomahana Mud is overlain by peat, the colour of the G horizon is completely bluish grey (SB 5/1) and mottles and concretions are either very few or absent.

SALINE GLEY SOILS AND ACID SULPHATE SOILS

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I SALINE GLEYS

Saline gley soils are developed most extensively in the inter-tidal zone of shallow, sheltered harbours where fine-textured sediments are accreting under mangrove and salt-marsh vegetation.

Soil profile development is initiated when mobile sediment is stabilised by vegetation. Continued accretion of mud gradually raises the surface towards mean high tide level while transpiration by the vegetation and evaporation at low tide brings about loss of water from the soil, shrinkage, and structural development. This process has been termed "physical ripening" (Pons & Zonneveld 1965). Table 1 outlines the classification of soil material at successive stages.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Suffix to horizon symbol</th>
<th>Consistence</th>
<th>n-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ripe</td>
<td>r</td>
<td>firm; does not stick to hands, or only slightly; cannot be squeezed through the fingers</td>
<td>&lt;0.7</td>
</tr>
<tr>
<td>nearly ripe</td>
<td>w</td>
<td>fairly firm; tends to stick to the hands; cannot be squeezed through the fingers</td>
<td>0.7-1.0</td>
</tr>
<tr>
<td>half ripe</td>
<td>wB</td>
<td>fairly soft; sticks to the hands; can be easily squeezed through the fingers</td>
<td>1.0-1.4</td>
</tr>
<tr>
<td>practically unripe</td>
<td>wY</td>
<td>soft; sticks fast to the hands; can be easily squeezed through the fingers</td>
<td>1.4-2.0</td>
</tr>
<tr>
<td>unripe</td>
<td>wO</td>
<td>liquid mud; cannot be kneaded</td>
<td>&gt;2.0</td>
</tr>
</tbody>
</table>

The degree of physical ripening is assessed in the field according to the consistence of the soil. A quantitative measure of ripening is provided by the n-value, the quantity of water in grams absorbed by one gram of clay in the soil, which is derived from the equation:

\[ n = \frac{A - 0.2R}{L + bH} \]

where A = percentage of water in field condition, calculated on a dry soil basis
R = the non-colloidal part of the soil; percentage silt + sand
L = percentage clay
H = percentage organic matter (%C x 1.724)
b = the ratio of the water-absorption capacity of organic matter to clay (3 for well-humified organic matter; 4 for partly-decomposed material).

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seawater for oxidation of the organic substrate. The reduced iron and sulphur species combine and accumulate in the soil as iron pyrite, FeS2.

Under mangrove vegetation (Avicennia marina, var. reevesii) (Forsk.) Vieh) in Northland, profile development varies according to topography. Along the banks of tidal creeks and rivers, where surface drainage is rapid, tall mangroves develop. Their extensive root system, with protruding pneumatophores densely covered by fibrous algae, accelerates sedimentation. Initially a shallow, practically unripe, olive brown surface horizon (Cg) with abundant fibrous roots and many crab burrows is developed over a practically unripe, dark grey or dark greenish grey substratum (termed Gr; G for gley, r for completely reduced).

While the surface is continually raised by deposition of fresh mud, soil ripening proceeds in the upper layers of the sediment, principally through the extraction of water by plant roots. A bluish grey or greenish grey, half ripe horizon (termed Go1, G for gley, o for partly oxidised) develops. Shrinkage of the sediment creates a very coarse prismatic structure. Oxygenated water entering clay fissures and percolating down the coarse vertical tubular pores leads to the oxidation and segregation of iron as soft, reddish brown pipes and ped face cutans. Below the Gol horizon the soil remains strongly reduced and practically unripe.

Ultimately, levees are built up above the level of high water neap tides and a nearly ripe G02 horizon is developed above the Go1 and Gr layers. The G02 is prominently mottled greenish grey and reddish brown. It has a strong coarse prismatic structure, and iron oxide pipes and nodules, but rarely ped face cutans.

At all stages of profile development the surface horizon of the most recently deposited mud (Cg) is soft and permeable. In more mature profiles it develops a medium or coarse nutty structure, probably as a result of shrinkage during neap tides.

On the extensive flats between the creeks, the general slope and the microtopography are so slight that during spring tides the soil is continuously waterlogged. The mangroves become increasingly stunted as surface drainage deteriorates; profile development is also curtailed. In the early stages of profile development a dense, fibrous root mat overlies the practically unripe substratum. When the flat has accreted to above high water neap tides a compact platy surface horizon (CG) is developed, and during neap tides in summer a halite efflorescence may develop on the surface. Below the CG horizon the same sequence of horizons is developed as in the levee soil - a nearly ripe horizon with prominent reddish-brown mottles, nodules and oxide pipes; a half ripe horizon with iron oxide pipes; and a strongly reduced half ripe or practically unripe horizon which is very dark grey or black and rich in partly-decomposed roots and iron pyrite. In addition, there may be extensive shell beds dating from the unvegetated mud flat stage of development. Basement sand commonly occurs at depths of less than one metre.

Appendix 1 gives profile descriptions and analytical data for representatives of a mature creek levee soil (R IV), a neighbouring but still immature flat soil (R V), and a mature flat soil (R II).

Pyrite contents as high as 11 percent of dry weight (6.5 percent total 5) occur in the practically unripe lower horizons of old saline gley soils which have developed under mangrove vegetation. The nearly ripe upper horizons have much lower pyrite contents. There is also a general decline in pyrite contents from north to south which can be attributed to lower rates of primary organic matter production and bacterial activity.

Temperate salt marsh soils develop the same sequence of horizons as those under mangroves. Their pyrite content is generally low and the segregation of iron in upper horizons is less pronounced. Mature salt marsh on fine-textured sediments commonly carries a superficial peaty horizon overlying ripe and nearly ripe G horizons.

Sandy sediments in the inter-tidal zone are less readily colonised by vegetation than are muds. Sandy saline gley soils close to mean high water level have deep, coarsely and prominently mottled horizons overlying dark bluish grey or dark grey, permanently-reduced material. Their organic and sulphur contents are generally much lower than those of their fine-textured counterparts, except where a peaty surface or buried organic matter is present.

II ACID SULPHATE SOILS

Natural or artificial drainage of soils rich in pyrite leads to severe acidification due to the oxidation of the pyrite to sulphuric acid. In the absence of sufficient calcium carbonate to neutralise the acidity the pH may drop initially as low as 2.0 - 3.5. At this low pH, further oxidation of pyrite results in the formation of the pale yellow basic iron sulphate jarosite (KFe3(SO4)2(OH)6) which buffers the pH at c. 3.8. Pale yellow mottles, pore fillings and cutans of jarosite are the most characteristic morphological features of acid sulphate horizons.

Appendix 2 gives the profile description and analytical data for a representative acid sulphate soil (Oue VI) developed from mature creek levees.

Forty years after empoldering, and after twenty years of grassland management, the field pH remains very low except in the thin topsoil. The further drop in pH following slow, moist oxidation in the laboratory (oxidation pH) suggests a considerable reserve of non-oxidised pyrite in the lower horizons. Compared with potentially acid saline gley soils, the acid sulphate soil exhibits a characteristic grey to JOVR 6/1 J2 horizon (J for jarosite) developed from the sulphidic Gr horizon, with incomplete ripening and the distinctive pale yellow pore fillings and cutans of jarosite. Salinity is reduced in the upper horizons but remains high in the lower, still waterlogged, layers. The high E.C.s value for the J2 horizon of the Oue VI profile may be caused by sulphate ions generated by the oxidation of pyrite, but this is not a consistent feature of acid sulphate profiles. Where the initial sulphur content of the G horizons is less than about 0.7 percent, extreme acidity does not develop following drainage and normal ripening produces a mottled Bg horizon.

Acid sulphate development on flats is essentially similar but is commonly moderated by the presence of abundant shells, which are dissolved leaving reddish brown moulds of iron oxide.
Large areas of marine alluvium lying just above MHWST, e.g. Kaipara clay, are former acid sulphate soils that developed by natural drainage and weathering of sulphidic saline gley soils. Drainage and weathering have proceeded to a depth of a metre or more leaving a strongly weathered, somewhat acid clay with coarse prismatic structure, occasional ironstone nodules, red and greenish grey mottles and, in its natural state, a peaty surface and prominent dark brown organic cutans. A jarositic acid sulphate horizon and completely reduced material with residual pyrite remain at depths of more than one metre.

The principal agronomic problems associated with acid sulphate soils are:

1. \(\text{Al}^{3+}\) toxicity and, in severe cases, \(\text{Fe}^{3+}\) and \(\text{Mn}\) toxicity engendered by the low pH. Continued heavy applications of lime are required to ameliorate the acidity.

2. Phosphate is unavailable as insoluble aluminium and iron phosphates. There can be no response to phosphate fertilisers until the pH is raised to c. 5.

3. Residual salinity where water table control is inadequate.

The range of species which tolerate these conditions is small. Shallow rooting in the less acid topsoil is general and the soils have a low available water capacity. Hence, in summer the crop suffers from drought, intensification of acidity and related problems, and sometimes from high levels of soluble salts.

### APPENDIX 1

**Profile R IV**

**Higher category classification:**

**Profile form:**

**Location:**

**Landform:**

**Slope:**

**Vegetation:**

**Parent material:**

**Drainage:**

**Moisture conditions in the soil:**

**Salinity:**

**Human influence:**

**Brief description of the profile:**

Nearly ripe saline gley

Sulfic Hydraqent (Soil Survey Staff, 1975)

Cg/Go2/Gol/11Gr at 1.6 m.

Muddy Creek, Rangaunu Harbour; grid ref. N6/724841.

Virtually level terrace 8-20 m wide on crest of mature levee; 20-35 cm knick along creek and inland margin coinciding with the edge of dense *Salicornia* meadow.

Flat.

Widely-spaced old mangroves 6 to 8 m high and up to 2 m girth; age in excess of 100 years. 100 percent ground cover of *Salicornia australis*.

Sulphidic estuarine mud overlying loamy sand on sand basement at 160 cm.

Poorly drained; tidal, not covered by neap tides.

At low tide, moist to 10 cm, wet below.

Class 3; strongly affected.

None.

6.5 cm of dark greyish brown porous half ripe silty clay; overlying 35 cm nearly ripe clay - greenish grey with prominent brown and reddish brown mottles, crisp iron oxide pipes and small ironstone nodules; overlying 20 cm practically unripe greenish grey silty clay with soft iron oxide pipes; overlying practically unripe black silty clay containing abundant partly-decomposed roots and smelling strongly of \(\text{H}_2\text{S}\). Dark grey sandy basement occurs below 160 cm.
**Detailed profile description:**

**Horizons** depth (cm)

Cg w8 0-6.5

very dark greenish brown (10YR 3/2) with few fine faint diffuse dark yellowish brown (10YR 4/4) mottles; clay; half ripe; weakly-developed fine crumb structure; many fine dendritic and interstitial pores; abundant fine fibrous roots; common clusters of white furry balls 0.5 mm diameter (fungal?); clear smooth boundary; pH 6.5.

Go2 w6 6.5-40

greenish grey (5GY 5/1) with 15 percent medium distinct diffuse brown (7.5YR 5/2) and 20 percent medium prominent sharp reddish brown (5YR 4/4) mottles; clay; nearly ripe; weakly developed coarse prismatic structure; many fine to coarse dendritic pores, commonly with residual woody fibres in situ; common crisp reddish brown iron oxide pipes 3 to 8 mm diameter and small (< 1 mm) hard red and black ironstone nodules; frequent fine roots and common medium and coarse woody roots; clear smooth boundary; pH 5.9 to 6.0.

Go1 w4 40-53/63

greenish grey (5GY 4/1) clay; practically unripe; very weakly defined very coarse prismatic structure; many fine to coarse dendritic and coarse vertical tubular pores, coarse pores frequently occupied by partly decomposed roots with epidermal and vascular tissues intact but soft and blackened, water drains quickly into the pit through these pores; 10 percent dark reddish brown (2.5YR 3/4) iron oxide pipes up to 1 cm diameter around vertical tubular pores; clear wavy boundary; pH 6.5, pH 6.0 in pipes.

Gr1 w4 53/63-160

black (5Y 2.5/2) with common coarse diffuse N 2/ mottles and, in the upper 15 cm, greenish grey (4GY 4/1) infilling coarse tubular pores; silty clay; practically unripe, structureless; many fine to coarse dendritic pores frequently occupied by partly-decomposed roots, few live medium roots; strong smell of H2S; abrupt smooth boundary; pH 6.7 at 110 cm.

II Gr2 160-220+

dark grey (5Y 4/1) with few medium faint diffuse olive and grey mottles; loamy sand; very firm; structureless; common fine and medium pores with partly-decomposed roots in situ; pH 7.0 at 170 cm.

---

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**Soluble Salts (me. per 100 g)**

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*Electrical conductivity.

---

**Additional data:**

- Electrical conductivity.
Profile R V

**Higher category classification:**
Half ripe saline gley
Typic Sulfaquent (Soil Survey Staff 1975)

**Profile form:**
Goz/Gol/Gr/IIGr at 80 cm

**Location:**
Muddy Creek, Rangaunu Harbour; grid ref. N6/725840

**Landform:**
Raised flat incorporating a residual clay island; microtopography 3-4 cm

**Slope:**
Virtually flat

**Vegetation:**
Senescent 2 m shrub mangrove, heavily covered with lichens, and an understorey of young 60 cm shrub mangroves

**Parent material:**
Sulphidic estuarine mud, overlying sandy basement at 80 cm

**Drainage:**
Very poorly drained; tidal, with standing surface water between tides during winter

**Moisture conditions in the soil:**
Wet throughout

**Salinity:**
Class 3; strongly affected

**Human influence:**
None

**Brief description of the profile:**
A thin surface layer of fluid mud overlies 16 cm half-ripe dark greenish grey clay with abundant fibrous roots and few small soft iron oxide nodules; overlying 20 cm dark grey half ripe clay; overlying 30 cm black practically unripe silt loam with abundant partly decomposed roots and smelling strongly of H2S; overlying 40 cm dark grey practically unripe sulphidic fine sandy loam, also rich in partly-decomposed mangrove remains; overlying dark grey basement sand at 120 cm.

**Detailed profile description:**

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**Moisture conditions in the soil:**
Wet throughout
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<td>18</td>
<td>3</td>
<td>27.1</td>
</tr>
<tr>
<td>12-16</td>
<td>4.5</td>
<td>25.6</td>
<td>6.2</td>
<td>107.3</td>
<td>143.6</td>
<td>124</td>
<td>15.0</td>
<td>33</td>
<td>18</td>
<td>3</td>
<td>36.2</td>
</tr>
<tr>
<td>25-30</td>
<td>4.9</td>
<td>27.7</td>
<td>5.8</td>
<td>110.0</td>
<td>148.4</td>
<td>131</td>
<td>14.8</td>
<td>35</td>
<td>22</td>
<td>5</td>
<td>43.6</td>
</tr>
<tr>
<td>40-45</td>
<td>5.2</td>
<td>23.9</td>
<td>4.4</td>
<td>88.8</td>
<td>122.3</td>
<td>96.5</td>
<td>(14.8)</td>
<td>n.d</td>
<td>n.d</td>
<td>n.d</td>
<td>37.8</td>
</tr>
<tr>
<td>90-100</td>
<td>3.2</td>
<td>15.2</td>
<td>3.0</td>
<td>59.5</td>
<td>80.8</td>
<td>61.8</td>
<td>(15.4)</td>
<td>n.d</td>
<td>n.d</td>
<td>n.d</td>
<td>35.1</td>
</tr>
<tr>
<td>140-150</td>
<td>1.4</td>
<td>5.6</td>
<td>1.3</td>
<td>23.5</td>
<td>31.9</td>
<td>28.1</td>
<td>(9.1)</td>
<td>n.d</td>
<td>n.d</td>
<td>n.d</td>
<td>37.8</td>
</tr>
</tbody>
</table>

* Electrical conductivity

### Profile KII

**Higher category classification:**
- Nearly ripe saline gleysulfic Hydraquent (Soil Survey Staff 1975)
- Cg + CG/Go2/Go1/Gr/IIGr at 80 cm

**Profile form:**
- Ng'apuke Creek, Kaipara Harbour; grid ref. N37/960933
- + 1.16 m

**Location:**
- Raised flat with slight microtopography of hummocks, amplitude 5 cm, around individual mangroves

**Landform:**
- Almost flat

**Slope:**
- c. 75 percent canopy of 40 cm high shrub mangroves; bare ground between punctured by pneumatophores

**Vegetation:**
- Sulphidic estuarine mud overlying sand at 80 cm; abundant shells below 120 cm

**Parent material:**
- Poorly drained, tidal. Site not inundated during neap tides

**Drainage:**
- At low tide, moist to 15 cm, wet below

**Moisture conditions in the soil:**
- Strongly affected; halite efflorescence on the surface during neap tides in dry weather

**Salinity:**
- None

**Human influence:**
- The surface horizon varies between hummock and depression. On hummocks it is up to 16 cm thick, light olive brown, blocky and porous (Cg); in depressions it is thinner, mottled, greenish grey and olive brown, platy and compact with a few small soft black nodules (CG). The underlying horizon is 20 cm thick, bluish grey with reddish brown mottles and iron pipes, and nearly ripe (Go2); it merges with a dark greenish grey half ripe horizon with iron pipes (Go1) which in turn merges with dark bluish grey half ripe mud rich in iron sulphide (Gr). Dark bluish grey sand and loamy sand occurs below 80 cm with abundant shells between 120 cm and 150 cm
Detailed profile description:

**Horizons**

- **Cg w**: 0-16 (Hummock sites)
  - Light olive brown (2.5Y 5/4) silty clay; nearly ripe; moderately developed medium blocky structure; many fine dendritic pores; common crab burrows lined with freshly deposited mud; frequent fine and medium roots; pH 6.6; clear smooth boundary.
  - Olive brown (2.5Y 4/3) with common medium faint diffuse dark greenish grey (5G 4/1) mottles; silty clay; nearly ripe; moderately developed fine (1-5 mm) platy structure with coarse, vertical polygonal fissures; continuous thick (2-3 mm) dark brown (7.5YR 4/4) cutans on ped faces; few small (up to 4 mm) soft rounded black nodules; rare fine roots but common pneumatophores 2-6 cm apart; abrupt smooth boundary.
  - Olive brown (2.5Y 5/4) mottles; silty clay; nearly ripe; weakly developed medium platy structure fissured to medium blocky; common fine dendritic pores; common small soft rounded dark brown (7.5YR 4/4) nodules; frequent fine fibrous roots, common woody lateral roots bearing pneumatophores; pH 6.6; abrupt smooth boundary.

- **CG1 w**: 0-3 (depression sites)
  - Greenish grey (5G 5/1) with common fine and medium distinct clear light olive brown (2.5Y 5/4) mottles; silty clay; nearly ripe; weakly developed medium platy structure fissured to medium blocky; common fine dendritic pores; common small soft rounded dark brown (7.5YR 4/4) nodules; frequent fine fibrous roots, common woody lateral roots bearing pneumatophores; pH 6.6; abrupt smooth boundary.

- **CG2 w**: 3-11 (depression sites)
  - Dark bluish grey (5B 4/1) with 30 percent medium prominent sharp reddish brown (5YR 4/4) and common fine distinct clear pale olive (5Y 5/4) mottles; silty clay; half ripe; weakly defined coarse prismatic structure; many fine to coarse vertical tubular pores; many thick-walled (up to 8 mm) crisp dark reddish brown iron oxide pipes around medium and coarse pores; occasional small polychaete worms to 20 cm; common fine to coarse roots; pH 6.4 to 6.6; gradual smooth boundary.

- **Gr2 w**: 35-56
  - Dark greenish grey (5Y 4/1) with common medium distinct clear pale olive (5.4) mottles on ped faces; silty clay; half ripe; weakly defined very coarse prismatic structure; common fine to coarse dendritic and coarse vertical tubular pores, soft reddish brown (5YR 4/4) iron oxide pipes around coarse pores; few live fine roots; pH 6.6; clear smooth boundary.

- **Gr1 w/B**: 56-80
  - Dark bluish grey (5B 4/1) silty clay loam; half ripe to practically unripe structureless; many fine to coarse dendritic pores, commonly occupied by partly decomposed roots and oozing black fluid mud, few live roots; pH 6.5; clear smooth boundary.

- **IIGr2**: 80-200+
  - Dark bluish grey (5B 4/1) loamy sand; firm but fluid when disturbed; structureless, abundant shells of Chione stutchburyi and Cyclomactra ovata between 120 cm and 150 cm, common shells below this; pH 7.0 at 110 cm.

**Shear strength:**

<table>
<thead>
<tr>
<th>depth (cm)</th>
<th>apparent density (g cm⁻³)</th>
<th>pore space (%)</th>
<th>shrinkage (%)</th>
<th>n-value</th>
<th>Loss on ignition (§75°C) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AJ 0-5</td>
<td>0.86</td>
<td>67.2</td>
<td>39.3</td>
<td>0.8</td>
<td>7.2</td>
</tr>
<tr>
<td>H 2-7</td>
<td>0.85</td>
<td>65.8</td>
<td>36.3</td>
<td>0.8</td>
<td>6.4</td>
</tr>
<tr>
<td>W 17-22</td>
<td>0.95</td>
<td>62.4</td>
<td>37.0</td>
<td>1.2</td>
<td>4.2</td>
</tr>
<tr>
<td>AN 30-35</td>
<td>1.07</td>
<td>58.2</td>
<td>33.2</td>
<td>1.5</td>
<td>2.4</td>
</tr>
<tr>
<td>O 40-45</td>
<td>1.09</td>
<td>59.0</td>
<td>32.9</td>
<td>1.5</td>
<td>0.8</td>
</tr>
<tr>
<td>P 50-55</td>
<td>1.04</td>
<td>59.5</td>
<td>34.3</td>
<td>1.5</td>
<td>1.7</td>
</tr>
<tr>
<td>T 70-75</td>
<td>1.00</td>
<td>60.9</td>
<td>37.1</td>
<td>1.5</td>
<td>2.3</td>
</tr>
<tr>
<td>AL 80-85</td>
<td>1.07</td>
<td>60.0</td>
<td>34.5</td>
<td>n/a</td>
<td>1.6</td>
</tr>
<tr>
<td>E 110-115</td>
<td>1.40</td>
<td>46.2</td>
<td>24.3</td>
<td>n/a</td>
<td>0.6</td>
</tr>
</tbody>
</table>

**Bulk samples:**

<table>
<thead>
<tr>
<th>depth (cm)</th>
<th>pH values</th>
<th>electrical conductivity (mS cm⁻¹)</th>
<th>C(%)</th>
<th>total S(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AKA 55a</td>
<td>0-2.5</td>
<td>6.6</td>
<td>7.5</td>
<td>6.5</td>
</tr>
<tr>
<td>b 2.5-10</td>
<td>6.6</td>
<td>7.0</td>
<td>5.9</td>
<td>5.9</td>
</tr>
<tr>
<td>c 15-25</td>
<td>6.4</td>
<td>7.6</td>
<td>5.9</td>
<td>5.9</td>
</tr>
<tr>
<td>d 30-35</td>
<td>6.6</td>
<td>7.7</td>
<td>6.2</td>
<td>6.0</td>
</tr>
<tr>
<td>e 60-65</td>
<td>6.5</td>
<td>6.8</td>
<td>3.1</td>
<td>2.0</td>
</tr>
<tr>
<td>f 110-120</td>
<td>7.0</td>
<td>8.4</td>
<td>6.5/4.5*</td>
<td>2.3</td>
</tr>
</tbody>
</table>

* high values adjacent to shell fragments
APPENDIX 2

PROFILE DESCRIPTION AND ANALYTICAL DATA FOR A REPRESENTATIVE ACID SULPHATE SOIL

Profile Oue VI

Higher category classification:
Profile form:
Location:
Landform:
Land use:
Parent material:
Drainage:
Salinity:
Brief description of the profile:

Unripe acid sulphate soil
Typic Sulfaquept (Soil Survey Staff 1975)
Brockliss' flats, Oue near Rawene, Hokianga; grid ref. N14/003318
Levee, microtopography 0.14 to 0.2 m
Good grass-clover pasture with a few rushes
Sulphidic estuarine mud
Imperfectly drained. Floodgates normally maintain the water table below 75 cm
Free above water table, moderately affected below

7-10 cm dark greyish brown moderately acid plough layer overlies 75 cm grey, mottled pale yellow strongly acid silty clay, ripe close to the surface merging to nearly ripe below 50 cm with a strongly developed coarse prismatic structure fissuring to blocky, and thick ped face and pore cutans of soft jarosite; overlying 65 cm bluish grey, half ripe, moderately acid silty clay with pipes and ped face cutans of iron oxide; overlying bluish grey practically unripe silty clay. Roots are concentrated in the plough layer but penetrate to the water table down wide fissures in the acid sulphate horizon.

Detailed profile description:

<table>
<thead>
<tr>
<th>Horizons</th>
<th>depth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1.1</td>
<td>0-0.5</td>
</tr>
<tr>
<td>A1.2 p</td>
<td>0.5-7/10</td>
</tr>
<tr>
<td>J2 wα</td>
<td>7/10-75</td>
</tr>
<tr>
<td>Go1 wβ</td>
<td>75-146</td>
</tr>
<tr>
<td>Gr wγ</td>
<td>146-220+</td>
</tr>
</tbody>
</table>

Very dark greyish brown (10YR 3/2) silty clay; friable; moderate medium crumb structure made up entirely of worm cast material; many fine inped and interstitial pores; abundant fine roots; abrupt smooth boundary, mixture of dark brown (7.5YR 3/3) fibrous peaty root mat and very dark greyish brown (10YR 3/2) material with 40 percent fine and medium distinct dark yellowish brown (10YR 4/4) mottles; silty clay; ripe; friable consistence; moderately developed medium granular structure mixed with clods of unaltered 8 Ja material; frequent fine roots; common earthworms in friable granular material; pH values 5.0 at 1 cm, 3.8 to 4.3 at 5 cm; abrupt smooth boundary, grey (7.5YR 5/1) with 20 percent fine and medium prominent sharply-defined pale yellow (SY 8/4) and, below 40 cm, 25 percent coarse diffuse dark greenish grey (SBG 3/1) mottles; silty clay; ripe decreasing to nearly ripe with depth; strongly developed very coarse prismatic structure, 20 cm cross section, strongly fissured to blocky with 1 cm wide vertical fissures filled with dark greyish brown granular soil; many fine to coarse dendritic pores with partly-decomposed roots in silt; ped faces and pores carry continuous thick, up to 1 mm, soft adhesive jarosite cutans, commonly with strong brown (7.5YR 5/6) to weak red (2.5YR 4/2) iron oxide cutans superimposed, coarse pores are loosely filled with powdery jarosite and root remains; live roots are rare within peds but frequent in fissures; pH 3.2-4.3; clear smooth boundary, bluish grey (SB 5/1) with 10 percent fine faint diffuse black mottles; silty clay; half ripe; moderately developed very coarse prismatic structure; many fine to coarse dendritic and coarse vertical tubular pores, commonly with partly-decomposed roots in silt; tubular pores encased in crisp iron oxide pipes up to 8 mm diameter; ped faces carry continuous thin brown (10YR 4/3) iron oxide cutans and occasional patchy thin jarosite cutans overlying a 5 mm thick grey (SY 5/1) oxidised zone; pH 3.8 at 80 cm, 4.7 at 140 cm; gradual smooth boundary, bluish grey (SB 5/1) silty clay; practically unripe, structureless; many medium and coarse dendritic pores occupied by partly decomposed roots.
Shear strength:

<table>
<thead>
<tr>
<th>depth (cm)</th>
<th>initial/residual shear strength (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>23/6</td>
</tr>
<tr>
<td>10-15</td>
<td>29/8</td>
</tr>
<tr>
<td>15-20</td>
<td>25/6.5</td>
</tr>
<tr>
<td>20-25</td>
<td>11/4.5</td>
</tr>
<tr>
<td>40-45</td>
<td>7/3.5</td>
</tr>
<tr>
<td>50-55</td>
<td>7/3.5</td>
</tr>
<tr>
<td>60-65</td>
<td>6.5/2</td>
</tr>
<tr>
<td>70-75</td>
<td>4.5/1</td>
</tr>
<tr>
<td>90-95</td>
<td>4/1</td>
</tr>
<tr>
<td>100-110</td>
<td>6.5/1.5</td>
</tr>
<tr>
<td>120-125</td>
<td>6/1</td>
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Core samples:

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<thead>
<tr>
<th>depth (cm)</th>
<th>apparent density (g cm⁻³)</th>
<th>pore space (%)</th>
<th>shrinkage on drying (%)</th>
<th>n-value</th>
<th>loss on ignition (375°C) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AG 10-15</td>
<td>1.04</td>
<td>58.2</td>
<td>20.5</td>
<td>0.58</td>
<td>6.6</td>
</tr>
<tr>
<td>K 25-30</td>
<td>0.93</td>
<td>62.6</td>
<td>27.4</td>
<td>0.67</td>
<td>6.3</td>
</tr>
<tr>
<td>AP 40-45</td>
<td>0.87</td>
<td>66.4</td>
<td>39.1</td>
<td>0.94</td>
<td>4.0</td>
</tr>
<tr>
<td>AD 75-80</td>
<td>0.87</td>
<td>66.5</td>
<td>40.3</td>
<td>1.01</td>
<td>4.2</td>
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</table>

Bulk samples:

<table>
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<tr>
<th>depth (cm)</th>
<th>pH values</th>
<th>Electrical conductivity (mS cm⁻¹ at 200% saturation)</th>
<th>C(%)</th>
<th>S(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>field</td>
<td>after slow oxidation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AKA 74a</td>
<td>5.0-3.8</td>
<td>4.7</td>
<td>1.1</td>
<td>6.2</td>
</tr>
<tr>
<td>b 10-15</td>
<td>4.3-3.2</td>
<td>3.8</td>
<td>2.0</td>
<td>2.1</td>
</tr>
<tr>
<td>c 54-50</td>
<td>4.0-5.5</td>
<td>3.0</td>
<td>1.9</td>
<td>1.3</td>
</tr>
<tr>
<td>d 95-105</td>
<td>4.5</td>
<td>2.5</td>
<td>1.7</td>
<td>1.1</td>
</tr>
<tr>
<td>e 125-135</td>
<td>4.7</td>
<td>3.9</td>
<td>2.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

MAPPING TECHNIQUES

W.C. Rijkse
N.Z. Soil Bureau, D.S.I.R., Rotorua

INTRODUCTION

Mapping of alluvial plains, often exhibiting intricate patterns of well drained and imperfectly to poorly drained soils, can be slow and time-consuming. Differences in natural drainage are usually not visible on common panchromatic aerial photographs, and soil boundaries have to be "augered out".

Methods have been developed using film material that is sensitive to parts of the visible and infrared range of the spectrum (Rijkse 1975a). Multispectral aerial photographs, taken on this material, show details of the soil and vegetation pattern that cannot be seen on conventional panchromatic photographs.

Multispectral photographs are taken simultaneously with four Hasselblad cameras mounted together in a frame (Physics and Engineering Laboratory 1976). The cameras are loaded with Kodak 2424 film, and multilayer interference filters are used. Thus, 4 images of each scene are taken as follows:

- Image or band no. | Wavelength
- 1 | 0.5-0.6 μm (green)
- 2 | 0.6-0.7 μm (lower red)
- 3 | 0.7-0.8 μm (upper red)
- 4 | 0.8-1.1 μm (infrared)

Areas of the Uawa Valley near Tolaga Bay and Waipu Valley near Ruatoria (East Coast, North Island) were selected to assess the use of multispectral aerial photographs for soil surveys and to compare their use with panchromatic photo-interpretation (Rijkse 1977a).

METHODS

Black and white prints of each of the four bands were made for use in the field.

Positive transparencies for the four bands were loaded in a Colour Additive Viewer (C³S) which enables the interpreter to combine, simultaneously, photographs of different wavelengths by registering and projecting them on a screen. Different colour filters can be placed before each transparency, and light intensity through each band can be varied. Thus, the colour combination or multispectral photograph appears on the screen of the C³S. Stereo viewing is possible, but is difficult and time-consuming. Since these coloured photographs are expensive to produce, overlays are used to interpret the spectral information.

RESULTS

The soils in both valleys consist of a pattern of well drained soils of levees and imperfectly drained soils of former swamps and fens.
Photo-interpretation of panchromatic aerial photographs of the Uawa Valley, near Tolaga Bay, distinguished only the extent of the flood plain from surrounding hill country, and a few low-lying river flats adjacent to the river.

The black and white separates of the two infrared channels (0.7-0.8 µm and 0.8-1.1 µm) show more details on the river flats. Light tones generally relate to well drained soils of the levees and low river flats, and dark tones indicate imperfectly to poorly drained soils. The multispectral photographs show these differences more clearly; deep red tones indicate well drained soils and bluish-grey colours correlate with poorly drained soils.

The agricultural pattern tends to obscure the soil pattern, and recently topdressed pastures with vigorous growing plants may show as reddish on imperfectly drained soils. Also, dense vegetation such as manuka shrub obscures the soil pattern. However, on hill slopes, sandstones show as greyish to greenish grey while mudstone or siltstone shows as red.

Terraces in Waiau Valley are more clearly defined and therefore panchromatic photo-interpretation is more effective. The infrared separates again indicate well drained soils by light tones and imperfectly drained heavy-textured soils by dark tones, and these differences are again clearer on the multispectral photos on which, also, gravelly soils can be detected by greyish red streaks. High-level well drained soils derived from volcanic ash register as deep red, as to hill soils derived from mudstone.

CONCLUSIONS

Multispectral aerial photographs are an effective tool in soil mapping, especially in river valleys and generally flat and rolling areas where differences in natural drainage are important. The agricultural pattern and heavy vegetation patterns may be related to the soil pattern, and the photos can also be used to analyse vegetation and crop species and topdressing trends.

Table 1 compares the types of interpretation possible with panchromatic photos, black and white infrared separates and multispectral photographs.

It is clear that multispectral photographs are a versatile tool for different kinds of surveys.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Panchromatic</th>
<th>Black and white infrared (0.7-0.8 µm and 0.8-1.1 µm)</th>
<th>Multispectral (0.5-0.6 µm; 0.6-0.7 µm; 0.7-0.8 µm and 0.8-1.1 µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>well drained levees</td>
<td>not visible</td>
<td>visible in many areas by light tones</td>
<td>clearly defined by deep red and orange tones</td>
</tr>
<tr>
<td>poorly drained back swamp</td>
<td>not visible</td>
<td>in many areas indicated by dark tones; agricultural pattern confusing the interpretation</td>
<td>in many areas indicated by brown, green and grey colours; different colours correlate with degrees of natural drainage; agricultural pattern disturbing to a degree</td>
</tr>
<tr>
<td>terrace levels; topography in general</td>
<td>clearly visible in stereoscopic viewing</td>
<td>gully erosion clearly visible by bluish colours; slumping detectable by stereoviewing; sheet erosion clearly visible by colour changes and different vegetation</td>
<td>clearly visible in stereoscopic viewing</td>
</tr>
<tr>
<td>erosion patterns</td>
<td>gully erosion clearly visible by light tones and shape; sheet erosion only where severe</td>
<td>gully erosion poorly visible by light tones; sheet erosion not detectable</td>
<td>agricultural pattern and natural vegetation clearly visible (obscures soil pattern in places); differences in topdressing visible</td>
</tr>
<tr>
<td>vegetation</td>
<td>agricultural pattern visible but difficult to interpret; natural vegetation visible by tone differences</td>
<td>agricultural pattern visible by light and dark tones; natural vegetation also visible by tone differences</td>
<td>indications from topography, under pasture (heavy parent materials (bentonitic mudstone, mudstone and siltstone) showed deep red; sandstone was greyish green, generally light tones). No detection possible under dense vegetation such as manuka shrub or forest</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parent Material</th>
<th>Panchromatic</th>
<th>Black and white infrared (0.7-0.8 µm and 0.8-1.1 µm)</th>
<th>Multispectral (0.5-0.6 µm; 0.6-0.7 µm; 0.7-0.8 µm and 0.8-1.1 µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(sandstones, siltstones)</td>
<td>not visible, except for topographical indications</td>
<td>not visible, except for topographical indications</td>
<td></td>
</tr>
</tbody>
</table>
MICROMORPHOLOGY OF TWO REPRESENTATIVE GLEY SOILS

B.C. Barratt
N.Z. Soil Bureau, D.S.I.R., Auckland

These notes are based on micromorphological studies (Barratt 1971a, b) which included two gley soils of the Soil Bureau reference set. Field and chemical data have been published for one of the profiles, Okarito peaty loam, (N.Z. Soil Bureau 1968b, Part 3); the other soil, Te Arakura silt loam, is on the unpublished supplementary list.

Okarito peaty loam is classified as a deep southern gley podzol (deep iron illuvial A-gleyed podic with superimposed madentipodic) (N.Z. Soil Bureau 1968); Te Arakura silt loam as a weakly leached central gley soil (weakly leached madentic) (Cowie 1972). The soils occur at altitudes of 30 m and 47 m respectively, under mean annual rainfalls of 2800 mm and 950 mm. They have formed on alluvium under podocarp and podocarp-dicotylous forests which have since been converted, respectively, to mixed fernland and to pasture with brown-top and clover.

MICROMORPHOLOGICAL DESCRIPTION

Micromorphologically, the profiles show similarities associated with the gleying process. The Okarito profile, however, shows some additional features which are the result of podzolisation.

Te Arakura silt loam - A1 horizons, viewed in thin section, consist largely of yellowish-brown clay organic colloid (mullicol), although the proportion of clay colloid (argillicol) increases with depth. Aggregates in these horizons are mostly angular or massive, but with some irregularly rounded and pelleted microstructure. Some unrecognisable brown plant fragments are present, as well as quartz, feldspar and hornblende grains and a few brown nodules.

The A2G horizon has massive microstructure, open and soil-infilled root pores, and a few discontinuous fissures. Skeletal minerals resemble those in the topsoil except that feldspars are embayed; they are set in a brownish-grey groundmass which appears to be mostly microcrystalline quartz.

The B1G horizon has similar microstructure and porosity to the A2G horizon but its mineral assemblage is richer in fresh muscovite, weathered hornblende, and other mineral particles. The strong brown colloidal groundmass is isotropic, waxy in lustre, and occurs mostly as discrete patches within peds but shows close packing adjacent to fissures and parallel layering along them.

The G horizon is massive, possessing a silt-rich mineral skeleton. Porosity is confined to root pores. The brownish-yellow groundmass is mottled, with strong brown isotropic patches, some recognisably organic in origin, infilling old root pores.

INTERPRETATION

Organic regime

Te Arakura silt loam - This has a fairly active organic regime; pelleted and irregularly rounded microstructure indicates that earthworm and macrofaunal activity extend as deeply as the A2G horizon. Earthworm activity is also reflected in the predominance of intimately associated clay and organic colloid (mullicol) in the groundmass plasma. Root pores are smooth, however, suggesting that faunal passages get closed up by local soil movement before they can be used as root pathways. Soil movement such as swelling and shrinkage probably also accounts for the predominance of fitting aggregates in A horizons.

Okarito peaty loam - By contrast, the soil organic regime here is weak. Soil fauna of the soil-mixing type appear to be absent, and organic matter is concentrated at the soil surface as a thick peaty layer. This peaty layer apparently contains little clay, although skeletal minerals (sand and silt) are quite abundant. Microscopic examination shows that it has the character of a sandy A0, rather than of a true A1 horizon as designated. The peaty layer has largely been converted to material of a very fine particle size; the main agents of decomposition appear to be fungi and mites. However, few faecal pellets of the latter are preserved and the total soil faunal biomass in the topsoil is low (Lee 1968). In its largely colloidal form, the organic matter is probably readily mobilised to take part in the eluvial process.
Wasting Regime

WEATHERING

In both profiles, weathering of skeletal minerals appears to be only moderate or weak. Both soils have moderate contents of weatherable minerals, including feldspars, pyroxene and muscovite, but the distribution of minerals with depth differs in the two profiles.

**Te Arakura silt loam** - Skeletal minerals are rather evenly distributed throughout the profile.

**Okarito peaty loam** - Minerals show a noticeable increase in degree of weathering in the A2g horizon, and greatest preservation from weathering in the BgC horizon. This weathering pattern, corresponding to redox zones of maximum eluviation and illuviation, has been observed in other podzols (e.g. Barratt 1965). The colloid in the illuvial horizon appears to act as a protective barrier against further weathering of the embedded grains.

GLEYING AND ELUVIATION

Both profiles are gleyed, as shown by mottling, and they are also eluviated, as shown by pale A2g horizons and corresponding illuvial Bg or Bgh horizons of warmer and darker colour. However, whereas gleying is the dominant process observed in the Te Arakura profile, podzolisation seems to be the dominant process in the Okarito profile.

**Te Arakura silt loam** - Gleying is of the pseudoglei type (Kubiena 1971). Clay movement appears to result mostly from local weathering and reorganisation to form nodules and diffuse mottles towards ped centres. Vacant root pores and structure faces become pale as a result of iron depletion, probably caused by migrating solutions.

**Okarito peaty loam** - By contrast, gleying here is of the stagnoglei character, as shown in the G horizon by the deposition of ferric colloid along root channels. This reflects the wetter drainage regime in the Okarito profile, with only short periods of oxidation, which favours the existing air spaces.

In the development of podzolised features in the Okarito profile, colloidal organic matter appears to be physically as well as chemically active. In A0 and A1 horizons, organic matter is very finely broken down and weakly aggregated and is probably both highly reactive and readily mobilised. In the A2g horizon it is incompensuous except as decomposed residues in old root pores. However, close examination reveals that skeletal grains are coated and embedded in a very thin, greyish brown, isotropic colloid which is slightly orientated around the grains. This is probably migrating downwards both between and along the grains.

In the BgC horizon, much strong brown isotropic colloidal material has been deposited, partly between and around grains where it forms discontinuous patches and coatings, and also along fissures. In fissures it forms a sharply defined, layered coating likely to be the result of repeated influx. The difference in colour between this colloid and the organic colloid in A horizons is evidence of a difference in composition and is probably attributable to the illuviation of iron as well as organic colloids as shown by chemical analyses (N.Z. Soil Bureau 1968b, Part 3).

### Table 1 Mean characteristics of gley soils of New Zealand

<table>
<thead>
<tr>
<th>Horizon</th>
<th>pH H₂O</th>
<th>1% Citric P</th>
<th>CEC</th>
<th>TEB</th>
<th>% BS</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
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<tr>
<td></td>
<td></td>
<td>(mg %)</td>
<td>(me.%)</td>
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<td>(me.%)</td>
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<tr>
<td>moderate natural drainage</td>
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</tr>
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<td>8.9</td>
<td>3.1</td>
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</tr>
<tr>
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<td>9</td>
<td>24.2</td>
<td>5.6</td>
<td>22</td>
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<td>54</td>
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<td>0.18</td>
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</table>

1 calculated from 1% citric-soluble K₂O figures (Metson 1961)
Those familiar with N.Z. Soil Bureau (1968a) will notice the omission of gley recent soils from Table 1. This is because the chemistry is not reported for the gley horizon. Samples retained for chemical characterisation usually represent the A, AB and B horizons only, G horizons not being analysed.

Because of the complexity of the chemistry the constituents phosphorus (P) and sulphur (S) and the cation exchange properties (CEC, ECat, % BS, exchangeable Ca, Mg and K) will be dealt with in a little detail.

**PHOSPHORUS**

Owing to the reduction of iron and its compounds in the anaerobic environment, and the formation of ferrous phosphate (Fe-P) complexes, acetic acid soluble P will be higher in gleyed than in associated freely drained soils (Crompton 1957). Glentworth (1947) found that the acetic acid soluble P reaches a maximum in the gley zone, where total P is a minimum.

There are two possible explanations for this P relocation within the profile:

1. That the P moves and is probably lost by continuous formation of FeHPO₄, which is relatively more labile than other Fe-P complexes (Russell 1961).

2. That the deficit of oxygen within the profile retards nitrification of ammonium compounds. This could lead to NH₄-P complex formation (Glinka 1963) which would also cause P losses to the drainage water.

Thus, the gley horizon would be richer in 'available' P but as this is continually being removed by lateral drainage, the reserves of total P in the soil would be depleted.

In New Zealand, citric acid soluble P was taken as offering a good indication of 'plant available' P (Metson 1956). Available P measured in this way provides the only P information for these soils. North Island gley soils attain only medium ratings for available P (Table 1), the medium range being 7-13 mg % P. Gley soils from the South Island appear to be lower, the available P decreasing with increasing depth to reach a minimum in the zone of maximum gleying.

The differences between these soils is probably due to the difference in parent materials between the two islands, although time and intensity of gleying must also contribute. The longer the soil remains saturated the more P would be lost through lateral 'leaching' of the soil.

Total P figures are, unfortunately, unavailable for these soils.

**SULPHUR**

In a comprehensive study on the effect of gleying on sulphur migration, Rejman-Czajkowska (1972) found that total S shifted from the reduction zone to the oxidation zone. The degree of this shift depended upon the acidity and was associated with Fe conversion, i.e. oxidation and precipitation of Fe(OH)₃. The time and intensity of gleying and the sulphur content of organic matter present also influenced migration.

The only other form of sulphur investigated was available sulphur. This was found to be retained in the colloidal clay fraction of the soil.

Neither total S nor adsorbed sulphate have been determined for New Zealand gley soils.

**CATION EXCHANGE PROPERTIES**

The anaerobic reduction of iron to the ferrous state means that the Fe²⁺ ion is free to partake in ion-exchange reactions with the soil exchange system (Russell 1961). This interference by Fe²⁺, and by the smaller quantities of H⁺ and NH₄, also present, causes a higher proportion of calcium (Ca), magnesium (Mg) and potassium (K) to be in equilibrium with the soil solution. The situation then develops in which the sum of the cations (ECat) is significantly less than the cation exchange capacity (CEC). Expressed as percent base saturation, the ratio of ECat to CEC for these soils is generally less than 60 percent.

Gleying also causes inversion of the Ca/Mg ratio as the intensity of gley development increases (Neslop and Brown 1969). This seems to be associated with the ease of displacement of Ca by Fe (II), relative to Mg. In soils derived from ferromagnesian materials, the already diminished Ca/Mg ratio may become very much smaller (Laing 1976).

For New Zealand gley soils, Ca values are generally medium to low whereas Mg values are high to medium. In topsoils, the Ca/Mg ratio is high, but it approaches unity in the G horizon.

The K status of the North Island gley soils is comparatively higher than for those of the South Island. North Island soils have very high ratings for topsoils, but ratings decrease markedly in the BG-G horizons, presumably through leaching losses. Mean K levels are lower in gley soils from the South Island showing the marked influence of gleying.

**CONCLUSION**

It is unfortunate that the soils mapped as gley soils to date are not 'true gleys'. They more closely represent pseudo-gley soils in that the water table not only occurs at depth (often beyond that of sampling) but also may be seasonally variable. The chemistry of these soils is therefore confounded, and related more to the 'dry' horizons than to the gleyed horizon.

The sampling and subsequent analysis of soil samples should include the gleyed horizons of both 'true' and pseudo-gley soils. Analysis, to be comprehensive, should possibly include the following:

- available, inorganic and total P,
- available (adsorbed) and total sulphur (where applicable), exchangeable bases,
- Tamm's Al, Fe, Mn and Si

for which methods are readily available (Blakemore, Searle and Daly 1972).
Only when these determinations have been made can the interpretation of the pedological processes, and implications regarding fertility and projected land use be considered.

**IRON-MANGANESE CONCRETIONS AND MOTTLES**

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**INTRODUCTION**

Concretions and mottles associated with gleying in soils result chiefly from oxidation of the relatively soluble, reduced forms of iron and manganese, Fe (II) and Mn (II), to the relatively insoluble forms Fe (III) and Mn (IV). Mobilisation occurs in the reducing regions of soil where Fe (II) and Mn (II) are stable relative to Fe (III) and Mn (IV) and remain in solution when weathered from primary minerals or reduced from secondary oxides. Fe (II) and Mn (II) move with the soil solution, and by diffusion, until conditions become sufficiently oxidising for the oxides and oxyhydroxides of Fe (III) and Mn (IV) to become stable and precipitation occurs.

Aspects of Fe and Mn chemistry

The chemistry of Fe and Mn transformations in natural environments has been discussed by Morgan & Stumm (1964), Hem (1972) and, with special reference to soils, by Ponnamperuma et al. (1967, 1969), Gotoh & Patrick (1972, 1974), Collins & Buol (1970), Crawford (1969) and v.d. Schuylenborgh (1971). Conditions of low pH and/or Eh (i.e. high H⁺ and/or electron activities) favour the reduced forms of Fe and Mn, and conditions of high pH and/or Eh (i.e. low H⁺ and electron activities) favour the oxidised forms of Fe and Mn. Also, Mn is more easily reduced and less easily oxidised than Fe, in a thermodynamic sense (Krauskopf 1957, Collins & Buol 1970, Childs 1973), and this provides a mechanism for separation of Fe and Mn in some cases.

Fe-Mn oxides in soils are important because of their ability to sorb other ions (Taylor & McKenzie 1966, McKenzie 1975, Murray 1975a, Jeanes 1968). In particular, Co is avidly retained by Mn oxides (McKenzie 1970, Loganathan & Burau 1975, Murray 1975b) and this can cause problems in overcoming Co deficiency in plants by the use of Co fertilisers (Adams et al. 1969). Ferruginous soil concretions can act as sinks for phosphorus (Taylor & Schwertmann 1974).

Formation of concretions and mottles

Fe-Mn concretions and mottles are not restricted to soils classified as 'gleys' but occur in any soil where relative reducing/oxidising conditions are intense or prolonged enough to produce significant mobilisation and reprecipitation of Fe and Mn. Thus, concretions are indicative of conditions (Eh, pH, water tables, drainage) operating during soil development rather than diagnostic of particular soils.

Within a small area, concretions may be found at one site but not another because of the local drainage pattern. On the other hand, mottles appear to be less variable and probably are formed when the movement of Fe and Mn is restricted (e.g. heavy clay soils) and/or oxidation occurs relatively fast so that Fe (II) and Mn (II) are unable to diffuse, and be oxidised at, a single growing surface. Bacteria can influence the rate of reduction and oxidation of Fe and Mn (Zajic 1969, Ottow 1975) and thus may be an important influence on the form of secondary oxides obtained. There has been considerable study (see Glassby 1972) of marine and freshwater Fe-Mn concretions (usually termed 'Mn nodules') which are economically important as potential sources of metals and surface active catalysts. In some respects these are similar to soil Fe-Mn concretions and bear comparison with them (Childs 1975).

**NEW ZEALAND STUDIES**

These have been concerned mainly with the nature of Fe-Mn concretions.

A selection of concretions from five reference soils (Hamilton, Marton, Waikiwai, Arapohue and Waimatenui) and a buried loess deposit (Greatford) have been studied (Childs 1975). The concentrations of Fe, Mn, Co, Ba, Cu, Ni, Mo, V and Pb are generally higher, and those of K, Ca, Si and Al are generally lower, than in the soil materials surrounding the concretions. Concentrations of Ti, Zn, S and P show little variation between concretions and surrounding materials. Electron-probe microanalyses of some concretions showed that Co and Ba are concentrated in the Mn-rich phases of the concretions rather than the Fe-rich phases. Possible mechanisms for the formation of concretions in some of these soils have been discussed (Childs 1972).

Concentrations of rare earth elements (REE) in the same concretions and surrounding soil materials as above have also been determined (Rankin & Childs 1976). The samples fall into two groups:

(i) those in which Ce is the only REE enriched in the concretions relative to the surrounding soil materials (Hamilton, Marton, and Waikiwai soils);

(ii) those in which all REE are enriched in the concretions relative to the surrounding soil materials and in which Ce and Tb show consistently higher degrees of enrichment than to other REE (Arapohue, Waimatenui soils, and Greatford deposit).

Ce and total-REE enrichments are related to Mn enrichment rather than to Fe enrichment in the concretions. Arsenic was also found to be concentrated in the concretions, and its enrichment was related to Fe rather than to Mn enrichment.

The translocation of Fe and Mn in a catenary sequence of yellow-grey earth soils (Aquic Fragiochrepts) in loess near Allanton has been studied (Childs & Leslie 1977). Fe-Mn concretions are abundant in the AB horizon (29% of whole soil) at the lowest site in the sequence and Mn has translocated downslope more readily than Fe. The elements Ti,
Co, S, P, Mo, Cu, V and in some cases Ba, Zn and Na are enriched in the concretions relative to the soil materials which surround them. Regression analysis showed the following significant positive relationships involving Fe:

Fe-Ti(***), Fe-P(***), Fe-Mo(***), Fe-V(***), Fe-S(***), and Fe-Co(**).

Significant positive relationships involving Mn were:

Mn-Co(***), Mn-Zn(***), Mn-Ni(***), Mn-Ba(*) and Mn-P(*)

For both sets of relationships *** = P < 0.001, ** = P < 0.01, and * = P < 0.05. In general, these relationships may be attributed to the different surface charges of Fe and Mn oxides at the natural pH values of the soils. Fe oxides and oxyhydroxides, being positively charged or near neutral, will attract oxanions (e.g. NO₃⁻, V₅O₇⁻), especially those which have strong specific interactions with the surfaces, while Mn oxides, being negatively charged, will be attractive to cations.

Fe and Mn oxides in soil concretions usually appear amorphous by X-ray diffraction, and spectra of concretions show only peaks attributable to soil particles which have been cemented by the oxides. Mössbauer spectroscopy, however, can detect much shorter range order than X-ray diffraction, and a study of some Fe-Mn soil concretions (Logan et al. 1976) indicates the presence of akaganéite (β-FeOOH) and lepidocrocite (γ-FeOOH) and/or goethite (α-FeOOH) (with particle size less than approximately 7 nm) in all samples.

**MINERALOGY**

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The mineralogy of a gley soil is very closely related to the mineralogy of the ungleyd material from which the soil is derived, since gleying is a process which acts upon the soil parent material. In general, therefore, any mineral found in an ungleyd soils could be found in the associated gley. However, some transformations take place within gley soils because of the somewhat different physico-chemical environment.

The key factor governing the formation of gley soils is impeded drainage which excludes oxygen from the soil or from some horizon of the soil. Anaerobic bacteria obtain their oxygen by the reduction of oxygen-containing compounds, and the Eh of the system is lowered. Under these conditions iron oxides become unstable and are dissolved, iron going into solution as ferrous ions which may or may not be complexed with organic matter. Thus, the thin films of amorphous iron oxide that give soils their yellow or brown colour are rapidly destroyed; eventually the most resistant crystalline iron oxides such as goethite, haematite and even magnetite break down. Because of the solution of iron oxides, gleyed soils very rapidly acquire their characteristic blue-grey colour.

The colour of gley soils is sometimes considered to be due to the presence of vivianite (Fe₃(PO₄)₂. 12 H₂O) or other minerals containing ferrous iron. However, the same colours are often shown by clay minerals that have been subjected to recrystallisation and complexing of iron during separation for analysis. These colours are stable when the clay is moist but upon exposure to air, and more particularly on heating, the clays regain a brown colour. It seems likely, therefore, that the colour of gley soils is due to the presence of ferrous iron, either adsorbed on the exchange complex or forming part of the structure of the clay minerals.

Most layer silicate clay minerals are stable at low pH in the absence of leaching pressure. Consequently, most of the common clay minerals will be found in gley soils if they could have been formed in or transported into the soil before gleying commenced. However, because of the impeded drainage and lack of leaching there is a build-up of cations, notably Ca and Mg, and, more important, of silica and alumina in solution (released in a more actively weathering system elsewhere, either up-slope or in the upper horizons of a profile and flushed into the lower horizons). Under these conditions montmorillonite becomes stable relative to its constituents. Thus, gley soils tend to contain higher amounts of montmorillonite in the clay fraction than do the corresponding ungleyd soils.

This effect is detectable in such New Zealand soils as Taitapu, Templeton and Ahuriri (N.Z. Soil Bureau 1968b), and is also present in the gleyed horizon of such yellow-grey earths as Marton. However, the effect is much more pronounced where weathering is more severe and mineral transformations are more rapid, such as in some soils of the south-west Pacific that have been examined recently (Campbell et al. in press).

Both in the Cook Islands and in Tonga, swamp areas containing gley soils are found in depressions; Tamarua soils in the depressions between the central volcanic core and the outer coral fringe in the Cook Islands, and Sopu soils in low-lying areas of Tongatapu. The mineralogies of the soils of these two island groups differ: in the Cook Islands, with the exception of Rarotonga, the soils consist largely of disordered kaolin, amorphous iron oxide and some gibbsite; on Tongatapu the soils are halloysitic. However, the gley soils of both island groups contain abundant montmorillonite formed by recombination of silica and alumina released by the solution of kaolin-group minerals which originated up-slope and which were flushed into the swamps.

Even the so-called acid sulphate soils may contain montmorillonite. In their accumulation phase these soils generally have pH values around 7 and differ from other gley soils only in that sulphates in sea water, as well as iron oxides, can act as oxygen sources for anaerobic organisms. Sulphates are reduced to sulphides and precipitate as ferrous sulphide. It is only upon drainage and oxidation of the sulphides that these soils
become strongly acid. Montmorillonite formed, as in other gley soils, during the earlier accumulation phase is reasonably stable at pHs of 3.4 and so persists during the acid stage. Montmorillonite has not yet been detected in acid sulphate soils from New Zealand, but it is found in similar soils elsewhere.

The presence of montmorillonite in soils is not always, or even usually, a result of gleying. For example, soils of the Glisborne Plains, most of which are strongly gleyed, contain much montmorillonite which is clearly derived from the bentonitic mudstones in the headwaters of the Waipaoa river. Montmorillonite of similar origin is very likely to be present in all of the gley soils of the Waikaraka - East Coast area where bentonite is likely to be present in the headwaters of streams providing the alluvium.

Montmorillonite also forms during the early stages of weathering of basalt, as in the Waitakeka soil from basaltic tuffs in Otago or in the soils of Raratonga. In tropical soils, montmorillonite remains stable as long as there are sufficient ferromagnesium minerals remaining to keep Ca and Mg ions above a threshold level. Thus, in all soils of the upland areas of Raratonga, montmorillonite is forming. It is present, also, in all soils formed from colluvium on the fringe of the island, and not only in the gley soils. However, the presence of authigenic montmorillonite in the gley soils is demonstrated by the increasing crystallinity of montmorillonite in gleyed horizons compared with ungleyd horizons.

Gleyed soils, as distinct from gley soils, show partial gleying in the form of spots or veins of grey-coloured material, as well as brownish motles. These are due to reduction and movement of iron out of the gleyed zone, and may not necessarily show much neoformation of montmorillonite. There is some evidence, however, that clays in veins may differ slightly from that in the body of the soil. For example, the clay within the body of some yellow-grey earths was found to be a 14 Å vermiculite, but in associated grey veins the clay was a 10 Å illite, indicating that there had possibly been a readsoption of potassium and a collapse of the mica structure in the clay veins down which soil solutions containing increased concentrations of potassium were passing. Other explanations are possible, however.

To summarise, gleying may result in the removal of iron minerals and the formation of montmorillonite. However, these processes take time and would only become obvious in soils in which gleying conditions had existed for a considerable time. The colour changes associated with gleying take place much more rapidly and, thus, a soil showing the features of a gley soil need not necessarily show any mineralogical changes upon laboratory investigation.

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**SOILS**

Gley soils are generally formed in basins of sedimentation or on alluvial flats, and are either accumulating or have accumulated from the deposition of small amounts of materials from successive floods. The geochemistry of this material can vary widely, depending on the nature of the soil mantle and rockform in the headwaters of the rivers, and their rates of erosion and texture.

Under excessive conditions of impeded drainage, organic matter may build up; thus many gley soils have high amounts of organic matter in their topsoils and in extreme cases peat formation takes place. Under these conditions, leaching rates can increase. Weathering, however, is often reduced and sometimes halted in gley soils; under these conditions, element levels within profiles are frequently uniform. Gleying may result in the removal of iron minerals; under these conditions, element levels within profiles are frequently uniform. Where large textural changes occur, either between profiles within the same series or between horizons within a profile, then significant changes in the levels of various elements may occur. For example, within the Takahiwai series (Table 1) Takahiwai peaty sand and Takahiwai peaty clay show considerable differences in element content for Al, Fe, Mg, Li, Rb, Cu, Ba, Zn, B, Ca, V, Ni, Mo, Co and Ni. Within a single profile, for example, Ahuriri clay loam (Table 1) considerable differences also occur between sand (horizon D) and clay (horizons GC11 and GC12) for the elements Ca, Li, Rb, Cu, Sr, Zn, B and Ni.

In Table 2 the average element composition of A and G horizons of 15 gley soils is given together with the range of values for each element. For comparison, the average element values for A, B and C horizons of the 54 soils described in Soils of New Zealand (N.Z. Soil Bureau 1968b) are also given.

In gley soils, the mean values for the elements Al, Na, Zn, Ca, Cr, Mo and Co in the G horizons are similar to the averages for the B and C horizons of the New Zealand average profile. The average values for the elements Li, Rb, Ba and Ni are above those of the New Zealand average profile while those for the elements Fe, Ca, Mg, Ti, Cu, Sr, Ba, Zr, V and Mn are below those of the New Zealand average profile.

The above-average values of Li, Rb and B reflect the present or past marine environment of several of the profiles considered, and not the gley process; for example, B 78 ppm, Li 130 ppm and Rb 260 ppm in the GC12 horizon of the Ahuriri profile. Also, high levels of Ca and Sr in this and other saline gley soils reflect the presence of shell fragments and not gleying.

The below-average values for Fe, Ca, Mg, Ti, Cu, Sr, Ba, Zr, V and Mn are probably the result of several factors operating either singly or in groups. These factors are:
<table>
<thead>
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<td>Mg</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Ti</td>
<td>5</td>
<td>15</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Element composition of three soil samples.
1. Low amounts of the element in the original parent materials; for example, low Ca, Mg, Cu, Sr and V in Netherton peaty loam (SB8925 A-F) and Te Kowhai silt loam (SB8221 A-D);

2. The alluvial deposit is high in siliceous sand; for example, peaty sand from Taikaruru MS/243-250;

3. The nature and degree of weathering of the clay in the alluvium; for example, low Ca, Mg, Fe, Zr, V, Sr and Ba in Takahiwai peaty loam from Franklin County (SB8267 A-F);

4. The solubility of the element; for example, low Sr;

5. The number of times and kinds of physical resorting. Thus, alluvial sorting followed by aeolian sorting followed by alluvial sorting will deplete the heavier ferromagnesian minerals resulting in a loss of Ca, Mg, Fe, Ti, Sr and Ba; for example, Makarewa silt loam (SB7691 A-D).

6. The degree of leaching and/or increased leaching due to low pH in highly organic or peaty gley conditions; for example, low Ca, Mg, Sr and Ba in Makarewa silt loam (SB7691 A-D) and low Ca, Mg, Na, Cu, Sr, Ba, V, Co and Ni in Takahiwai peaty sand from Taikaruru MS/243-250;

7. Gleying: Considering the influence of all of the above processes, very little influence on element levels can be attributed to gleying alone.

PLANTS

Sweet Vernal

Analysis of sweet vernal grass collected from untopdressed gley soils has shown that the average value for most elements is very similar to the New Zealand average for sweet vernal (Table 3). However, some elements - i.e. Al, Fe, Ti, Mo, Mn and Ba - show a considerable range of values.

This wide variation exhibited by these elements can be related to one of two factors:

1. Contamination by soil, resulting from wet muddy conditions and producing high Fe, Al and Ti values;

2. Fluctuations in groundwater levels, where high levels give rise to reducing conditions in the topsoils, increasing the availability of Mo and Mn to the plants.

Clover

White clover has been sampled from both topdressed and untopdressed sites and the results are presented in Table 3 and Figure 1.

Comparing the values computed for average New Zealand clover with those for clover grown on gley soils (Table 3) it can be seen that levels of P, K, Ca and S; i.e. the major elements involved in fertiliser programmes; are similar to the New Zealand average. However, wide variations in content
### Table 3  Element content of Sweet Vernal grass and clover grown on gley soils

<table>
<thead>
<tr>
<th></th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>S</th>
<th>Na</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SWEET VERNAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gley soils</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean of 11 sites</td>
<td>1.0</td>
<td>0.27</td>
<td>0.11</td>
<td>0.14</td>
<td>0.07-0.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>1.0-2.3</td>
<td>0.21-0.36</td>
<td>0.08-0.16</td>
<td>0.07-0.22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N.Z. Average</td>
<td>1.0</td>
<td>0.29</td>
<td>0.12</td>
<td>0.17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CLOVER - from gley soils</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taupiri</td>
<td>0.30</td>
<td>2.0</td>
<td>1.1</td>
<td>0.26</td>
<td>0.22</td>
<td>0.08-0.39</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>0.13-0.49</td>
<td>1.0-4.1</td>
<td>0.45-1.4</td>
<td>0.14-0.69</td>
<td>0.08-0.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whangarei*</td>
<td>0.37</td>
<td>1.9</td>
<td>2.0</td>
<td>0.32</td>
<td>0.30</td>
<td>0.18</td>
<td>0.51</td>
</tr>
<tr>
<td>Mean of 9 sites</td>
<td>0.29-0.48</td>
<td>1.7-2.2</td>
<td>1.6-2.2</td>
<td>0.28-0.39</td>
<td>0.26-0.39</td>
<td>0.13-0.26</td>
<td>0.40-0.65</td>
</tr>
<tr>
<td>Range</td>
<td>0.29-0.48</td>
<td>1.7-2.2</td>
<td>1.6-2.2</td>
<td>0.28-0.39</td>
<td>0.26-0.39</td>
<td>0.13-0.26</td>
<td>0.40-0.65</td>
</tr>
<tr>
<td>Waitakakura*</td>
<td>0.34</td>
<td>3.3</td>
<td>1.2</td>
<td>0.30</td>
<td>0.36</td>
<td>0.26</td>
<td>1.7</td>
</tr>
<tr>
<td>2 sites</td>
<td>0.39</td>
<td>3.3</td>
<td>1.2</td>
<td>0.30</td>
<td>0.36</td>
<td>0.26</td>
<td>1.7</td>
</tr>
<tr>
<td>Range</td>
<td>0.30</td>
<td>1.7</td>
<td>1.7</td>
<td>0.25</td>
<td>0.26</td>
<td>0.34</td>
<td>0.67</td>
</tr>
<tr>
<td>- from saline sites</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whangarei*</td>
<td>0.34</td>
<td>1.7</td>
<td>1.7</td>
<td>0.25</td>
<td>0.26</td>
<td>0.34</td>
<td>0.67</td>
</tr>
<tr>
<td>3 sites</td>
<td>0.33</td>
<td>2.2</td>
<td>2.2</td>
<td>0.57</td>
<td>0.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.20</td>
<td>2.4</td>
<td>0.44</td>
<td>0.32</td>
<td>0.58</td>
<td>5.1</td>
<td></td>
</tr>
<tr>
<td>1 site</td>
<td>0.35</td>
<td>2.5</td>
<td>1.2</td>
<td>0.24</td>
<td>0.35</td>
<td>0.10</td>
<td>0.50</td>
</tr>
</tbody>
</table>

* Top dressed
occur amongst the micro elements.

Figure 1 shows that content of some elements in white clover grown on Waiwhetu silt loam at Taita can vary markedly from season to season (for example, Mo and Sr) while that of other elements shows only small seasonal changes (for example Ba). The seasonal pattern for Mo - showing marked increases in the winter - is followed in form by a group of elements, viz. P, Si, Al, Fe, Ti, Mn, Cr and Ni. Under winter conditions, plants growing on gley soils suffer considerable contamination by soil and, consequently, Si, Al, Fe and Ti are high. High groundwater levels during winter give rise to reducing conditions in the topsoil which increase the availability of Mo, P and Mn. The high levels of Cr and Ni are probably the result of both contamination by soil and increased availability within the soil.

The pattern for Sr is the reverse of that for Mo, i.e. low in the winter and high in the summer. K also follows this seasonal pattern but the degree of variation is much smaller. These two elements are readily leached and removed in solution by the high winter ground waters.

Clover grown on saline gley soils (Table 3) has higher levels of Mg, Na, Cl, Mo and B than both clover grown on non-saline gley soils and New Zealand average clover. However, K, Si, Mn, Sr and Ba are generally below average; the low levels of Mn are a consequence of the higher pH (often due to the presence of shell) which makes Mn less available.

Thus, from the above it can be seen that the gleying process is only a small component in the geochemistry of gley soils but that it has a marked influence on the availability of several elements to plants growing on these soils.

Little physical data on gley soils in New Zealand has been obtained. Results for three gley or gley recent soils, Temuka silt loam, Taitapu silt loam and Ahuriri clay loam, were published by N.Z. Soil Bureau (1968b). Subsequently, determinations have been made on the Te Arakura silt loam in the Manawatu. Results for this soil are set out in Table 1.

The dry bulk densities of the A2, B and C horizons appear rather high. However, dry bulk density is usually greater for soils containing little clay than for soils with much clay (Gradwell 1971). Renger (1971) has corrected dry bulk density figures for this texture effect by adding .009 X (clay %) to them. The correction factor, .009, is close to that indicated for North Auckland soils (Gradwell 1971). Added to the figures for Te Arakura silt loam, the correction yields the "index of compactness" for each sample given in the table. Values greater than 1.75 indicate a compact soil and those less than 1.40 a loose soil. Thus, the subsoil of the Te Arakura silt loam is medium to compact. The three gley soils mentioned by N.Z. Soil Bureau (1968) were of medium compactness.

Another index of profile compaction that is independent of texture is the volume of large pores, indicating the least volume of air likely to be found in the soil when the water table is not high. More than 10% large pores indicates a rather open soil; less than 5% a poorly drained one. The Te Arakura silt loam is rather poorly endowed with large pores, as were the Temuka and Taitapu silt loams. The Ahuriri clay loam, however, had a good content of large pores.

The figures of available water capacity for the Te Arakura subsoil are similar to those for zonal soils, lying between the mean figures for the central and southern yellow-brown earths (Gradwell 1974, Table 6).

Generally, the limited data available for gley soils suggest that they are similar in intrinsic physical make-up to the zonal soils around them. The deviate results for large pore contents of the Ahuriri clay loam raise the possibility that they may be rather variable in physical properties, depending on conditions of deposition, and that the common factor of a high water table may not have obliterated the differences.
Table 1 Physical properties of Te Arakura silt loam

<table>
<thead>
<tr>
<th>DEPTH (cm)</th>
<th>0-8</th>
<th>10-18</th>
<th>20-30</th>
<th>30-65</th>
<th>65-94</th>
<th>97-127</th>
</tr>
</thead>
<tbody>
<tr>
<td>HORIZON</td>
<td>A11</td>
<td>A12</td>
<td>A2gc</td>
<td>B2gc</td>
<td>BCg</td>
<td>Cg</td>
</tr>
<tr>
<td>MECHANICAL ANALYSIS</td>
<td>% silt (.02-.002 mm)</td>
<td>27</td>
<td>24</td>
<td>21</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>% clay (&lt;0.02 mm)</td>
<td>20</td>
<td>20</td>
<td>18</td>
<td>20</td>
<td>18</td>
<td>6</td>
</tr>
<tr>
<td>CORE SAMPLES</td>
<td>dry bulk density (g/cc)</td>
<td>1.15</td>
<td>1.29</td>
<td>1.52</td>
<td>1.62</td>
<td>1.53</td>
</tr>
<tr>
<td>large pores (% v/v)</td>
<td>10.3</td>
<td>8.5</td>
<td>6.7</td>
<td>5.3</td>
<td>5.9</td>
<td>5.7</td>
</tr>
<tr>
<td>index of compactness</td>
<td>1.33</td>
<td>1.47</td>
<td>1.68</td>
<td>1.80</td>
<td>1.69</td>
<td>1.61</td>
</tr>
<tr>
<td>SMALL CORE SAMPLES</td>
<td>DEPTH (cm)</td>
<td>3-11</td>
<td>10-18</td>
<td>30-38</td>
<td>48-56</td>
<td>71-79</td>
</tr>
<tr>
<td>est. field capacity (% w/w)</td>
<td>34.5</td>
<td>27.3</td>
<td>19.4</td>
<td>18.1</td>
<td>21.3</td>
<td></td>
</tr>
<tr>
<td>wilting point (% w/w)</td>
<td>14.4</td>
<td>12.6</td>
<td>11.4</td>
<td>10.7</td>
<td>11.5</td>
<td></td>
</tr>
<tr>
<td>dry bulk density (g/cc)</td>
<td>1.36</td>
<td>1.36</td>
<td>1.58</td>
<td>1.62</td>
<td>1.59</td>
<td></td>
</tr>
<tr>
<td>available water capacity (% v/v)</td>
<td>23.3</td>
<td>20.0</td>
<td>12.6</td>
<td>12.0</td>
<td>15.6</td>
<td></td>
</tr>
</tbody>
</table>

Some physical properties of a Waikato Gley Soil

W.E. Cotching
N.Z. Soil Bureau, D.S.I.R., Rotorua

The Puniu silty clay loam is a central gley soil found south-west of Te Awamutu in the Waipa valley. This soil is formed from predominantly pumiceous alluvium on terraces of the Waipa River. Some physical properties are presented in Table 1.

The dry bulk densities are normal for a soil having the clay contents presented in the table (Gradwell 1971). The available water capacity value of the B horizon is only slightly lower than the value given by Gradwell (1974) for central yellow-brown earths (10.1 cf. 10.7).

The pore size ratio was calculated as:

\[
\text{pores > 0.2 \mu m (% v/v)} = \frac{\text{pores > 0.2 \mu m}}{\text{pores < 0.2 \mu m}}
\]

All three values given for the Puniu silty clay loam are less than 1.0. It is suggested that this ratio might be used to distinguish soils which have poor drainage. For a soil to be freely drained and to have a ready supply of plant available water it must have a major proportion of its total porosity as pores greater than 0.2 \mu m. If the pore size ratio of a soil is less than 1.0 then more than 50% of its total porosity consists of pores less than 0.2 \mu m (diameter of pores drained at wilting point) and this means that the soil has poor drainage.

Water stable aggregates larger than 2 mm in diameter make up a major part of the A horizon when under pasture and comprise less than 40% of the B horizon. The values for mean weight diameter of dry soil aggregates show that the A horizon of this soil has aggregates of a size suitable for a crop seedbed, but in the B horizon aggregate diameter increases owing to the lower organic matter levels and increased clay content.

The Puniu silty clay loam is used mainly for pasture but increasing areas are being planted in maize. However, repeated maize cropping on this soil has increased the dry bulk density and decreased water holding properties, aggregate size and stability. The first two years of maize cropping are beneficial to the soil, only in terms of dry bulk density and porosity, but these benefits are lost with further cropping (Cotching 1978).
Table 1 Physical properties of Puniu silty clay loam

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>0-5</th>
<th>6-16</th>
<th>25-35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizon</td>
<td>A</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Particle size distribution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% silt (0.02-0.002 mm)</td>
<td>33</td>
<td>31</td>
<td>34</td>
</tr>
<tr>
<td>% clay (&lt;0.002 mm)</td>
<td>45</td>
<td>46</td>
<td>55</td>
</tr>
<tr>
<td>Dry bulk density (g cm⁻³)</td>
<td>0.83</td>
<td>1.03</td>
<td>1.17</td>
</tr>
<tr>
<td>Available water capacity (% v/v)</td>
<td>15.7</td>
<td>14.6</td>
<td>10.1</td>
</tr>
<tr>
<td>Pore size ratio</td>
<td>0.80</td>
<td>0.75</td>
<td>0.46</td>
</tr>
<tr>
<td>Water-stable aggregates &gt; 2 mm (% w/w)</td>
<td>88.1</td>
<td>91.9</td>
<td>39.2</td>
</tr>
<tr>
<td>Mean weight diameter of dry soil aggregates (mm)</td>
<td>2.8</td>
<td>3.4</td>
<td>4.3</td>
</tr>
</tbody>
</table>

THE HYDROLOGIC REGIME

J.P.C. Watt
N.Z. Soil Bureau, D.S.I.R., Havelock North

INTRODUCTION

Gley soils (and gleyed horizons) are, by definition, saturated and under reducing conditions (i.e. waterlogged) for significant periods of the year. For saturation to occur there must be an excess of water entering the soil system over that which can leave. This can occur where a high groundwater level exists or where low permeability of the underlying material controls the slow disposal of precipitation. For reducing conditions to occur there must be poor aeration of the soil water. This may be an inherent feature of some groundwater, a result of stagnation from previous seasons, or seasonal depletion of oxygen by plants and soil organisms when soil temperatures are above biologic zero (5°C).

The hydrologic regime of gley soils is therefore described primarily by the duration of saturated conditions and the time of year that these conditions occur.

In a groundwater controlled system the seasonal rise and fall of the water table defines much of the regime. However, in summer, when evapotranspiration is significant and water tables fall, moisture depletion at the surface can be significant and carefully controlled spray irrigation may be practiced (as, for example, on the Temuka and Waterton series of the Canterbury Plains).

In a permeability controlled situation (which can give gleyed horizons if not a gley soil), saturation occurs above the impermeable horizon soon after the summer deficit has been satisfied by autumn rains. Saturation persists for a duration that depends on the winter rainfall, the position of the site, the lateral conductivity of surface horizons, and the efficiency of any drainage system. In this kind of situation, when trying to specify the duration of (near) saturated conditions, it is probably useful to distinguish between consecutive days (days in a row) and the cumulative total for a season, especially in the topsoil horizons. Where a permeable topsoil overlies a poorly permeable subsoil, the upper layers of the subsoil should remain saturated for the longest period.

SOIL MOISTURE CLASSES

Although there is no quantitative data on the hydrologic regime of gley soils in New Zealand, the general moisture regime classes of the U.S.D.A. (Soil Survey Staff 1975) probably apply. When the water table occurs at or very near the ground surface all year round, as in many of the saline gley soils, the moisture regime is "peraquic" by definition. In most other cases, where in most years the soil is saturated with oxygen-depleted water at some season of biologic activity but where at other times the water table may drop, the regime is defined as "aquic". The duration of the period of saturation is not known; it can exceed 9 months and may extend right to the surface, but it may be a much shorter period providing reducing conditions exist. In the New Zealand system of soil moisture classes (Taylor & Pohlen 1970), most gley soils would be "hydrous" (at or wetter than field capacity in all months, and near saturation for long periods), although some appear to have "hygrous" features in that the surface horizon may become drier than field capacity for a period in the summer. The difference between 'hydrous' and 'hygrous' moisture classes assumes a clear distinction between a field capacity value and saturation. In field situations, particularly those in which gley soils occur, it is now appreciated that if field capacity is a state in which downward drainage of water has ceased, it may often occur at or very near the saturation (tension = 0) water content. This being so, the distinction between 'hydrous' and 'hygrous' moisture classes becomes vague.

QUANTITATIVE MEASUREMENT OF HYDROLOGIC REGIMES

In describing the hydrologic regime of gley soils in quantitative terms, three characteristics of the water table are of specific interest: the seasonal amplitude, the duration of saturated conditions at any depth, and the time of year that saturation occurs at any depth. Examples of...
quantitative measurements appear in the overseas literature and the following is an outline of some selected studies.

The durations (± of year) for which water tables remained above certain depths (e.g. 75 cm) over a 2-year period have been described for a Maryland catena (Fanning et al. 1973). They showed that soil wetness, as defined by water table and morphology data, was well correlated with the criteria used in placing these soils in subgroups of the U.S. taxonomic system. Water table fluctuations in a catena are also described by Boersma (1967). In the Netherlands, water table classes are defined by van Wallenburg (1973) in terms of mean annual high and mean annual low water table level. The amplitude of the mean values was 40–160 cm below the surface. In a study in Yugoslavia, Kresulovic et al. (1973) found wet (< 0.5 at.) moisture levels persisting in all layers for not less than 5 months and up to 8 months in the layer (25-50 cm) having the longest wet phase. An example of a permeability controlled hydrologic regime is described for surface water gley soils of the United Kingdom by Thomasson & Bullock (1975), and is summarised above. This regime is very similar to that existing in winter on the New Zealand yellow-grey earths. Thomasson (1973) also examined waterlogging of gleyed clayey soils in the U.K. at 30 and 60 cm and found differences in the water regime which could be expressed in terms of gley morphology. Land use also had an effect on the hydrologic regime, arable use causing a deterioration in structure, reducing permeability and increasing waterlogging. Thomasson also makes the point that, in permeability controlled situations, the precise conductivity of individual layers is less important in terms of waterlogging than the relationships of the layers to each other. These relationships can result in differences in the effectiveness of drainage measures, even within the generally gley soils which he studied. Burke et al. (1974) determined relationships between precipitation and surface runoff for a clay soil in Ireland and also assessed the influence of mole drainage on the hydrology of a moled area. Some other studies relevant to the hydrologic regime of gley soils are summarised by Koenigs & Bolt (1973).

RELATIONSHIPS BETWEEN HYDROMORPHIC PROFILE CHARACTERISTICS AND THE HYDROLOGIC REGIME

These relationships, for gley and related soils, have been studied by several overseas authors, e.g. Crompton (1952). Latshaw & Thompson (1968), Crown & Hoffman (1970), Daniels et al. (1971), Simonson & Boersma (1972), van Wallenburg (1973) and Moore (1974). The general conclusion is that good correlations exist but that it is unlikely that a set of relations valid for all soils or all regions can be established. On the basis of probable correlation, a recent New Zealand study (B.R. Purdie, pers. comm.) used gley morphology to infer average periods of surface waterlogging. However, the exact relationships between duration of waterlogging and specific hydromorphic characteristics have yet to be established.

* For example, in the Netherlands, the upper boundary of distinct grey mottles is about 30 cm below mean annual high water table level, and the top of the G horizon marks the mean annual low water table level (van Wallenburg 1973).

DRAINAGE CLASSES

A qualitative description of the hydrologic regime of gley and related soils is expressed in the assignment of drainage classes. These classes, following the U.S.D.A. system, have been used in soil survey in New Zealand to describe the overall drainage of a site. Surface runoff, soil permeability and internal soil drainage (ability) water is removed from the soil and for which the soil is wetter to a soil largely on the basis of the estimated duration and depth of waterlogging. For soils less prone to waterlogging, drainage classes are defined more in terms of permeability. In New Zealand and the United States the classes 'very poorly drained' (soil is wet 'for the greater part of the time'), 'poorly drained' (wet 'for a large part of the time') and 'imperfectly drained' (wet 'for significant periods but not all the time') represent an attempt to qualitatively define the saturation regime. (It is not altogether a coincidence, then, that the maximum seasonal extent of the saturated zone in a small Vermont catchment, and the area of imperfectly ('somewhat poorly') drained soils as mapped by the U.S.D.A.).

MOVEMENT OF WATER

In gley soils, movement of water is an important aspect of the hydrologic regime. An understanding of profile development requires a knowledge of water movement since the products of chemical reaction are in solution. In gley soils there is obviously vertical movement associated with water table fluctuation. Horizontal movement may or may not be at the site. No New Zealand studies have been reported. Childs (1973) and Koenigs & Bolt (1973) have commented on some recent overseas work.

SOIL CORROSION

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N.Z. Soil Bureau, D.S.I.R., Lower Hutt

Mild steel

Corrosion in gley soils depends critically on the height of the water table and the depth of burial. Attack is even, without much pitting, and is greatest within the zone of the fluctuating water table. The rate of corrosion in waterlogged soils is low to moderate; the

* In England and Wales (Avery 1971) drainage classes are defined exclusively as a function of waterlogging, while in Canada (Canada Department of Agriculture 1974) the definition is in terms of moisture contents in excess of field capacity.
more waterlogged the soil the slower the corrosion rate. The rate of attack tends to remain constant rather than to decrease with time as occurs in oxidising soils.

Copper and lead are much more resistant than mild steel to soil corrosion. The use of lead and aluminium underground is confined to cable sheaths, and protective coatings are always used.

Saline gley soils (derived from old estuarine muds) are in a special class. These are alkaline and contain shells and sulphates. Anaerobic sulphate-reducing bacteria thrive in these conditions, and corrosion of mild steel is very rapid (Penhale 1971, Romanoff 1957).

Concrete and asbestos-cement

Soils with groundwaters that are high in aggressive carbon dioxide are especially corrosive; for example, Kara strongly gleyed loam or Waihehu silt loam. Soils with pH near neutral attack cement products only extremely slowly (Penhale 1956, Romanoff 1957).

Corrosion rates

Typical corrosion rates are listed in Table 1.

### Table 1 Corrosion rates for mild steel, and concrete and asbestos-cement, in gley and gleyed soils

<table>
<thead>
<tr>
<th>Soil Name</th>
<th>Classification</th>
<th>Locality</th>
<th>Mild steel rate of attack</th>
<th>Concrete and asbestos-cement rate of attack</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Av. (μm/yr)</td>
<td>Pit</td>
</tr>
<tr>
<td>Lagoon silt loam</td>
<td>Saline gley recent</td>
<td>Blenheim</td>
<td>33</td>
<td>185</td>
</tr>
<tr>
<td>Kaiapo silt loam</td>
<td>Central gley</td>
<td>Hastings</td>
<td>31</td>
<td>186</td>
</tr>
<tr>
<td>Kara strongly gleyed loam</td>
<td>Northern yellow-</td>
<td>Whangarei</td>
<td>24</td>
<td>114</td>
</tr>
<tr>
<td></td>
<td>brown earth, strongly podzolised</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>strongly gleyed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motukara sandy loam</td>
<td>Southern saline gley recent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waihehu silt loam</td>
<td>Central recent, gleyed, from alluvium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teauka silt loam</td>
<td>Southern gley</td>
<td>Hinds</td>
<td>12</td>
<td>57</td>
</tr>
<tr>
<td>Puakepuke black sand</td>
<td>Central gleyed</td>
<td>Himitangi</td>
<td>10</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>yellow brown sand</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Rates in parentheses are estimates only - no samples in these soils.

In considering drainage, gley soils are most conveniently confined to the wet soil classes, "very poorly drained" and "poorly drained". In most cases these soils will be located on sites distinguished by basin-type or near level-relief and, very often, by the lack of well-defined outfalls.

Gley soils can be divided into two groups, the subgleysoils (groundwater gleys) and the supragleysoils (surface water gleys) (Fitzpatrick 1974). In the former, water will rise from deep in the profile, a condition usually associated with medium to coarse-textured soils. In the latter, the soil has a slow rate of percolation; this condition is normally associated with fine-textured soils of low permeability. Commonly, the soil will be saturated below the surface, even in drought conditions.

**DRAINAGE METHOD**

There is usually no conflict in the choice of method, provided preliminary field data have been properly collated (Bowler 1973). Surface drainage may be the only method available in some circumstances, while open drains may have to be used to achieve primary drainage and consolidation prior to more intensive development by subsurface treatments, if these are justified.

Where pumped outfalls are needed, the design of such installations should include adequate depth allowance for the discharge of subsurface drainage if this is to follow at some future date.

**DRAINAGE DESIGN**

In gley soils, provision should be made for certain minimum pipeline gradients consistent with the textural class of the soil and the drainage coefficient to be used (Hudson et al. 1962). Inspection upstands at convenient parts of the system are recommended for ease of servicing and observation of flows.

The spacing of pipelines in subgleysoils should be based on measures of the hydraulic conductivity of the soil (van Beers 1965), but where mole drainage is used to supplement pipelines in supragleysoils, mole lengths should be limited according to standards given by Hudson et al. (1962).
Gravel envelopes used with pipes installed in coarse to medium textured soils will improve the performance of systems, while gravel backfills over pipes in clay soils which are to be moled can be recommended on level or near-level sites.

When the installation of pipes in gley soils is in prospect, a preliminary check on the pH of the soil at design depths is important, particularly if concrete pipes are to be used. These pH values may be quite low and if they are less than 6 special standards should be used in manufacturing the pipes, otherwise future corrosion will be a serious risk. Well made clay and plastic pipes are not usually affected by corrosion due to low pH.

Where a high watertable ensures a perennial flow of water, and this is associated with low pH as is possible with certain subgley soils, there is a prospect of iron sludge, commonly called Ochre, developing in the pipelines. This may restrict the efficient functioning of subsurface drainage systems by blocking free water flow into the pipe inlets. Iron sludge deposits are primarily due to "iron bacteria" which oxidise and precipitate reduced iron in drainage waters. A large proportion of the material is organic, probably bacterial cell bodies and waste products. The inorganic portion is mainly hydrated iron and aluminium oxides (Spencer et al. 1963).

Currently there is no really effective treatment available for either remedying or preventing what is now called Ochreization. As a preliminary assessment of risk, if watercourses or open drains at a particular site show signs of iron sludge and/or oily slicks on the water, especially where there is a low pH, the prospects of blocked drains is serious. Subsurface drainage systems that flow only seasonally are not usually affected.

Soil type is an important factor in determining possible clogging from ochre. Gley soils often occur in association with basin peats, and the latter are particularly prone to blockage: Gleys developed in andesitic parent materials with mafic mineral contents also offer a greater hazard than most other soils: Sandy soils which contain ferrous iron, as can be the case in the coastal areas of Manawatu and Wanganui, are likewise a problem: Gleys derived from clayey materials, once successfully drained, usually discharge water only seasonally and are free from the problem.

MOLE DRAINAGE

In principle, supragleysoils are likely to respond to mole drainage used to supplement pipe drains. This assumes that there is little or no buried timber which would obstruct the operation. Where soiling is possible, a rapid improvement in aeration and structural development soon follows.

If the ground surface is very rough, however, at least part of the mole drainage system first installed may need renewal once the surface has been smoothed, but this is a low-cost treatment and normally part of drainage maintenance in any case.

Drainage of gleyed soils is imperative for productive pursuits particularly agricultural; pasture, cropping, fruit and berry growing. The degree to which drainage is developed must relate to the purpose for which the land will be used, and while there may be a diversity of criteria regarding topography, location, original soil formation, climate, etc., some broad basic requirements are indicated. Probably, there is no single factor which gives such an early or quick economic response as artificial drainage, nor any which, under attentive management, will have such a permanent effect.

Gley soils may occur in a number of situations and at a variety of altitudes, but it is proposed to deal only with those of relatively level surface occurring on valley floors and lowland fans. Mostly, the soils have been transported by alluviation or erosion and, especially in the region of the North Island with which I am acquainted, owe their origin to volcanic sources with small zonal areas from sedimentary (greywacke) parent material. Some areas near the coastal belt have soils derived from estuarine muds overlying marine oozes which appears to be gleyed. Salinity does not pose a problem and with satisfactory artificial drainage they are of high value for agriculture (Hauraki Plains).

While evidence of gleying may be adduced, the process is not as evident today after some fifty years of development and agricultural use. In some districts, impermeable ironstone pans, often overlying sands, still exist in the lower horizons.

In common gley soils on the Hauraki Plains, the profile is normally of good particle size, liable to be fine in the lower horizons.
where illuviated clays and silts occur, and with varying depths of partially or undecomposed organic materials in the upper horizons. In the natural gleyed state the soil has no or very little bearing strength.

ESTABLISHMENT OF DRAINAGE

The initial aims of drainage for agricultural purposes fall into three categories:

1. To reduce the water content of the soil.
2. To produce a weight-bearing ability at the surface.
3. To create a climate within the soil (aerobic) capable of supporting root growth according to the potential use of the land.

In many places where gleying exists, waterlogging is continuous or intermittent and the soil is affected by predominantly anaerobic activity. To support useful plant growth an aerobic regime is necessary, and this can only be maintained by the passage of air through the soil. Without movement of air and water (both of which must come from an outside source - atmosphere and rainfall) within the soil, the soil is virtually useless for productive growth. The removal of excess soil water, together with aeration, improves the soil temperature with consequent benefit to plant growth and microbial activity.

To initiate a drainage pattern, two features are desirable:

(i) A channel across or through the land with a suitable slope or flow gradient, and
(ii) An adequate outfall (river, stream, canal) existing or constructed in a convenient place.

Taking the most elementary view of water in a gley situation, let us accept that there are two types of flow, one vertical within the soil profile, the other horizontal or stagnant in the lower strata or bedding material. The objects of drainage will be to depress the water table in the soil and to produce a lateral flow towards the drainage ditch or other disposal facility.

As a first stage, the usual procedure may be to construct a drain (ditch) of even gradient with a relatively slow flow rate at an appropriate depth. The capacity should be sufficient to carry away the water present and cope with normal rainfall without overflow of the drain. The purpose is to dry out the top portion of the soil profile at least, and provide a margin of percolation so that water falling on the surface may enter the soil and not escape too quickly by internal flow through the ground or by evaporation. The depth of the drainage ditch will be more-or-less related to topography, depth of soil, size of area and, possibly, the potential use (shallow for grasses or cropping, deeper for fruit trees, etc.). A set of conditions should emerge which permit working over the surface in the subsequent dry season, often only a matter of months later.

With the drying process, some shrinkage will occur, particularly in the A horizons where organic matter (humus, peat) is often present and where the impact of cultivation is felt directly.

CONTINUING MANAGEMENT OF GLEY SOILS

Gley soils appear to possess a notable range of plant nutrients in the early years of cultivation, dissipating after two or three seasons to the detriment of pasture and crops. This is no doubt due to the release of stored minerals through the drying process and aeration, with the promotion and expansion of the microbial population. The practical farmer competent to identify the signs will take steps accordingly to redress the situation by adjusting the drainage systems and fertilizer applications. By their nature, gley soils do not seem to be strong in micro-nutrients and they can very readily become deficient of the more soluble ones. Again, with the altered micro-climate, soil development may result in the formation of minerals and chemical compounds which can be harmful, or can upset the soil balance, with consequent adverse effects on plant and animal. The most popular view is that the soil condition may be "sweet" or "sour", a diagnosis which may have merit when it comes from the eye and nose of an experienced farmer who knows the remedial practices. However one is led to believe that it would be more beneficial for the scientist and the laboratory to be closer to the problem.

As development progresses, soil may become "sour" or "fetid" with retardation of plant growth and disappearance of some grass species. Generally, this is due to a deterioration of drainage, as a result of either a rise of the groundwater table or depression of the land surface. It is at this stage that an amended and improved drainage system may be installed; one which should suffice, with regular maintenance, on a permanent basis.

At times the soil may compact (consolidate) while retaining good tilth, to an extent where disposal flow and freeboard become insufficient. This can lead to the need to install pumping equipment to raise water beyond the field or area and to restore a gradient and aeration of the root zone within the area. Oversed, if one part of the catchment consolidates to a greater degree than the rest, the gradient increases and weirs for flow retardation become necessary to retain soil moisture balance and to prevent erosive forces in the drains. Field "humping and hollowing" (lands) is fairly common and produces a dry and warm surface state to obtain early spring response.

The important object of drainage in gley soil development is to establish a soil water level allowing aeration and slow dispersal of the water content. Development of good crumb structure should follow naturally.

Owing to the original nature of the surface layers, there is the problem of plugging under wet weather conditions, with attendant poaching and decimation of grasses, while in dry periods cracking occurs or the land reduces to dust under heavy stock grazing. From observation, the problems lessen as the soil is developed and matures. Where possible, ploughing and rotational cropping assists this process. One difficulty may arise during dry periods - pasture growth may weaken or regeneration fail and the ground is left bare. Maintenance of a sufficient protective sward can depend upon irrigation, usually by spraying, but care must be taken that the water is not chemically loaded or mineralised if drawn from underground sources.
Once the soil has reached a sound productive level, further diversification into appropriate crops or pastures may be achieved by subsurface tile drainage. This may be done in a haphazard manner but the greatest returns derive from scientific field study and systematic approach, since skilled management of field capacity in water control is critical. Some notable work in this direction under actual field conditions has been carried out and recorded by Massey University.

Having regard to the factors which assist the developed gley soils to produce, some care must be exercised in preserving the soil physical properties, soil animal activity, and micro-organism equilibrium in the productive cycles.

Widespread surface dressing with organic effluents, weedsprays or fungicides possessing residual effects may reduce the available soil oxygen, destroy the microbiological status, or pollute and impair the moisture content. It may block aerated interstices where beneficial soil water and air lodge. At best, only fast passage of the water through the soil layers will flush the undesirable elements into the drainage water. No work has been put forward to demonstrate that the advocated spraying of soils with fungicides formulated to correct internal stock ailments (worms) does not have an ill-effect on earthworms, other soil animals, micro-organisms or soil bacteria populations and on their survival.

Finally, care must be taken in introducing plant species, especially in humid and sub-humid areas. Tall fescue can become dominant and deleterious, while Australian sedge, alligator grass, Manchurian rice grass and *Glyceria maxima* (*Poa aquatica*) can become rampant, blocking the drainage ways and expanding beyond the scope of control methods.

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**BIOLOGY**

**NEMATODES**

G.W. Yeates  
N.Z. Soil Bureau, D.S.I.R., Lower Hutt

Temuka silt loam was the only gley soil included in the survey of nematodes of 77 soils from under pasture by Yeates (1975). For the 77 sites there was an average of 15.7 genera per site. In Temuka silt loam the following 14 genera were recorded, *Tylenchus, Heterodera, Pratylenchus, Aphelechus, Aphelenchoides, Panagrolaimus, Cephalobus, Eucephalobus, HeterocephaZebus, Anaplectus, Monhystera, Mesodorylaimus, Aporoealaimus and Belondira.*

The site came in the cool, dry category (i.e. mean annual air temperature below 12°C and mean annual rainfall 1000 mm or below) but the presence of *Pratylenchus, Anaplectus* and *Monhystera* place it in the damper part of this category. The five starred genera occurred at 75% or more of the 77 sites sampled. Both *Heterodera* and *Pratylenchus* are likely to have some adverse effect on pasture production.
8 AGRICULTURE AND FORESTRY

NOTES ON LAND USE, AGRICULTURAL LIMITATIONS AND PRODUCTION
OF SOME GLEY SOILS, GLEYED RECENT SOILS AND SALINE GLEY
SOILS IN THE SOUTHERN NORTH ISLAND

Compiled by R.G. Smith, Ministry of Agriculture
and Fisheries, Palmerston North, from
contributions by W. Osborn, F.W. Phillips,
V.A. Outwhaite, J. McNeur, C.J. Collier,
P.G. O’Connor and N.S. Brown

GLEY SOILS

Taranaki
Soils: Glenn silt loam, Awatuna loam, Rahotu loam.
Main uses: Dairying.
Limitations: Drainage is required on all soils; for Awatuna, terrain is broken by gullies, swamps and boulder
outcrops.
Fertiliser (P + K) requirements are high (high
P fixation); maintenance rates average 500-700
kg/ha super. plus 200-250 kg/ha KCl.
Production: Rahotu 300 kg BF/ha; lower on Glenn and Awatuna.

Manawatu
Soils: Te Arakura series.
Main uses: Dairying, fat stock, intensive mixed cropping and sheep.
Limitations: Intensive tile and mole drainage required.
Requires P, S, lime; possibly K and Mo also.
Production: 290 kg BF/ha; 15 LSU/ha; 5000 kg/ha barley and wheat;
good grass seed crops 1200 kg/ha.

Hawkes Bay
Soils: Raumati series.
Main uses: Sheep and beef cattle, dairying, fat stock (not
an important soil).
Limitations: Drainage is important; rushes invade pastures readily.

GLEY RECENT SOILS

Manawatu
Soils: Parewanui series, Kairanga series.
Main uses: Dairying, fat stock, mixed cropping and sheep;
intensive cropping on Kairanga.
Limitations: Intensive drainage required (tile and mole).
Fertiliser P, S and possibly K required.
Production: Kairanga 310 kg BF/ha; 17 LSU/ha; 4500 kg/ha
wheat. Parewanui 300 kg BF/ha; 15 LSU/ha; 4000 kg/ha wheat and barley.

Manawatu
Soils: Opiki complex.
Main uses: Cropping (potatoes, maize, peas), dairying and
fat stock (cattle mainly).
Limitations: Open drainage is important, but water level control
is also required. Dries out in dry summers; hard
to wet.
Production: 300 kg BF/ha; Grass seed 1300 kg/ha; potatoes -
Rua 20 tonne/ha, Ilam Hardy 15 tonne/ha; barley
5000 kg/ha; maize 8500 kg/ha.

* As included in soil set no.106, N.Z. Soil Bureau (1954).
Hawkes Bay
Soils: Kaiapo series, Pokowhai series.
Main uses: Sheep and beef cattle, dairying, fat stock, some process and cash crops on Hastings and Pokowhai.
Limitations: Drainage is required in most localities, especially on Kaiapo, and on clay loams.
Production: No data available.

Gisborne
Soils: Makaraka series, Makauri series.*
Main uses: Cropping (maize, process crops on Makaraka in particular), fat stock.
Limitations: Require tile drainage; this less successful on Makauri because of excessively heavy subsoil.
Production: Maize 9700 kg/ha on Makaraka, 8500 kg/ha on Makauri.

Wairarapa
Soils: Ahikouka loam, Pukeo clay loam.
Main uses: Dairying, cropping, sheep and cattle.
Limitations: Cropping is limited, mainly by slow drainage; tiles and moles recommended; some hump and hollow on Pukeo in flood-prone areas. Fertiliser and lime requirements not great.
Production: Wheat and barley 4000 kg/ha; peas 3300 kg/ha; maize 9400 kg/ha (area of maize increasing); 250-300 kg BF/ha; 13-15 LSU/ha.

SALINE GLEYED SOILS
Hawkes Bay
Soils: Meeanee-Farndon, Ahuriri.
Main uses: Sheep and cattle; dairying on Meeanee-Farndon; supplementary and cash crops.
Limitations: Adequate drainage and control of the winter water table is required for removal of salt. Copper is required, also Mo on Ahuriri.
Production: No data available.

* As described in Pullar (1962).

Wairarapa
Soils: Onoke silty clay.
Main uses: Sheep and cattle - usually farmed in conjunction with other soils (limited area).
Limitations: Channelling is required to prevent flooding and to remove surface water in winter. Salinity levels are high and high initial rates of lime are recommended for development. Fertility varies.
Production: Low, usually about 5 LSU/ha, although up to 12 LSU/ha can be achieved where development allows a build-up of organic matter.

SANDY GLEYED SOILS
Manawatu
Soils: Hokio series, Pupepeke series, Carnarvon series.
Main uses: Dairying, sheep and fattening; limited cropping.
Limitations: Surface drainage is required; wet in winter. Fertiliser P and K are required; also Cu and Se for stock.
Production: Hokio 10-12 LSU/ha. Pukepeke and Carnarvon 18-20 LSU/ha, 290 kg BF/ha. Barley on Carnarvon 4500 kg/ha.

FORESTRY ON GLEY SOILS IN THE SOUTH ISLAND

C.G.R. Chavasse
Forest Research Institute, Rotorua

In the South Island, the natural vegetation of lowland gley soils in Westland, Nelson, Canterbury and coastal areas of Otago and Southland was almost certainly kahikatea forest. However, the wettest areas, subject to regular flooding (particularly stream-side sites in the Taieri Valley and in Southland), carried non-forest swamp vegetation, including flax (Phormium tenax). Several of the kahikatea forests were destroyed by fire prior to European settlement, giving way to similar swamp species. Coastal areas, also, probably never carried forest, especially where subject to saline winds; the natural vegetation would have been flax, rushes, sedges, cabbage trees and koromiko.

In the drier inland areas of Otago and Southland the natural vegetation of gley soils was probably red tussock (Digitaria elongata) while at higher elevations in the north-west of Southland scrubby mountain beech (Nothofagus cliffortioides) forest may have been present; this also was largely destroyed by fire in the early stages of European settlement. Rapid development of dairying led to the logging of residual areas of
kahikatea forest in the early part of this century, the timber being particularly suitable for butter boxes. Only in Westland has this species regenerated, especially on recent gleys (Harirhari and Karangarua soils).

Where sufficiently large stands of kahikatea remain it is desirable to maintain them as reserves. Small areas are subject to attrition and decay. Management of some kahikatea stands on gley soils would be feasible in Westland, but care would be needed to ensure that swamp conditions do not develop; some draining may be necessary to obtain rapid regeneration of trees, and logging operations must not cause blockage of natural channels.

In general, however, gley soils are not attractive for production forestry, especially exotic conifers, for reasons of shallowness, wide fluctuations in water tables between winter and summer, and periodic flooding. Such conditions lead to shallow rooting and thus the danger of windthrow, and also root rots. Moreover, due to wet conditions, logging operations can be difficult. Nor are gley soils suitable for poplars, unless they are drained. Exotic tree species which grow on gleys include alders (especially Alnus glutinosa) and willows.

SOUTH AUCKLAND AND WAIKATO REGIONS

G.E. Orbell
N.Z. Soil Bureau, D.S.I.R., Hamilton

Extensive areas of gley soils are to be found in this region on the northern side of Waikato Heads, in the Hauraki Plains and in the Morrinsville/Waihou and Hamilton/Te Awamutu/Otorohanga districts. In the Hauraki Plains district these soils occur on low marine terraces; elsewhere they occur on low river terraces or inter-levee positions of old braided river courses. Frequently, in the latter case, they form a complex soil pattern with the well drained soils occurring on the old levees (for example, Horotiu-Te Kowhai complex of the Hamilton district and Waihou-Waitoa complex of the Morrinsville district) and may not be of sufficient contiguous area to be farmed as separate soils.

The common land use on these soils throughout the region is pastoral, for dairy farming. High milk production levels are to be obtained on these soils under this system of farming. In addition, increasing use is being made of these soils for various field crops. In the Waikato Heads (Ake Ake swamp) district, successful crops of potatoes have been grown in rotation with dairy pasture. In the other regions, maize is being successfully grown, though there have been some difficulties in obtaining a good tility in the necessary spring cultivation in wet conditions. There is also some problem at harvest time if conditions are wet from April onwards as, when wet, these soils have low bearing capacity and the large combine harvesters become bogged down. It also appears that these gley soils have a relatively higher requirement for N than nearby better drained soils, but this is still a low requirement by international standards. Conversely, the wetter nature of these soils is a considerable advantage during the not-infrequent dry summers experienced in this region.

Overall, these gley soils appear to be ideally suited to producing short-season field crops and, provided that other cultural problems can be overcome, crops such as soya beans and sunflower can be potential land uses.
WAIARAPA DISTRICT

Areas of gley and related soils are widespread in the Wairarapa district but are most extensive on the Wairarapa Plains (Heine 1975a). Here they occur in the lower parts of the fans of the Waingawa, Waikine and Tauherenikau rivers, and in low-lying land around Lake Wairarapa.

The Moxoa and Otukura soils are imperfectly to poorly drained gley soils from alluvium, and occur on terraces and at the toes of fans. Their poor natural drainage is their main limitation to intensive use but when drained they are suitable for dairying with some cropping.

The Ahikouka and Pukeo soils are gleyed recent soils, the Ahikouka being slowly accumulating and the Pukeo being rapidly accumulating. They are fertile soils and when adequately drained are suitable for cropping, horticulture or dairying. Some areas of the Pukeo soils, however, are difficult to drain because of their low-lying position and are liable to flood.

Onoke soils are gley recent soils formed on estuarine material dredged out of the new Ruamahanga diversion channel between Lakes Wairarapa and Onoke. In places this material, as well as being high in soluble salts, has a high content of sulphides. On exposure to air, with drainage, oxidation results in the formation of sulphates and then sulphuric acid, producing acid sulphate soils. Experience elsewhere has shown that very large amounts of lime are necessary to correct this acidity and these soils are difficult to farm.

WELLINGTON

Gley and related soils in the Wellington district are restricted to low-lying parts of the valley floors or to estuarine areas. They include the Waiwhetu, Gollans and Pauatahanui soils (Heine 1975b).

Waiwhetu soils are gleyed recent soils on flood plains. Land use has been mainly dairying for town milk supply, and horticulture, but most areas are now urbanised.

Gollans soils are poorly and very poorly drained gley soils from alluvium and are used mainly for dairying for town milk supply, although some areas still remain in native swamp vegetation.

Pauatahanui soils are saline gley recent soils from estuarine muds and sands. Parts have been reclaimed but most areas remain in their original saline vegetation and these would be best retained as coastal reserves.

SUMMARY

Although gley and gley recent soils are not of great extent in the Manawatu, Wairarapa and Wellington districts they play an important part in this region's agricultural production through their intensive use for dairying (including town milk supply), cropping and horticulture. However, their area is finite and continued urban expansion within the region poses a distinct threat to their continued agricultural production.
As urban areas expand they displace market gardens and town milk supply farms which then have to be relocated further out. These, in their turn, displace other uses in a shunting effect. At present there is probably enough slack in the system to cope with this. Intensification of farming to provide more dairy farms is going ahead in areas such as Motua, lower Wairarapa valley, and the west coast sand country, but can it continue indefinitely?

EAST COAST REGION

W.C. Rijkse, N.Z. Soil Bureau, D.S.I.R., Rotorua

Gley soils in northern parts of the East Coast Region are the Tokata and Makaraka series near Hicks Bay and the Awatere Valley, and Papawea, Wahoa and Puhunga series in Waiapu Valley. Most of these soils are used for fattening lambs and beef cattle. The major area of these soils is not artificially drained, and they are therefore not used to their fullest potential which would include a range of crops such as maize, sweet corn, tomatoes, potatoes, peas and beans.

Further south, gley soils in Tolaga Bay are very similar to those of the Gisborne Plains and include gley soils such as Kaiti series, Uwa series and Makauri series, and gleyed recent soils such as Makara series. Most of these soils are artificially drained and used for pasture (fattening sheep or beef cattle) or for cropping. Tomato yields are 12000 to 16000 kg/ha and sweet corn yields 4500 kg/ha. One vineyard has been established on Kaiti series, but maize remains the main crop on these soils.

RANGITAIKI PLAINS, BAY OF PLENTY REGION

W.A. Pullar, N.Z. Soil Bureau, D.S.I.R., Rotorua

The Rangitaiki Plains border the Bay of Plenty coast between Matata and Whakatane, a distance of 22 km, and they extend inland about the same distance to Kawerau. The plains are associated with the Whakatane graben and the Taupo volcanic zone. Their area is approximately 34000 ha, of which land gley soils and gleyed soils occupy up to 80%.

ARTIFICIAL DRAINAGE

At the time of European settlement, much of the land was swampy and the few roads constructed were confined to ridges of inland dunes and natural levees of rivers and streams. To traverse the swamps, the Maori wore a kind of water shoe, not unlike a snow shoe, to walk on the water weeds. The mouth of the Rangitaiki River was artificially reconstructed in 1914 as a first step to drain the land. Large canals were then dug and eventually a drainage system was installed. The land is now intensively drained and the ground water level controlled by pumping. Much of the plains area is now in high production, largely dairy farming, but if the drains are not maintained the land will soon revert to its natural state of high water table and very poor soil drainage. With efficient artificial drainage, some field properties such as mottled (B) horizons and peaty A1 horizons could be said to become obsolete, but the farmer has to work hard at the drainage environment to keep these properties obsolete.

SOIL PROFILES

The gley and gleyed soils of Rangitaiki Plains are commonly layered with thin beds of airfall tephra, pumice alluvium and peat. Consequently, some soils may be composite. The only soils that are free from this layering are those formed from fine greywacke alluvium deposited by the Whakatane River. It is in this kind of parent material that the classical grey mottling of the (B) horizon is seen (Rewatu silt loam, previously Paroa mottled silt loam). Mottling either is not seen or is very difficult to distinguish in the (B) horizon of fine pumice alluvium deposited by the Rangitaiki River (Paroa series). Coarse pumice alluvium deposited by the Tarawera River may have iron oxide mottles in the C horizon and occasionally iron oxide pans, particularly where the A1 horizon is wholly within the Tarawera Ash (Kawerau series).

Whilst the classical morphology for gley soils appears to be absent in some soils we know they must have been groundwater gleys at the time of European settlement. At the present time gley soils and gleyed soils might be best regarded as 'mottled' soils, bearing in mind that they could easily revert to groundwater gley soils.

Gley soils are also non-accumulating.

LAND USE

Detailed information on land use for the eastern half of the plains is taken from Pullar et al. (in prep.), "Soils and Land Use of Whakatane Borough and Environs". More general information for the western half was taken from a report by Pullar & Hewitt (1970) to the Bay of Plenty Catchment Commission. Only the principal soil types are discussed here.

Gley Soils

Rewatu silt loam (previously Paroa mottled silt loam)
Present use: Dairying, maize for grain, and beef production.
Potential use: No increase in dairying envisaged. Beef production up to 780 kg carcass beef per hectare. High potential for maize for grain; present yield of 10 tonnes/ha could be lifted to 12.5 tonnes/ha. Trials with soya beans and grain sorghum yielded 3.1 and 7.7 tonnes/ha respectively.
Potatoes have yielded 50 tonnes/ha and in places two crops have been grown yielding 15 tonnes/ha in spring and 23 tonnes/ha in following autumn. Dwarf tomatoes have yielded 65 tonnes/ha.

Boysenberries, kiwi fruit and citrus trees have been grown but ventures were only moderately successful because of cool air at ground level and heavy soil texture.

Carrying capacity and dry matter production: Present levels of 20 stock units/ha and 18000 kg/ha of dry matter can be raised to 30 and 20000 respectively, provided soil drainage is attended to. The pasture sward reverts readily to *Paspalum distichum*, buttercup and rushes.

Paroa silt loam; Paroa silt loam on peat on gravel
Present use: Dairy farming and beef production.
Potential use: Dairy and cattle farming has a high potential. Milk fat production can be raised to 560 kg/ha and beef production to 670 kg of carcass beef per hectare, provided no replacement livestock are carried. Problem is pasture wastage in a wet winter. Forage crops including turnips (89 tonnes/ha), chou moellier and millet have been grown.

Maize for grain has yielded 9.4 tonnes/ha and this can be raised to 12.5 tonnes. Trials with peas for food processing yielded 5 tonnes/ha for first crop but a much lower yield for second crop. The area is marginal for peas because of frequent showers during the flowering stage.

Main crop potatoes can yield up to 50 tonnes/ha but there is a moderate risk of waterlogged soil. Maize tolerates temporary waterlogging better when established.

Lettuce and tomato growing on Paroa silt loam is only moderately successful possibly because of cool temperatures at ground level.

Boysenberries and apples have been grown on Paroa silt loam but these ventures are not yet proved for commercial horticulture.

Paroa silt loam on peat on gravel is unsuitable for market gardening and horticulture.

Composite gleyed regic soils
Otahiri series (Tarawera Ash on pumice alluvium)
Present use: Dairy farming, pine tree nursery, cropping (maize and barley for grain), horticulture (strawberries, peppers and egg fruits), market gardening (onions, tomatoes).
Potential use: As above.
mixed farming (raising fat lamb and cropping). Some soils, particularly peaty phases, are used for horticultural crops.

Suitable crops are barley, wheat, peas, small seeds, linseed, brassicas, pumpkins, lettuce, potatoes, beans and sweet corn. The gley and related soils are regarded as unsuitable for most root crops, asparagus and fruit.

The predominant limitation of gley soils is poor natural drainage. However, most of these soils still dry out in summer and to maintain good pastures and high crop yields, supplementary sprinkle irrigation is used on many farms (water is readily available because of high groundwater tables). Heavy texture is another limitation; heavy-textured soils are difficult to cultivate and tend to compact with intensive cultivation or heavy rains.

In Canterbury, where the main limitation to production is soil moisture deficiency, gley soils are highly valued. Their major potential will no doubt remain intensive dairying, but peaty phases, silt-textured soils and the more readily drained soils have a high potential for cropping and market gardening. Crop yields on these soils, provided they are well managed, are among the best in Canterbury.

Soils in Motukarara series have a greater limitation (salinity) than other gley soils and therefore most of these are not developed to their fullest potential.

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