PHYSICAL ENVIRONMENT

A.V. Milewski and N.J. Hall

Climate

The Barlee–Menzies Study Area has a semi-arid climate with cool winters and hot, dry summers with slightly more rainfall during winter than summer (Figure 3). Apart from the south-western sector, the climate has been classified according to the classification of Koppen (Dick 1975) as Dry and Hot Steppe with the possibility of precipitation in any month. According to the Thornthwaite System, which is preferable to the Koppen system for Australian conditions (Gentilli 1948), the climate of the Barlee–Menzies Study Area is Arid Mesothermal, with rainfall deficient in all seasons (Beard 1976). Alternatively, according to the classification system of Bagnouls and Gaussen (1957) (UNESCO–FAO 1963), the climate of most of the Study Area is Desert, giving way in the south-western sector to Accentuated Subdesert. Beard (1976) describes the Study Area as Semi-Desert Mediterranean, grading into Desert with Summer and Winter Rainfall in the north.

The only weather station in the Study Area with records of daily rainfall and temperatures over a long period is Diemals (29°40'S, 119°18'E), which has recorded both since 1970. Cashmere Downs (28°58'S, 119°34'E), situated just across the northern border, has recorded rainfall since 1919 and temperature since 1972. Other recording stations in the eastern portion of the Study Area that have rainfall records are Riverina (since 1964), Mt Ida (1913–41) and Davyhurst (1901–57) (Bureau of Meteorology, Australia 1988a).

Temperature

The average monthly temperatures for 1977–1981 and the long term mean for the Barlee–Menzies Study Area are shown in Figure 3. Mean annual temperature in the Study Area is approximately 19°C. Mean maximum temperature for each month ranges from 36°C (January) to 17°C (July). Frosts are experienced during winter but snow has not been recorded. Recorded extremes of temperature are 46.5°C and –4.6°C (Diemals).

Rainfall

The mean monthly rainfall for 1977–1981 and the long term mean for the Barlee–Menzies Study Area are shown in Figure 3. Rainfall decreases slightly from the south-west (260 mm) to the north-east (220 mm) of the Study Area. Recorded annual average rainfall ranges from 210–282 mm with records of 210 mm (Mt Ida), 239 mm (Cashmere Downs), 259 mm (Davyhurst), 269 mm (Riverina) and 282 mm (Diemals).

The average annual rainfall tends to be evenly distributed throughout the year, being slightly higher in winter than in summer with spring tending to be particularly dry (see Figure 3). During winter, the light falls (associated with the passage of cold fronts originating to the south of Western Australia) decrease from south-west to north-east. Heavy (50–150 mm) falls occur unreliably during summer from thunderstorms, and from cyclones of northerly origin which have degenerated into rain-bearing depressions.

The three different types of precipitation occurring in the area differ in their effectiveness for plant growth (Milewski 1981). Winter frontal rains occur fairly reliably every year but are light and usually ineffective for the growth of plants other than herbaceous species. Summer

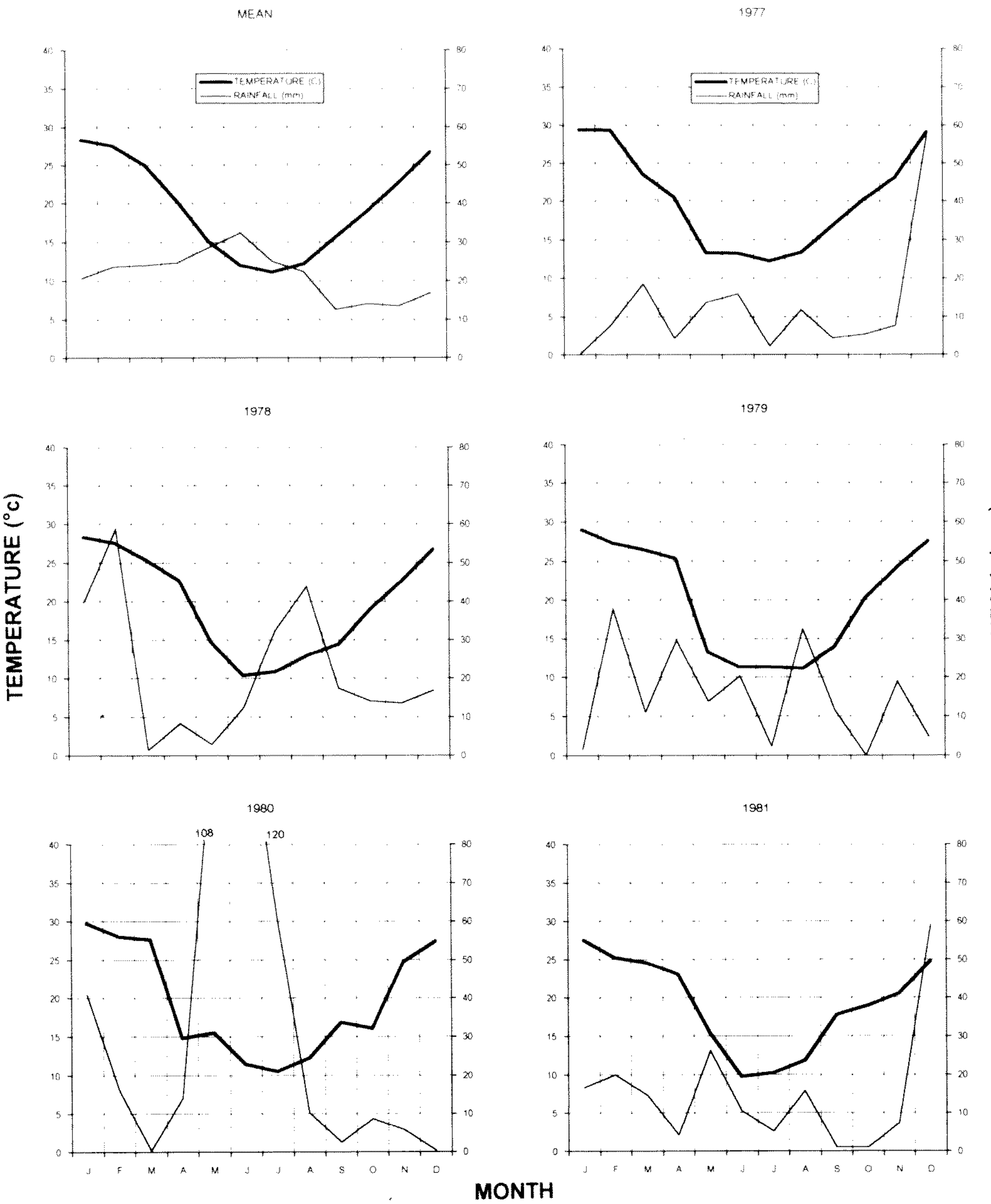

Figure 3 Ombrothermic diagrams showing the mean monthly rainfall and average monthly temperatures for the Barlee-Menzies Study Area from 1977-1981 and the long term mean.

convective rains are intense but brief. Rainstorms derived from tropical cyclones and epitropical storms are intense, prolonged and effective for the growth of woody plants. Since tropical depressions occur only occasionally in the Eastern Goldfields as a whole, the effectiveness of the most frequent precipitation events is limited by its intensity and duration. Sporadic heavy falls of 20 mm or more can be expected to occur up to three times per year on average.

The important aspects of the rainfall are its unreliability and sporadic nature. There is also a marked difference between highest and lowest annual rainfall records: 146 mm and 541 mm (Diemals), 78 mm and 563 mm (Cashmere Downs), and 99 mm and 497 mm (Davyhurst). This leads to large differences between mean and median rainfall, particularly in the later summer months when all rainfall is of the convective or tropically derived types.

During the biological survey of the Study Area (1979–1981), annual rainfall was exceptionally good in 1980, with above average rainfall recorded at Diemals (398 mm) and Cashmere Downs (378 mm). Substantial monthly totals of rainfall (40 mm or more) were recorded in February and April 1979, January and May–July 1980 and January, June and December 1981 (Figure 3). The longest period of prolonged rainfall occurred in May to July 1980 (291 mm at Diemals and 287 mm at Çashmere Downs).

Evaporation

Mean annual evaporation increases from the south to the north but is generally about 3 300 mm per year (Bureau of Meteorology, Australia 1988b).

Radiation

Average daily radiation varies from 550–600 $mWhcm^{-2}$ grades from a high in January of 800–850 $mWhcm^{-2}$ to 350–400 $mWhcm^{-2}$ in July (Bureau of Meteorology, Australia 1988b).

Geology

The geology of the Study Area, tectonically stable since the Proterozoic, has been mapped and described in detail for Barlee (Walker & Blight 1983) and Menzies (Kriewaldt 1970). Most of the area is underlain by Archaean gneisses and other granitoid rocks eroded into a flat plain, and covered with Tertiary weathered materials, with only scattered exposures of bedrock. The area includes part of several Archaean greenstone belts, with spines of banded ironstone, running roughly north-south, and eroded into low hills and ridges separated by colluvial flats. The hardest metamorphosed sediments form several series of abrupt rocky outcrops rising above the plain, resulting in high, scarped Hills such as the Mt Manning Range and Die Hardy Range.

In the north of the Study Area is Lake Barlee, a large salina with an extensive bare floor extending into several prominent arms, the longest of which encompasses Lake Giles and penetrates southwards, east of the Mt Manning Range, to the southern border of the Study Area and beyond.

The physiography of the Barlee–Menzies Study Area is related, albeit subtly, to the underlying rock types. The main feature is a plain of great age which has not suffered mountain building or glaciation for the last 300 million years. Granitoid rocks of the Yilgarn Block underlie most of the Study Area. As used in the present publication, the term granite refers to all these rocks, including gneisses and granites. They all weather into similar soils which support vegetation of similar structure and species composition. The topography is generally subdued.

Most of the area, except for hills, is covered by a mantle of deeply weathered, colluvial or alluvial materials. Eroded into the plain is a portion of an ancient, shallow river valley. The Study Area is dominated by gently undulating relief of 6–30 m (maximum less than 200 m), while the largest salt lake (Lake Barlee) is contained in a depositional plain of relief less than 15 m covering several thousands of hectares (Campbell *et al.* 1975). During past arid periods, ending about 15 000 years ago (Bowler 1976), material on the bottomlands was blown south-eastwards into extensive sheet deposits which include some small dunes.

The Study Area is within the Salinaland physiographic division of Jutson (1950) and is mostly flat, with a gentle slope from south-west to the north. Altitude on the southern boundary is about 470 m, falling to a minimum altitude of 350 m on the floor of Lake Barlee. The Mt Manning Range (about 500–600 m) provides one of the highest points in the Study Area. The broad flat bottom of the main bottomland system in the Mt Elvire area, is 50–125 m below the upland plain level in the Mt Manning area.

Since internal relief generally does not exceed 100 m and slopes are generally less than 3°, some areas are virtually featureless plains and run-off consequently occurs only with the heaviest falls of rain. There are no permanent streams and few pronounced drainage lines of any kind in the Barlee–Menzies Study Area. Creeklines do not exceed 10 km in length and are known to flow only ephemerally. Extensive areas have a covering 1–2 m deep of sand or gravelly sand which rapidly absorbs rain. Very seldom is there sufficient rainfall to saturate the soil. The base level of present-day erosion corresponds to the floor of Lake Barlee, which provides internal surface drainage for most of the Study Area. This floor is completely bare, or covered with up to 30 cm of water for short periods following abnormally heavy rains, as happened during the current survey in 1980.

High rates of evaporation maintain a high salt content in parts of the bottomlands. The origin of the salt is partly from the parent rocks in the area and partly from atmospheric sources (Hingston & Gailitis 1976). However, in the northern part of the Study Area the large proportion of rain derived from northerly, cyclonic influences appears to be the cause of changes in the soil chemistry. Here, very occasional downpours lead to thorough saturation of the loamy soil to a depth of several metres in late summer and autumn, when temperatures are high. This leaches minerals, including salts, horizontally out of the soils and dissolves silica which has reformed as a peculiar hardpan (Teakle 1936).

Although covering a small area, the various hills and other rocky environments provide an important habitat for plants. Trending NNW to SSE are linear belts of metamorphosed rocks of two distinct types, both about as ancient as the granites. Greenstone consists of volcanic material and banded ironstone consists of lacustrine deposits of iron oxides and quartz sands. Banded ironstone is more resistant to weathering than granites and usually occurs as long strike-ridges, or low hills. Greenstone weathers at rates intermediate between banded ironstone and granite. The sharp ridges of banded ironstone thus represent jaspilite layers which have been highly folded and then exposed by erosion of the soft rocks around them. Close to the southern boundary of the Study Area is an abrupt, relatively steep and rugged ridge of banded ironstone constituting the Die Hardy–Mount Manning system. Mount Manning is the best example of a long, prominent hog-back ridge of this rock type. Smaller hill systems elsewhere in the Study Area include the Johnson Range and Mount Elvire.

A few outcrops of granite, varying from prominent hills or outcrops, such as the monolith at Pigeon Rocks, to flat sheets, are scattered through the Study Area. Exposures of metabasalt are less common here than farther eastwards in the adjacent Edjudina–Menzies Study Area. During the Tertiary, areas of laterite developed over deeply weathered granite. A few remnants of this surface remain as Breakaways. However, Breakaways are not as common as in the extreme northern parts of the Eastern Goldfields.

Landform Units

Newbey and Milewski (unpublished) have developed a classification of 10 units to describe the landforms of the Eastern Goldfields. They are briefly described below. Eight units were recorded in the Barlee–Menzies Study Area and two of these (Hills and Undulating Plains) were divided into sub-units on the basis of bedrock type (see Table 1). Drainage Lines and Calcareous Plains were absent from the Study Area.

Breakaways (B)

Occasional Breakways occurred in the Barlee–Menzies Study Area, particularly in the north-eastern part where they punctuated the plains, tending to separate Sandplains from Broad Valleys. A large proportion were associated with weathered outcrops of granite or other bedrock. Bluffs with a free face 3–4 m high had scree slopes of 12°–15°, and were partially covered with Gritty Loams. Soil on the top was restricted to shallow sheets and pockets in exposures of duricrust, all with variable drainage. Similar soils were found on the scree slopes. Substantial colluvial soils of the pediment became waterlogged at times by run-off from the bare areas of the Breakaways above them.

Dunefields (D)

Lake dunes and lunettes with deep sandy soils containing variable amounts of gypsum (calcium sulphate) occurred widely in the Barlee–Menzies Study Area, but were high and extensive enough to constitute Dunefields in a few areas only. Dunefields of siliceous sands associated with Sandplains were found in several localities widely scattered throughout the Study Area, particularly on the eastern boundary.

Granite Exposures (G)

Outcrops of granite were relatively low, rounded features and bore shallow sandy loam directly weathered from the bedrock. Each flat to low-domed exposures of bedrock varied in size from a few square metres to 0.5 km^2. Exposed granite was mainly bare rock, but skeletal sheets of soil accumulated in slight depressions on the exposure, or along faint drainage lines. Granitic Soils were present on the rock and formed a peripheral apron. The apron consisted of soil up to 2 m thick weathered *in situ* from the underlying granite. The frequency of waterlogging and the rate of drying were inversely related to the depth of soil.

In some areas the bedrock was within 2 m of the soil surface but was not exposed at all. Granite Exposures of this kind had soils similar to those of the apron of the other Granite Exposures. The main difference between Granite Exposures and Granite Hills was that the latter were more than 30 m high and uniformly covered with perennial vegetation.

Hills (H)

Hills throughout the Eastern Goldfields were divided into sub-units based on their bedrock type. Examples of this landform rose more than 30 m above the surrounding plains and had slopes ranging from 5° to 15°. The surface was largely covered with skeletal and excessively-drained soils, and numerous small areas of bare rock. Most prominent were Hills of banded ironstone (HI) such as the Mt Manning Range on the southern border of the Study Area. However, isolated examples of Hills of granite (HG) and of greenstone (HN) were also present.

Salt Lake Features (L)

Saline bottomlands occurred as the fringe of the large salt Lake Barlee, and were therefore located mainly in the northern and north-eastern half of the Study Area. Salt lakes were flat-floored with ephemeral water up to 30 cm deep following rain. Peripheral lake dunes and lunettes, 1–4 m high, occurred mainly on the southern and eastern margins, and in some areas constituted Dunefields (D). Where a former, major drainage course had been reduced to a string of scattered salt lakes, extensive areas of associated flats were usually present.

The soils of Salt Lake Features had a complex history which included colluvial, alluvial and aeolian actions and frequent reworkings, especially by wind during recent arid periods (Bowler 1976). Saline, alluvial flats lay 15–30 cm above the level of the lake floor, and endured varying regimes of salinity and waterlogging. Low sandy rises in places alternated with clay-rich swales. The colour of the soil surface in saline bottomlands was pale in some areas and dark in others. Well-drained flats lay 2–4 m above the salt lake floor and had deep, freely drained soils of aeolian origin, not suffering from waterlogging. Lake dunes and lunettes, with deep sandy soils containing variable amounts of kopai (gypsum, calcium sulphate), were relatively uncommon in the Barlee–Menzies Study Area. Most areas of these loose, basic sands to clay loams were stabilized by vegetation.

Sandplains (S)

The almost flat upland plains of the Barlee–Menzies Study Area, as well as some of the upper and middle valley slopes, were referred to as Sandplains. The dividing line between Sandplains and Broad Valleys was the change of valley slope from erosional to colluvial. Few Sandplains gradients exceeded 2° and internal relief was generally less than 15 m. The yellow to red, freely drained, coarse soils of the Sandplains have developed from coarse-grained parent rocks (mainly granite that has been lateritized to some extent) over a great period of time. In some places extensive sand sheets have developed with a major component of colluvium from slightly elevated surfaces on the Sandplains.

Extensive dunes and other evidence of aeolian activity were generally absent although scattered tracts of low dunes, the now vegetated remnants of past arid epochs, were present. The last major dry period appears to have ended less than 15,000 years ago (Bowler 1976). Definite creeklines were absent although water might flow on the surface for short distances following heavy rains. Large areas of Sandplains were scattered widely throughout the Study Area except for the parts taken up by Salt Lake Features. Sand in the northern parts of the Study Area was redder and in some areas less gravelly (ironstone) than in the south-west.

Undulating Plains (U)

As in other Study Areas in the Eastern Goldfields, Undulating Plains were subdivided on the basis of bedrock types. Where the bedrock was greenstone (basic, compared to the generally acidic granitic rocks), the landform (UN) consisted of minor ridges (slopes generally less than 10°) and colluvial flats (50–500 m wide and 5 m below the ridges) of alkaline soils separated by a lime layer from the underlying rock. Soils derived from greenstones were rich in magnesium and calcium. Elevated surfaces often consisted of basalt, which was relatively resistant to weathering, while depressed surfaces often overlay ultrabasics. Shallow Calcareous Earths where colluvium had collected, but were seldom deeper than 1 m. Undulating Plains occurred as large belts or islands surrounded by Broad Valleys, or small areas at the base of Hills. The broadest colluvial flats were drained by single channels up to 1 m deep and 5 m wide, not qualifying as Drainage Lines.

Undulating Plains over banded ironstone (UI) formed relatively small belts, generally within belts of greenstone. The chemical nature of the rock differed from greenstone and the resultant soils were skeletal and relatively low in pH, sandy and red. Abrupt, blocky strike-ridges were the main topographical form.

Broad Valleys (V)

Overlying much of the extensive area of granite in the Barlee–Menzies Study Area were scarcely discernible valleys roughly 15 km wide, some of which were saucer-shaped, with an internal relief usually of less than 20 m and slopes generally less than 2°. The ground was well-drained but the indistinct creeklines only flowed following very heavy falls of rain. Broad Valleys were widespread in the Study Area. In the southern part of the Study Area they were the choked remnants of former drainage systems active under a past regime of plentiful rainfall. The valley floors were flat to gently concave, and 20–50 m below the surrounding Sandplains.

The soils had an intricate history of *in situ* weathering, colluvial, alluvial and aeolian action. An important soil aspect was the calcareous subsoil. These carbonates were largely derived from leaching from the surrounding Sandplains. In the north of the Study Area a siliceous hardpan was present, as elsewhere in the northern parts of the Eastern Goldfields. The main soil types were thus Deep Calcareous Earths (southern edge) and Red Earths (the remainder).

Soils

The soils of the Barlee–Menzies Study Area have been described briefly by Northcote *et al.* (1968). In general terms, they are mainly dark reddish brown loams, although skeletal soils occur on the rocky ridges and clays occur in the bottom lands. Various siliceous topsoils, poor in all cations, are the most widespread soil group and cover much of the erosional and depositional surfaces alike, although the weathering products of all parent rocks, including acidic ones, tend to be concentrated into a calcareous sub-soil layer under the arid climate of the Study Area. Thus a calcareous subsoil or hardpan is widespread especially on basic parent materials.

In addition to soils resulting from current processes of erosion and redeposition, there are extensive areas in which the soil is deep, neutral to slightly acidic earthy sand or gravelly sand – a relic from past geological periods when the climate was first wetter (leading to leaching) and then drier (leading to particle sorting) than that reigning today. Although largely flat, these high-lying plains are well-drained. Depressions throughout the Eastern Goldfields are generally saline. Alkaline soils occur wherever the underlying rock is basic. Although soils developed directly over granite and banded ironstone have a typical coarse sand component, they are neutral to slightly alkaline, and not acidic as found under a moist climate in the south-west of Western Australia. Fairly deep loamy or earthy soils, with lime nodules at depth, predominate in both the upper (Mt Manning Range) and lower (Mt Elvire) land surfaces of the Study Area. However, shallow soils over bedrock of banded ironstone or granite occur as well.

Although sandy terrain mainly represents the remnants of a Tertiary landscape, the present day climate has affected all soils in the area which share the qualities of loaminess or earthiness, dark colour (extensively red), subsoil neutrality or alkalinity and the absence of an A_2 (eluvial) horizon of subsurface bleaching. Within this framework there is wide variation from place to place in rockiness, salinity, sandiness, lime content, soil depth and profile differentiation, and chemical composition in general. In the current terminology, the soils of the Barlee–Menzies Study Area are solonized brown soils or calcareous red earths, with red and brown hardpan soils entering in the drier (mulga) country in the northern half. Solonchaks are found on saline bottomlands, while soils related to lateritic podzols are found on Sandplains.

According to the system of classification of soil adopted by Newbey and Milewski (unpublished), Deep Sands were general on Sandplains in the Study Area, with Gravelly Sands occurring on some low rises. On Broad Valleys, Deep Calcareous Earths were common in the south of the Study Area, with patches of Granitic Soils, while Red Earths were common in the north of the Study Area. Aeolian Loams and Deep Sands were also present in places. Present on Salt Lake Features were Saline Soils and Sub-saline Soils (lake floors) and Aeolian Sands and Loams (small peripheral dunes). The colluvial flats of Undulating Plains (greenstone) consisted of Deep Calcareous Earths while Shallow Calcareous Earths were present on the rises, ridges and hills on this rock type.

Granitic Soils with small patches of Shallow Calcareous Earths occurred on Granite Exposures with *in situ* formation of soil from present day weathering. The outer apron of soil was shallow, the inner apron was skeletal, and the soil petered out on the exposed bedrock. Hills (banded ironstone) were covered with Red Sands, skeletal on the crest, upper and middle slopes, and shallow on the colluvial lower slope. Gritty loams occurred as various deposits on Breakaways: small pockets on the rim, very shallow, patchy sheets on the summit, skeletal on scree slopes, and fairly shallow on pediments.

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