RECORD
1993/5

GYPSUM DEPOSITS OF WESTERN AUSTRALIA

by D. C. Jones

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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by

D. C. Jones

(with contributions from R. M. Hocking and M. J. Freeman)

Perth 1994

MINISTER FOR MINES
The Hon. George Cash, J.P., M.L.C.

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K. R. Perry

DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
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100 Plain Street
EAST PERTH, WESTERN AUSTRALIA 6004
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Introduction

Object and scope

This Record reports the results of a survey of gypsum deposits in Western Australia undertaken by the author during the period from September 1989 to December 1990. The object of this survey was to compile and summarize the available geological, analytical and resource information on the known gypsum deposits and to assess their marketability.

An earlier report on gypsum in Western Australia appeared as Mineral Resources Bulletin 6 (de la Hunty and Low, 1958). That publication presented an assessment of all gypsum deposits known at the time. It was based on investigations extending over three years during which the authors inspected, mapped, and estimated the resources of thirty-six deposits, and compiled information on twenty-one other occurrences. Since that study, some of the deposits described have been mined — either partially or completely — and numerous others have come to attention through the efforts of miners, farmers, and prospectors, or during regional geological mapping carried out by the Geological Survey of Western Australia (GSWA) and the Australian Geological Survey Organisation (AGSO, formerly Bureau of Mineral Resources).

This present survey aims to update knowledge of the State's gypsum deposits by adding to the information presented by de la Hunty and Low (1958). In particular, advances in knowledge of climate and palaeogeomorphology since the 1950s suggest broad regional controls for the deposition of gypsum.

As the study is concerned mainly with potentially economic deposits of gypsum, many minor occurrences noted in the literature have been omitted, including numerous records of gypsum found as an alteration mineral of sulfide deposits, or as a component of the weathering profile in arid regions. The very large size of some anhydrite deposits found in sedimentary basins during exploration for petroleum also warrants their being included as possible future resources of calcium sulfate.

A secondary purpose of the study was to update information on the uses of gypsum in Western Australia, and on the economics of gypsum mining in the State in relation to the general world and Australian scenes.

Sources of information

This Record has been compiled from various published sources; from unpublished reports of tertiary institutions and mining companies; from Department of Minerals and Energy and Geological Survey files, and analytical and petrological studies; and from field inspections made in 1989 and 1990. A list of references appears at the end of the Record. Although data from de la Hunty and Low (1958) are drawn on heavily where still relevant, their maps are not reproduced here. This Record may therefore need to be read in conjunction with the earlier Bulletin.

Descriptions of many deposits include the current mining tenements. It should be noted that Departmental information on such tenements may be confidential at the date of publication but could move into the public domain (WAMEX M-series open-file system) at some later date.

Terminology and abbreviations

$	Australian dollars
%	percent, percentage
ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
BP	before present (years)
calct	calcite
DOA	Department of Agriculture
DME	Department of Minerals and Energy
G	giga (10^9)
GSWA	Geological Survey of Western Australia
gyp	gypsum
ha	hectare
km	kilometre
m	metre
M	million
max	maximum
min	minimum
na	not available
s	second
Sheet	1:250 000 series map sheet

t	tonne
µ	micron
UK	United Kingdom
US$	United States of America dollars
WAMEX	Western Australian Mineral Exploration Database
wt	weight
XRD	x-ray diffractometer or x-ray diffraction

Survey, sampling and testing

Method of survey

During this survey, most attention was paid to deposits in the southern and western parts of the State as these areas are the only ones within reasonable distances of markets or ports. However, for completeness, a summary of information on deposits in the northern and eastern regions of the State is also included.

Initially the State was subdivided into geographic regions to facilitate data collection and field inspections. Subsequently the deposits and data were re-grouped on the bases of broad geological controls, and, in the case of salt lake occurrences, by the palaeodrainage basins in which they occur. This latter format is used in the Record.

During the survey, field inspections were restricted to deposits which appeared to be of significant size, but about which little was known. These comprised mainly deposits discovered since the work of de la Hunty and Low (1958) and for which there were little or no data available from company exploration.

Sampling and testing

Because of the broad scope of the study, sampling was generally restricted to one or two samples per deposit. Consequently, analyses must be viewed as only indicative of the quality of the gypsum available from any particular deposit or at any specific location. Lake Hillman is the sole exception: eight gypsum, two salt, one clay and ten wood/carbon samples were collected.

All samples, except for the wood/charcoal, were analysed for major elements and mineral components. The samples of organic material were forwarded to Dr P. Thorpe of the Hydrogeology Section for C^{14} age determinations. The results are discussed under the heading *Age of the salt lakes*.

All the samples (except the wood/charcoal) were collected by one of three methods. The first method was to take grab samples where only a thin surface coating or a thin layer of gypsum was observed. Single samples supplied to the author by individuals were also considered grab samples. Channel samples (method 2) were obtained with a small trenching tool from outcrops, quarry faces, or the sides of costeans, where a significant thickness of gypsum was present. The third method of obtaining samples was by auger drilling. Such auger holes, sometimes reaching 4 m, were drilled by hand where good outcrops were few or non-existent.

Wood/charcoal samples from recent quarry faces with sufficient quantities of apparently old carbonaceous material were individually collected and carefully bagged.

Material collected by channelling or augering was bagged for analysis on the basis of lithology, so that each sample represented apparently similar material. In this way, outcrops, quarry faces, costeans, or auger holes of say 2–3 m would yield 3–5 representative samples for analysis from the different gypsiferous zones.

Chemical and XRD analyses of all samples were conducted by the Government Chemistry Centre, Department of Minerals and Energy, Perth. Analyses requested were the actual percentages of acid soluble CaO, MgO, SO_3, CO_2, and Cl (as NaCl) and the calculated percentages of $CaSO_4.2H_2O$, $CaCO_3$, NaCl, and the remaining residues. The percentage residues, calculated by difference, included CaO, SO_3, sand, and clay.

The Chemistry Centre furnished the following description of the technique employed to determine these chemical analyses (written communication, September 1990):

> 'Crushed material was treated with dilute hydrochloric acid, and calcium, magnesium and sulphur were measured on the resultant solutions using inductively coupled plasma atomic emission spectrometry. Chloride and

carbon dioxide were determined by titrimetric and gravimetric methods respectively.'

XRD determinations of major and minor minerals involved standard procedures to obtain sample tracings. Only qualitative results were requested and these are presented as percentage ranges for gypsum, quartz, halite, calcite, aragonite, K-feldspar, plagioclase, kaolin, illite, smectite, and 'others'.

All gypsum samples analysed during the course of this survey were split, with one part being forwarded for analysis, and the other being recorded in the Geological Survey's ROCKMIN database before being placed in permanent storage. The 'GSWA No.' used for samples described in the text is also used as the permanent identification number in ROCKMIN and on stored samples. Samples in storage are available for inspection by the general public (by appointment). Results of the chemical and mineralogical analyses are given in Appendices 1 and 2 respectively.

Analyses of samples obtained during other investigations by the GSWA, private companies, and individuals are included in summarized form with the data for each deposit. References are also given so that the original data source may be consulted.

Sampling limitations

Auger holes were difficult to extend beyond 4 m depth because of the compactness or hardness of the gypsum. As well, sampling had to be monitored carefully to prevent collapse of the auger hole walls or the inadvertent scraping of the hole walls while lowering or raising the auger.

Water encountered in lake beds, and the watertable in holes and costeans always limits the depth from which samples could reasonably be obtained, as samples disaggregate during recovery from below or at the watertable, and soluble components may be dissolved during recovery. Graphic logs of samples collected from locations where water was encountered have the waterlevel indicated on them.

Acknowledgements

The author wishes to thank members of the Merredin Research Station (DOA), the Chemistry Centre (DME), and various tenement holders, mining companies, and land owners for their valuable input and unstinting assistance.

Mineralogy, geochemistry, properties and uses

Mineralogy

Gypsum is a naturally occurring mineral which forms monoclinic crystals. Cleavage is perfect along one direction, giving slightly flexible, inelastic plates and very fine flakes. Its chemical composition, in pure form, is $CaSO_4.2H_2O$, with the proportion of chemically combined water being 20.9%. Pure gypsum is seldom found in commercial quantities — impurities of clay, sand, limestone, iron oxide, and plant matter usually contaminate the large deposits.

On Mohs' scale, gypsum has a hardness of 1.5–2.0, being sufficiently soft to be scratched with a finger nail. It is white when pure (or clear in large single crystals and clusters), but is commonly grey, red, brown, or yellow due to impurities. Gypsum is sometimes fluorescent in ultraviolet light, soluble in hydrochloric acid and hot water, and fuses moderately easily, losing water and turning cloudy and opaque.

There are six commonly recognized forms of natural gypsum (after Holmes et al., 1982, and Adamson, 1988):

1. *Rock gypsum* or *massive selenite* — a compact massive form, usually deposited in fairly extensive beds under marine conditions, which may be interbedded with limestone, salt, and anhydrite. *Massive selenite* is composed of crystals, in places more than one metre long, in intimate contact, and forming a solid mass. The compact, sometimes banded, very fine-grained variety of rock gypsum with waxy lustre is called *alabaster*.

2. *Gypsite*, *kopi* (*or kopai*, *copi*), or *flour gypsum* — a fine-grained (<0.06 mm), loose, powdery or earthy form which is often found on the surface of dry saline lakes and in adjacent dune deposits. It may become cemented into a moderately hard crust.

3. *Selenite* or *crystal gypsum* — crystalline form, commonly colourless and transparent or translucent, in single crystals (from 2 mm up to 1 m long) or twins (swallowtail or spearhead). May be found in lake beds, commonly in clay. Crystals found in rosette-shaped aggregates, of a reddish colour, are known by the name *desert rose*.

4. *Seed gypsum*, *gypsum sand*, or *gypsarenite* — rounded to subangular crystals of gypsum found with kopi on the surface of dry lakes and in kopi dunes. The term *gypsum sand* is used for grain sizes of 0.06 to 2.0 mm, and *gypsarenite* for loosely cemented and firmly cemented (a form of *rock gypsum*) masses of gypsum sand.

5. *Satin spar* — the fibrous form, with silky lustre and elongated crystals. Satin spar occurs in narrow seams mainly in massive gypsum deposits.

6. *Cellular* or *spongy gypsum* — aggregates of small, interlocking crystals and plates of gypsum found under kopi in salt lakes and dunes.

Gypsum may be found in close association with anhydrite ($CaSO_4$). In nature, anhydrite will slowly absorb water, if available, and slowly revert to gypsum. The presence of any quantity of anhydrite in a gypsum deposit renders the material useless for plaster manufacture (de la Hunty and Low, 1958).

There are marked similarities between gypsum and anhydrite in the field, but several easy tests can be used to distinguish them. For example, gypsum is lighter and softer than anhydrite and gives off copious water when it is heated in a closed tube, whereas anhydrite loses little or none. Anhydrite has a pseudocubic habit and, despite weathering, remains hard and white; whereas gypsum weathers to a soft, incoherent powder (gypsite or kopi). Lastly, anhydrite is soluble, with difficulty, in hydrochloric acid; gypsum is easily soluble in a solution of comparable strength.

Chemistry of formation

Gypsum is usually classed as an evaporite mineral — being formed principally by the evaporation of saline brines of either marine or terrestrial origin. It is a naturally occurring form of dihydrous calcium sulfate ($CaSO_4.2H_2O$), having two molecules of combined water in its crystal structure. Gypsum may be the only evaporite mineral present in a particular stratigraphic section, or it may be interbedded with other minerals of similar origin. The most common evaporite minerals found with gypsum are halite ($NaCl$, common salt), sylvite (KCl), calcite ($CaCO_3$), dolomite ($(Ca, Mg)(CO_3)_2$) and anhydrite ($CaSO_4$).

Anhydrite may be found interlayered with, or adjacent to, mainly subsurface gypsum deposits. This form of calcium sulfate is almost never found at the surface, whereas gypsum is found both on the surface and underground.

The major deposits of gypsum are precipitated directly from brines of either marine or terrestrial origin at temperatures below 42°C. At or above 42°C, anhydrite ($CaSO_4$) precipitates instead of gypsum from the same brines. When a confined or semi-confined brine progresses from saturated to supersaturated, principally due to evaporation, minerals begin precipitating. Precipitation ceases when equilibrium is reached, the solution returns to the saturated condition, or when some other variable is introduced, such as dilution of the solution by rain or an influx of surface or groundwater. This sequence may be repeated at regular (seasonal) or irregular intervals, and the result may be continuing thicknesses of one mineral, or alternating thicknesses of different minerals, depending upon the concentration attained by the solution during each cycle.

Laboratory studies of the evaporation of seawater have found that the first mineral to precipitate is gypsum (or anhydrite), followed by calcite or limestone, which may alter to dolomite if magnesium is available, then halite, and finally the mother liquor salts (mainly potassium salts). This is exactly the sequence (minus the mother liquor salts) described by Haynes et al. (1989) in their study of the Upper Silurian Salina Formation of the Appalachian and Michigan Basins (USA). These authors describe several repeated cycles of deposition beginning with gypsum (anhydrite), followed by limestone, and then ending with halite. This depositional sequence has also been observed when seawater is concentrated in solar evaporators during the production of sea salt (Hanford, 1990). Figure 1 provides a simplified view of the mineral precipitation series from seawater.

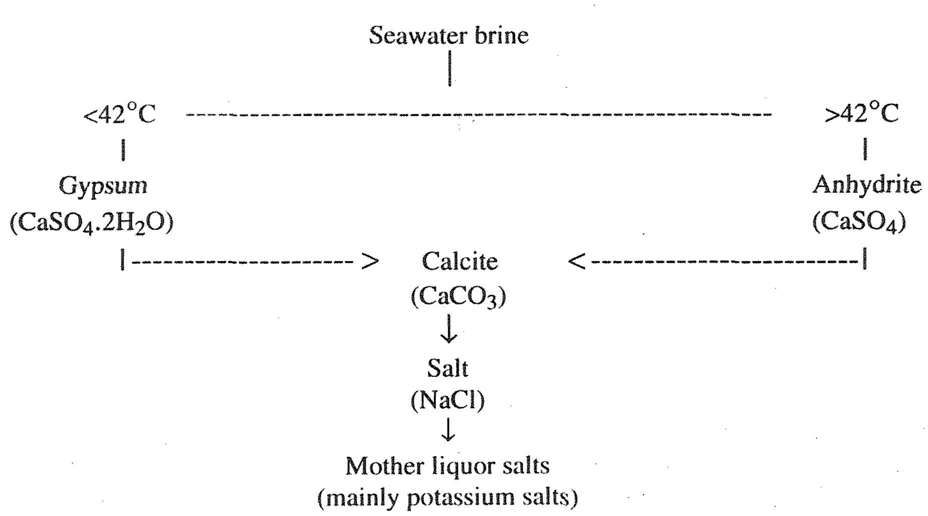


Figure 1. Simple mineral precipitation series from seawater brine

When terrestrial brines of approximately oceanic composition are confined or semi-confined, the same suite of minerals will precipitate in the same sequence as those precipitating from seawater. However, variations in the brine concentration, temperature, resident organisms, and depth of ponding will result in changes to the sequential order, thickness, and type of minerals precipitated from terrestrial brines compared with their marine equivalents. Recent studies by Thompson and Ferris (1990) demonstrating the impact of cyanobacteria on the precipitation of gypsum, calcite, and magnesite; and by Wood and Sanford (1990) investigating semi-confined terrestrial brines open (in part) to the groundwater system; have both confirmed that significant variations were introduced.

A detailed description of the geochemical evolution of a Western Australian salt lake presented by Salama et al. (1992) concluded that salt was introduced by surface and groundwater inflow, and has been subject to a continuous process of recycling between brine and halite. The buildup of salt and other evaporites is due in part to beds of impermeable mudstone in the lower part of the lake sequence which prevent brine from migrating downwards.

Gypsum may dehydrate to form anhydrite if it is subjected to the appropriate conditions — such as increased pressure and temperature, or loss of water. Similarly, anhydrite may revert to gypsum in the presence of water and lower temperatures (Dickson, 1989). Evidence for this dehydration–rehydration was presented by Haynes et al. (1989) who described Upper Silurian primary gypsum deposits that were dehydrated to anhydrite on burial and then rehydrated to gypsum by near-surface groundwaters after uplift. Generally then, if these two minerals are found in the same strata, the uppermost layer, or caprock, is more likely to be gypsum because of the reduced pressure, lower temperature, and increased penetration by groundwater of this upper layer.

Properties and uses

Gypsum is dihydrous calcium sulfate ($CaSO_4.2H_2O$); plaster is hemihydrous calcium sulfate ($CaSO_4.\frac{1}{2}H_2O$); anhydrite is anhydrous calcium sulfate ($CaSO_4$); and hydraulic gypsum is calcium-enriched anhydrite (some SO_2 having been 'boiled off'). 'Plaster of Paris' is another term used for hemihydrous calcium sulfate (plaster), the name originating from the processing of gypsum deposits found under that French city.

When gypsum is calcined at temperatures between about 150° and 900°C it forms several types of plaster and specialist cements, and an inert industrial filler. The plasters and cements are very desirable products. They can be transported in a dry, powdered form that when mixed with a controlled proportion of water, becomes mouldable during rehydration, eventually becoming solid at room temperature. Minor amounts of setting-time retarders (organic compounds) or accelerators (natural or synthetic salts) are added to calcined gypsum products to increase their range of applications.

Progressive calcining of gypsum to temperatures of 149–166°C, 177–204°C, 482°C, and 899°C will yield, respectively, plaster, soluble anhydrite, insoluble anhydrite, and hydraulic gypsum. Figure 2 presents a simplified flowchart for the production of calcined gypsum products. The details of the calcining process and the equipment employed are described by Appleyard (1983).

----------------------- > Calcining end temperature (°C) ----------------------->				
-------------->	149–166° -------->	177–204° ---------->	482° ----------->	899°
raw gypsum	plaster	soluble anhydrite	insoluble anhydrite	hydraulic gypsum

Figure 2. Simple gypsum calcination flowchart

Worldwide, deposits of gypsum are located in nearly every country, although only 83 countries are currently reporting production. It is fortuitous that gypsum deposits are so widespread as raw gypsum and calcined gypsum products are vital components of modern construction materials. It is not surprising, therefore, that the construction industry totally dominates consumption.

Few figures regarding the actual world consumption of gypsum or calcined gypsum products are available, but generally they are thought to mirror the consumption trends of the U.S. market. Davis (1990a) reported total gypsum consumption for the U.S. in 1988 as 22 973 000 t. Of this 21.2% was sold as raw gypsum and 78.8% was sold as calcined gypsum or plaster. An estimated 74.2% of the raw gypsum sold went into Portland cement and 25.8% into agricultural and miscellaneous uses. Of the calcined gypsum sold, 96.0% went into plasters and 4.0% into prefabricated products.

Raw gypsum is principally used as a setting-time retarder in Portland cement. In this process a small amount, usually between 3 and 7%, of raw gypsum is added to the cement clinker when it is ground. Normally gypsum makes up about 4% of the weight of the finished cement in Australia (more commonly 5% in Western Australia) and 5% by weight in the U.S. Table 1 gives the specifications for gypsum used in this process.

Another major use for raw gypsum is in agriculture where it is used primarily as a soil conditioner or fertilizer (also called 'land plaster'). Reasons for applying raw gypsum to the land are:

1. to deflocculate compacted clays and generally improve the physical condition (structure) of a soil, which also increases porosity and aids in drainage;

2. to supply soluble calcium for certain crops such as peanuts, mushrooms, lucerne, clover, yams, cotton, and potatoes;

3. to supply sulfur (as sulfate) in a readily available form;

4. to help neutralize sodium compounds where alkaline conditions exist;

5. to help correct sodium-enriched irrigation waters;

6. to increase the availability and use of nitrogen (S–N relationship);

7. to clear muddy waters in ponds, tanks, and dams; and

8. to stimulate micro-organisms in the soil.

More details of the use of gypsum in agriculture are presented by Burvil (1941), Appleyard (1983), and Sullivan and Fosbery (1984).

When raw gypsum is applied to certain types of soil in Western Australia it partially deflocculates the clay and, due to its minimal ion exchange properties, also helps remove salt. In many instances, after application of gypsum, soils show increased aeration, increased water retention capability, and a lower salt content.

Table 1. Specifications for major uses of gypsum

Portland cement	
Gypsum purity [a]	+80% $CaSO_4.2H_2O$ +90% usual
Amount of gypsum added	3–7% by wt 4–5% usual
Total sulfuric anhydrite (SO_3) [b]	30% max
type A and B cements	3.5% max
type C and D cements	3.0% max
Magnesia (total) [b]	4.2% max
NaCl (total) [b]	0.2% max
LOI [b]	3.0% max
Insoluble residues [b]	2.0% max
Agricultural fertilizer	
Purity	+70% $CaSO_4.2H_2O$
NaCl impurity	2.0% max, less than 1.0% preferred
Grain size	WA — sand-size or larger Elsewhere — powdered or granular
Wallboard/plasterboard	
Particle size [c]	Equal granular
Purity	+80% $CaSO_4.½H_20$ +90% usual
NaCl impurity [d]	0.1% max -0.02% usual
Total impurities	20% max
Compressive strength	8.4 MPa min
Initial setting time	20–35 minutes
Free surface moisture	10% max
Fineness	99% -600µ

(a) The gypsum purity may vary as only the final cement product is important. Gypsum impurities, except NaCl, may actually be beneficial to the end composition
(b) These limits refer to the manufactured cement
(c) This is the only specification for crude gypsum; all the others refer to calcined gypsum (plaster)
(d) Having 1% Cl^- reduces the strength of plaster by 50%
LOI Loss on ignition
wt Weight

Results of tests conducted by the Western Australian Department of Agriculture (DOA) have shown increases of 13 to 459% in crop yield for wheat. The best results were obtained after the sole addition of 5 t/ha of raw gypsum to hardsetting, grey, sandy loam over sandy clay (Sullivan and Fosbery, 1984). Officers of the Merredin Research Station (DOA), where the tests were conducted, may be consulted concerning the use of raw gypsum on specific soil types within Western Australia (DOA, pers. comm., 1990). The specifications for raw gypsum used in this way are given in Table 1.

There are several minor industrial uses for raw gypsum of which only *terra alba* and glass batch are mentioned here. The term *terra alba* is applied to finely ground (-325 mesh), high-purity (95%), very white, raw gypsum. Actual specifications as to colour and particle size may vary slightly, depending upon the end use. Table 2 gives the general specifications for *terra alba* used as an inert filler or diluent, a filter, or a source of biologically extractable calcium (pharmaceutical). When used in pharmaceuticals and bakery products, *terra alba* must meet rigid food specifications and is usually made from +97% pure raw gypsum. Lastly, *terra alba* is also used in the brewing of beer. This is because it was discovered that sulfate fillers in water assist in the development of yeast fermentation, settling out the yeast, and the clarification of the beer (Appleyard, 1983).

Table 2. Specifications for minor uses of gypsum

	Purity	*Colour*	*Fineness*
Moulding, casting and dental plasters	+94% $CaSO_4.½H_2O$	White	
Terra alba (pharmaceutical/filler/filter)	+97% $CaSO_4.2H_2O$ +99% usual	Very white	95% -45µ (-325 mesh)

Glass batch gypsum is also raw gypsum. Its specifications require that it be reasonably pure, of about the same fineness as sand, and be fairly dust free. It is used in the manufacture of glass, where it serves as an oxidizing agent, as a fining agent, and assists in the removal of scum.

The main use for calcined gypsum is in the manufacture of wallboard (also called plasterboard, drywall or gyprock). Wallboard is used in many countries, including Australia, to cover the wall and ceiling surfaces of steel, wood, and sometimes brick-framed buildings. Besides facilitating the quick, clean covering of interior surfaces, wallboard is non-combustible. In fact, when subjected to the heat of a fire, the rehydrated gypsum dehydrates (calcines) again, emitting water vapour (steam) and hampering the combustion of other materials.

Wallboard is an inexpensive, readily available construction material. It is manufactured from calcined gypsum (plaster) by sophisticated, highly automated, high-speed machines at the rate of 0.3 to 1.0 m/s. Consisting of a gypsum core encased by treated paper, wallboard is made in sheets, typically 1.2 m x 2.4 m x 12.7 mm, for ease of handling and maximum surface coverage by single sheets. This product requires very pure gypsum, usually +95% purity, because the setting time and strength are critical to the high rate of production and to the resulting finished product (see Table 1 for other specifications). Additives are used to control the setting time of the calcined gypsum in this process to between 5 and 6 minutes.

As with wallboard, moulding and casting plasters are valuable construction and industrial materials because of their low cost and adaptability. These plasters — used, as the names suggest, to make moulds and casts — require very high-quality calcined gypsum. The primary consumers of moulding plasters appear to be the sanitary ware, pottery, metal casting, and decorative objects industries. Both moulding and casting plasters are sold on the basis of their demand for water, strength, colour, setting time, and closely controlled expansion and shrinkage qualities (see Table 2 for purity and colour specifications). Included in this category is dental plaster, a highly specialized material made for dental and orthopaedic work, which has an accelerated setting time of 3 to 4 minutes.

New uses for calcined gypsum or plaster are constantly being discovered — one of which was the use of plaster in a gold mine at Norseman, Western Australia. Here, plaster was mixed with water at the surface and pumped underground to create support pillars, allowing the old ore-bearing support pillars to be mined. Load-bearing capacity for these plaster pillars was found to be 20 MPa. The total cost, including a $2 million plant and placement cost, was less than $50/m^3 (Suttill, 1990). This was far lower than cemented fill or any other alternatives considered, and was due to the availability of local supplies of raw gypsum on Lake Cowan.

Soluble anhydrite (Fig. 2) has a high affinity for water which makes it an efficient desiccant. It is marketed in a range of particle sizes for use in laboratories and commerce. Finely ground soluble anhydrite is also used as a desiccant with some types of insecticides which must remain absolutely dry for the insecticide to maintain its toxicity.

Insoluble anhydrite (Fig. 2), also called 'dead-burned gypsum', is used as an inert industrial mineral filler and to produce Keenes cement. The industrial filler is used in place of calcined gypsum where extra whiteness of the product is required or where process temperatures may go over 49°C (thus releasing water from calcined gypsum). Keenes cement is composed of insoluble anhydrite which, with special additives, can be made to set and harden after being mixed with water. The setting time for this cement is 4 to 12 hours and the major use is for wall plaster where extra density, hardness, and strength are required.

Hydraulic gypsum, sometimes called 'Estrich gypsum', refers to lump-sized calcined gypsum which has been heated to 899°C, to drive off SO_2 and leave the calcined product enriched in calcium. This calcined gypsum, when mixed with water, is slow-setting compared with other calcined gypsums, and yields a very hard, dense, and durable surface. In Europe it has been used as a flooring material, although this use has yet to gain acceptance in Australia or the U.S.

Raw and calcined gypsum are both utilized agriculturally as stock feed additives for beef cattle, dairy cows, and sheep. They are used to supply the total sulfur requirements, increase the efficiency of nonprotein nitrogen in urea feeds, as an ideal supplement for ensilage enhancers, and as an effective regulator for self-feeding on the range (Appleyard, 1983).

Further information on the uses of gypsum and its derivatives is given by Appleyard (1983).

Methods of mining

All Western Australian gypsum production comes from surface mining of gypsite, seed gypsum, crystal gypsum, and rock gypsum deposits. A variety of methods are used which are determined by site-specific criteria — such as thickness and nature of the overburden, thickness of the gypsum and the distribution of interbedded materials, rock hardness, climatic conditions, and processing or separation requirements. All of these factors influence the mining equipment used. Washing, screening, and initial milling may be done on-site or at a nearby facility. Mining equipment typically consists of front-end loaders, scrapers, bulldozers, mechanical shovels, and screens.

Beneficiation

Most beneficiation of raw gypsum is undertaken to improve quality or produce equigranular grains prior to export, application in agriculture, or consumption (calcining to plaster).

High-grade gypsum deposits require very little on-site beneficiation. Loose gypsite (kopi) of good quality is used locally or sold for agricultural use after screening to remove the lumps, rocks, and vegetation. High-quality seed gypsum is also screened before transport to the calcining or cement plant. Seed gypsum is preferred by farmers in Western Australia because it is not blown away as easily as gypsite. Low-quality seed gypsum may be milled and washed on-site or at point of use (e.g., a calcining plant) depending upon the costs involved and availability of fresh water. Impurities in seed gypsum, which may include salt, limestone, sand (silica), clay, iron oxides, and vegetable matter, can add significantly to the costs if they are not removed before transport over long distances.

It is necessary to process a parent material (usually a clay) to obtain crystals of gypsum or selenite. This may or may not require fresh water, but when the larger crystals are crushed to obtain the equigranular crystals required for calcining, fresh water washing is mandatory. Washing significantly reduces all impurities except silica, which requires other separation methods. Australian production of crystal gypsum has declined over recent years because of the processing costs compared with those for seed and rock gypsum.

Rock gypsum normally requires ripping and/or blasting to break it up, then grinding or milling to further reduce the pieces to the desired size(s). Washing is necessary at some stage to remove the fine-grained gypsum and impurities and to dissolve other material, such as salt.

Milling and calcining of raw gypsum to plaster can now be accomplished on site by using mobile processing plants. These plants are reported to be variously capable of handling 1–2.5, 5, or 10 tph, depending upon size. They use hot air from a clean-burning gas-fired or oil-fired heater (Staff, 1990). With plants like these available, the making of general purpose plasters could move right onto the quarry site. Specialty plasters and cements, however, still require specialized calcining plants.

Substitute materials

It is very difficult to replace gypsum in its major uses (wallboard, plaster, cement, and agriculture), because of the particular combination of properties exhibited by its family of products: dehydration–rehydration attributes, cement setting-time reactions, resistance to fire, whiteness, and inertness of non-soluble products. Other positive factors for gypsum are geographic location of deposits, process technology availability, economical mining and processing, and sheer adaptability.

There are, however, a few substitute minerals and materials that can replace small quantities of gypsum and calcined gypsum products. These include: inert materials such as diatomite, limestone, clay and talc; pozzolanic materials in cement such as diatomite, clay, pumice, various chlorides and other sulfates; and agricultural fertilizers (phosphate and nitrate compounds) and stockfeed supplements (clay and diatomite).

'Desulfogypsum' obtained as a result of desulfurizing flue gas, is often called 'FGD gypsum' and can replace a significant quantity of raw gypsum used for plaster in the construction industry. The main problem with using this waste product of stack gas scrubbing is assuring the quality of the resulting gypsum. Currently, the Japanese are leading the research into utilization of this by-product (Ellison and Makansi, 1990) to replace some of the raw gypsum consumed in plaster manufacture.

Markets, production and prices

World overview

History of use

The mineral gypsum has been used by man for thousands of years. It was probably discovered in a similar fashion to clay and clay–shales. No doubt early experiments in trying to fire this white, clay-like substance resulted in the discovery of its calcining properties and led to its use as plaster.

The first reported historical use of gypsum plaster was by the Ancient Egyptians some 5000 years ago. 'It appears they discovered that gypsum rock, when heated, decomposed into a powder which when mixed with water formed a putty that could be plastered onto rough mud brick or stone walls to make a smooth finish' (Appleyard, 1983).

For thousands of years, gypsum plaster continued to be used as a surfacing material for ornamental purposes, its only major problem being a rapid setting or hardening time of only 25 to 30 minutes.

France developed the first real understanding of the chemistry of gypsum and gypsum plaster around 1755 and most current uses developed from that time (Appleyard, 1983). Around the middle 1870s, a way to retard the setting time for plaster to 2 or 3 hours was discovered, thus leading to the manufacture of 'slow-set plaster'. This development was the key to the rapid growth in the use of gypsum in the building industry.

The first reported use of gypsum in the U.S. was as a 'land plaster' sometime during the Revolutionary War (mid-1770s). In this use, raw gypsum was ground very finely and used as a soil conditioner (Appleyard, 1983). Gypsum is still sometimes referred to as 'land plaster' in the U.S.

Documented English usage of gypsum in cement manufacture apparently dates from 1756 — John Smeaton's carefully proportioned hydraulic cement. In 1824, Joseph Aspdin patented a cement which he named 'Portland cement' after the famous dimension limestone quarried from the Isle of Portland, on England's south coast (Ames and Cutcliffe, 1983). Portland cement, which includes 3 to 7% gypsum to control the setting time, has probably become the most important construction material of this century and gypsum is an integral part.

World-wide, the use of gypsum has generally reflected technological advancement of nations. A country requiring wood and stone for building and construction used very little steel, cement, and/or plaster. But as building technologies changed — following the industrial revolution and the beginning of mass-production techniques — more and more plaster and cement were needed.

The early 1900s, saw a rapid shift towards the use of interior plasters and plaster-based building materials, followed closely by the increased use of external cement and cement-based materials. Currently, most buildings in the industrialized countries use plaster-based materials for interior walls, ceilings, and borders (cornices, etc), and cement or cement-based materials for exterior walls, floors, and foundations.

The use of cement in concrete made huge advances in the late 1800s and early 1900s after the invention of Portland cement. Projects like dams and public buildings which had previously been made of stone (with its corresponding limitations) could now be moulded in concrete with steel reinforcing. Then came slip-forming (allowing continuous pouring of huge concrete structures without seams); specialty cements and concretes (which offered control over factors such as setting time, early and late strength, durability, corrosion resistance and penetration by various fluids); and now pre-stressing of concrete pieces, with the resulting increase in load-bearing capacity. These advances in the use of concrete and cement-based materials allowed the creation of immense structures, monuments, and buildings all over the world. Through all of these advances, Portland cement has played the key role, resulting in a large consumption of gypsum, which has no substitute as a setting-time retarder.

Production and prices

International prices have been stable for the last eight years at around US$9–12/t. This is consistent with the widespread occurrence of recoverable gypsum resources around the world and would seem to indicate that there were no supply problems over this period.

Production, however, continues to fluctuate in response to the demands of the building and construction industry. Increases in production (and presumably demand) averaged 1–2% per year for the period 1982–87, and totalled 90.4 Mt in 1987 (see Table 3). In 1988 the reported production jumped by 5% to 95.2 Mt, followed in 1989 by a 3.5% increase to 98.5 Mt of raw gypsum. In April 1988, Benbow (1988) forecast the 1989 slow-down — based upon anticipated slow-downs in the residential and commercial building industry in the U.S.

Table 3. World gypsum production and prices (1986–92)

Production (Mt)	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
Raw	89.3	90.4	95.2	98.5	98.9 [(b)]	93.9	97.9
Value [(a)] (US$/t)	9.00	10.20	10.20	9.60	12.35	10.50	9.60

(a) Estimated
(b) Raw, ex-mine or CIF U.K.
Sources: Production from Davis (1990a, 1990b); USBM (1993)
Prices from December *Industrial Minerals* magazine

Total world production in 1989 was just under 98.5 Mt by 82 reporting countries, in 1990 production was 98.9 Mt, in 1991 93.9 Mt, and in 1992 it was 97.9 Mt. Many small operations (1–2 persons) which produce solely for local consumption are not included in these figures. Reported world production capacity in 1989 was about 97.1 Mt (Davis, 1990a), although this was probably a very conservative figure.

The main gypsum producing countries in 1989 (Davis, 1990a) were the U.S. (14.9 Mt), Canada (8.5 Mt) and Iran (8.4 Mt). The main consuming country of raw gypsum (about 25.4 Mt) and plaster (calcined gypsum) products in 1989 was the U.S.

Resources

World reserves have been placed at 2359 Mt (Davis, 1991). This figure represents the reported reserves of the U.S. and Canada (1270 Mt), plus an estimated 1089 Mt for the rest of the world. The other major producing countries had not reported their domestic reserves at the time of the survey.

World resources of natural gypsum are unknown at this time although they are considered to be extremely large, possibly as large as 10 000 Mt. This estimate does not account for the new resources currently being deposited or for the by-product gypsum resulting from the scrubbing of industrial stack gases (FGD).

Gypsum mining in Australia

History of mining

In Australia, sizeable deposits of gypsum were known long before actual mining and calcining began late last century.

The first reported plaster production in Australia came from Gypsum Palace (near Ivanhoe) in western New South Wales. The Gypsum Palace Inn was constructed in 1856 using blocks of locally obtained burnt gypsite and ashes.

The first two leases for gypsum were granted around 1874 on the Yorke Peninsula, South Australia (Adamson, 1988). Several companies were formed over the next 35 years to mine and calcine gypsum from this deposit, but steady production was not achieved until 1914–15 when calcining facilities were organized in Adelaide, Melbourne, and Sydney. Since then Australian plaster production has been nearly continuous.

Gypsum deposits are common in the 'mallee country' of northwestern Victoria, and production has taken place there since 1902.

The first recorded gypsum production in Western Australia was in 1921, and since 1924 gypsum has been produced regularly within the State, mostly for local consumption.

Production and prices

Gypsum deposits occur in virtually every state but the quality, size, and location of the deposits determines their viability for extraction. Currently four states in Australia are mining and calcining gypsum worth approximately 9.5 million dollars (see Table 4).

Australian production closely follows the vagaries of the building industry. Reported production and prices were at a high in 1984 — 1 931 205 t and $6.25/t respectively — but then declined steadily to 1987 when only 1 580 331 t were produced at an average reported price of $4.79/t (see Table 4). Production increased slightly in 1988 but the average price fell to a new 5-year low of $4.15/t. In 1989 production rebounded to a new high of 2 184 452 t, and the reported price increased to $4.35/t — still well below the 1984 price.

Table 4. Australian gypsum production (tonnes) and prices ($A) (1986–92)

	1986	*1987*	*1988*	*(a)1989*	*1990*	*1991*	*(b) 1992*
NSW[(b)]	47 280	34 497	33 700	27 820	29 000	27 500	18 700
SA	1 135 841	1 229 377	1 277 183	1 399 400	1 400 000	1 222 500	1 173 900
Vic[(b)]	173 399	180 412	233 000	241 400	301 000	49 200	na
WA	314 481	136 045	112 017	166 000	155 000	82 500	101 800
Total	**1 671 001**	**1 580 331**	**1 655 900**	**1 834 620**	**1 885 000**	**1 381 700**	**na**
Value ($'000)[(c)]	8 578	7 576	6 689	8 187	7 372	5 185	na
Unit value (average $/t)	5.13	4.79	4.04	4.46	3.91	3.75	na

(a) Figures for 1986–88 are for calendar years.
From 1989 ABS changed to fiscal year reporting

(b) Preliminary figures

(c) Ex-mine value usually reported

Sources: ABS files (unpublished)
Various States' production information (unpublished)
ABARE, 1993 (rounded figures)

South Australia generally accounts for about 70–75% of Australia's gypsum production, most of which goes to the eastern states and New Zealand. Three other states (New South Wales, Victoria and Western Australia) produce gypsum mostly for their own local markets (see Table 4). Big increases in domestic consumption are not expected in the near future.

Between 1985 and 1989 exports of crude gypsum declined 90% (from more than 420 000 t to less than 40 000 t). The reported sale price also declined between 1985 and 1988, but recovered in 1989, reaching $19.46/t (see Table 5), possibly due to the high quality of Australian gypsum.

Calcined gypsum (plaster) exports also fell during the period 1985 to 1988, although the value increased ($166.98 to $190.03/t). During 1989 there was a 70%

jump in international sales of Australian calcined gypsum; however, this increase may also have precipitated a 36% fall in the reported price per tonne (see Table 5) which fell to $122.29/t. The international market appears to be currently oversupplied with gypsum, resulting in lower prices and limited demand for Australian crude or calcined gypsum.

Australian imports of crude and calcined gypsum have generally risen since World War II (see Table 5 for recent figures) because the use of gypsum and specialty calcined gypsum products or plasters has risen dramatically in the construction and commercial industries. Australia does not produce all of the specialty calcined gypsum products nor does it have any readily accessible deposits of natural anhydrite. Consequently, these materials must be imported.

Table 5. Australian exports and imports of gypsum (tonnes) (1986–93)

	(a) 1986	*(a) 1987*	*(a) 1988*	*1989*	*1990*	*1991*	*1992*	*(f) 1993*
Exports								
Crude (t) (b)	423 236	195 364	116 200	68 100	na	53 200	160 700	161 600
Value, fob ($'000)	7 702	2 968	1 391	1 048	285	759	1 775	1 807
Unit value (average $/t)	18.20	15.19	11.97	15.39	na	14.27	11.05	11.18
Calcined (t) (c)	5 348	4 866	4 704	3 940	10 437	5 702	6 128	8 610
Value, fob ($'000)	893	848	845	752	1 032	1 100	1 318	1 958
Unit value (average $/t)	166.98	174.27	179.6	190.86	98.88	192.91	215.08	227.41
Imports								
Crude (t) (b)	364	704	824	1 093	(e) 20 426	(e) 48 631	(e) 102 905	(e) 143 004
Value ($'000) (d)	158	357	337	262	500	995	2 162	4 692
Unit value ($/t)	433.88	507.01	409.15	239.62	24.48	20.46	21.01	32.81
Calcined (t) (c)	522	1 557	1 118	1 118	(e) 574	613	716	685
Value ($'000) (d)	265	666	441	391	315	351	410	403
Unit value ($/t)	507.08	427.62	394.19	349.91	549.10	572.23	572.57	588.19

(a) Figures for 1986–1988 are for calendar years.
From 1989 ABS changed to fiscal year reporting
(b) Gypsum and anhydrite
(c) Calcined gypsum and plasters (made of calcium sulfate). Figures do not include plasters specially prepared for dentistry
(d) These values are assumed to be CIF and they vary widely due to the numerous specialty products included such as plasters, powders, coatings and fillers/extenders
(e) Imports between 1990 and 1993 are for calendar years
(f) Preliminary figures
Sources: Australian Bureau of Statistics data (unpublished)
ABARE, 1993

It should be noted that the amount of 'crude' gypsum apparently imported includes natural anhydrite, and that 'calcined' gypsum includes calcium sulfate derived as an industrial by-product as well as that made from natural gypsum. These factors may give a misleading impression of Australia's balance of trade in gypsum and its products.

Resources

There are no available figures concerning total reserves or resources of gypsum in Australia. However, indications are that even if Australia increased the mining of gypsum by 500% (to around 25 Mt), currently known available resources would last hundreds of years.

Gypsum mining in Western Australia

History of mining

Recorded gypsum mining in Western Australia began in 1921 when 675 t was extracted from the Koorda deposit for plaster production. It was worth about $1.84/t. Mining continued in the following years, and today gypsum is still an important industrial mineral to the Western Australian economy. Gypsum was exported between 1958 and 1987, but most ongoing production has been for local consumption. Since 1921, Western Australia has recorded a total production of about 6.1 Mt of gypsum, worth $47 million. In 1991, the highest reported production came from Lake Brown where 22 778 t, worth $121 761 (about $5.30/t) was produced. A summary of production from each Western Australian gypsum deposit is given in Table 6.

Production and prices

Western Australia has about 180 known deposits of gypsum (Plate 1) and in 1990–91 14 operators reported production worth some $635 000 per year (Table 7), although annual output fluctuates appreciably, depending on the state of the building and housing industries. Production reported to DME for 1993 was 145 200 t worth $1 329 400. Historically, production peaked at 637 683 t in 1984 due largely to exports from Lake Cowan and Shark Bay. Some 64% of the production in 1991 was obtained from three deposits: Cowcowing Lakes (12 843 t); Lake Hillman (18 317 t); and Lake Brown (22 778 t).

Production figures and estimated usage of gypsum between 1951 and 1991 are shown in Figures 3 and 4. Western Australian domestic production of gypsum is consumed mainly by the plaster, cement, and agricultural industries.

Table 6. Western Australian gypsum production, 1921–1991

Deposit	*Period*	*Subtotal for period (t)*	*Total (t)*	*Comments*
Baandee	1924–1961		95 268	
Chandler	1968–1978		49 282	(b)
Cliff Head	1941	67		
	1963–1967	346		
	1989–1991	8 983	9 396	Includes Dooka
Cowcowing Lakes	1924	495		
	1958–1972	52 448		
	1974–1991	301 422	354 365	
Elphin Siding	1984–1988		3 714	
Hines Hill	1924–1928	2 743		
	1949–1973	45 450		
	1983–1991	85 324	133 517	Includes Burran Rock South
Kellerberrin		7		
	1970–1974	143	150	
Kondinin	1985–1987		9 681	
Koorda	1921–1929	6 664		
	1988	5 000	11 664	
Lake Brown	1935	448		
	1938–1941	8 675		
	1948–1992	716 182		
	1951–1952	60 269	785 574	(a) (c)
Lake Camm			6 790	
Lake Campion N. R.	1984–1990		10 257	M77/2
Lake Cobham	1984–1990		16 398	
Lake Cowan	1935–1936	1 423		
	1946–1973	87 226		
	1983–1986	484 845	573 494	
Lake Goorly			20 916	
Lake Gulson	1985–1991		17 126	
Lake Hillman	1977–1991		312 299	Includes Burran Rock
Lake McDermott			271	
Lake Seabrook	1926–1941	11556		
	1946–1991	1 107 862	1 119 418	(a)
Lake Tay	1990–1991		6 518	
Lake Wallambi	1968–1969	203		
	1972–1974	153		
	1977–1989	177 507	177 863	
Mount Walker	1987–1988		4 974	
Mukinbudin	1989		500	
Scadden			20 902	
Useless Loop	1968–1987		2 494 282	
Woolundra	1924–1953		54 415	
Yarra Yarra Lakes	1988–1990		11 144	
Total			**6 300 178**	

(a) Some 41 423 t of gypsum from Lake Seabrook has been attributed to Lake Brown in published statistics
(b) Does not include 60 269 t produced between 1951 and 1952, and attributed to Chandler by de la Hunty and Low (1958)
(c) Includes 60 266 t produced between 1951 and 1952, and attributed to Lake Chandler in de la Hunty and Low (1958)

Whereas records of gypsum used to make plaster have been maintained since 1951, those for the quantities of gypsum employed for cement manufacture and agriculture are incomplete. Available information suggests that annual consumption of cement in Western Australia, during the past 20 years at least, has ranged from 500 000 to around 600 000 t. Assuming that most of this is manufactured locally, some 25 000 to 30 000 t of gypsum would be needed to produce it, making the cement industry the largest consumer of gypsum (about 40% in 1991).

Table 7. Gypsum producers in Western Australia — 1990–1991

Deposit	*Producer*	*Production (t)* 1990	1991
Burran Rock, 4 km south	Marley, F J	930	-
Burran Rock, 10 km south	Enright, A M and B A and Pustkuchen, J V	7 350	760
Cliff Head	Expeto Pty Ltd/Framel Pty Ltd	210	8 242
Cowcowing Lakes	Westdeen Holdings	33 817	12 843
Lake Camm	Hewson, A R and K J	-	4 126
Hines Hill	Smith, R J	2 430	-
Hines Hill	Smith, R J	3 686	408
Hines Hill, north	Giles, B D and G S	1 100	483
Lake Cobham	Green, K L and P M	5 500	-
Lake Goorly	Bywaters, L P	5 925	2 935
Lake Gulson	Kidman, G A & J E	4 487	2 592
Lake Hillman	Hathaway, G R, S J and R J	700	1 375
Lake Hillman	Lake Hillman Mining Pty Ltd	17 078	4 483
Lake Hillman	Swan Portland Cement Ltd	14 989	12 459
Lake Brown	H B Brady & Co Pty Ltd	13 263	15 722
Lake Seabrook	H B Brady & Co Pty Ltd	14 317	7 056
Lake Tay	Prima Resources NL	5 500	1 018
Scaddan	Hillerman, Wandel and Sime	11 738	1 248
Yarra Yarra Lakes	Green, D B	3 791	-
	Total reported production (t)	**146 811**	**75 750**
	Total reported value	$ 1 061 190	635 499

Source: Department of Minerals and Energy

Until a few years ago, the plaster industry dominated domestic consumption of gypsum in Western Australia, but the decision by one major manufacturer to close down its local quarry in favour of importing material from South Australia, coupled with a downturn in the building industry, has resulted in gypsum production for this purpose declining from a peak of about 72 000 t in 1985 to 23 000 t in 1991, or about 30% of the total consumed.

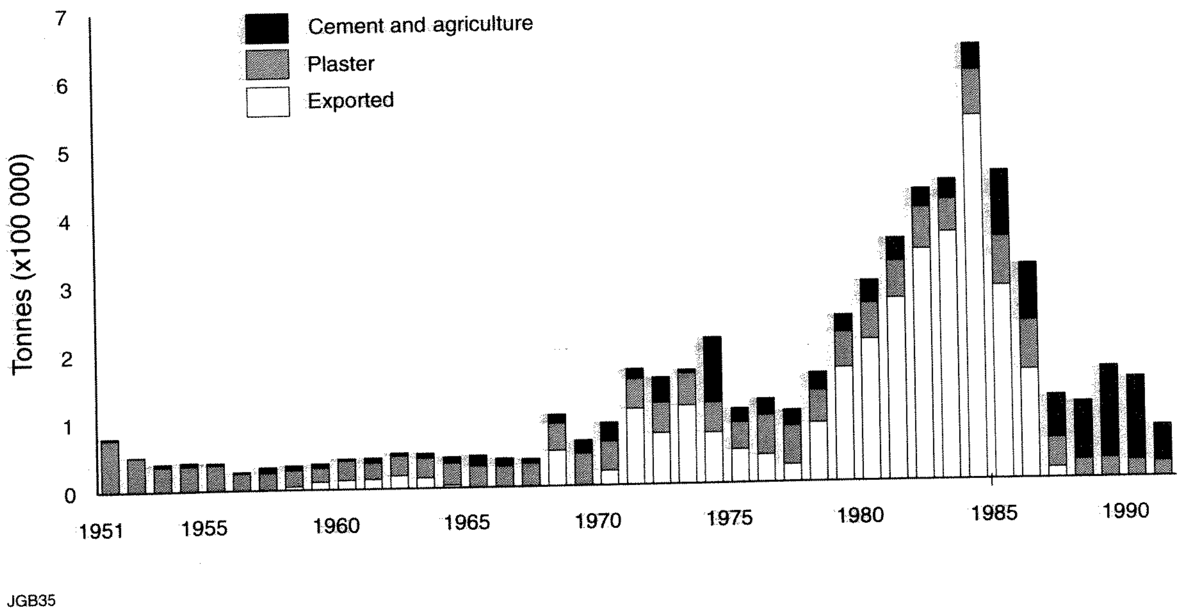


Figure 3. Estimated annual usage of Western Australian gypsum, 1951–1991

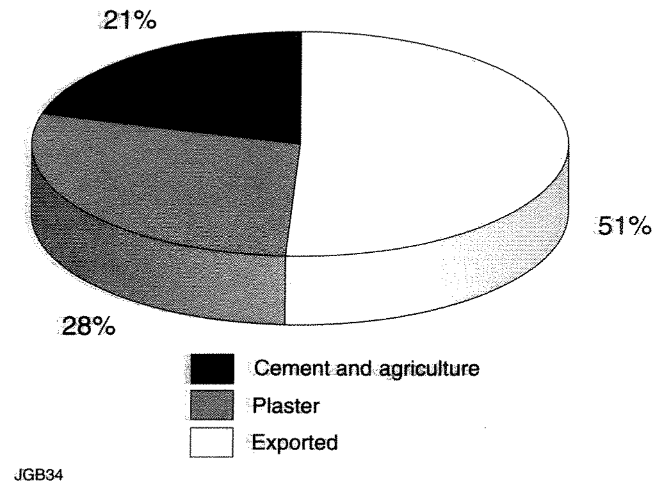


Figure 4. Estimated total usage of Western Australian gypsum, 1951–1991

The third major use of gypsum in the State is for agriculture, where the mineral is used to supplement phosphatic fertilizers on soils that tend to develop an impervious surface layer. An estimated 20 to 25% of Western Australian production went into this industry in 1991.

A further significant use for gypsum during the past two or three years has been as a clay suppressant in heavy mineral sands dredging at Eneabba. The material is spread over the deposit ahead of mining, mixing with the ore during treatment and settling the clay that normally builds up in the dredging pond.

Exports of crude gypsum ended in 1986 when, with the benefit of somewhat lower transport costs, Thailand increased sales on the world market. Figure 3 shows the rapid rise and fall experienced in the export market for gypsum. The average reported export price in 1989 for Australian crude gypsum rose to $19.46 per tonne, the first price rise in some years. This may indicate a renewed demand for Australian gypsum and possibly a re-evaluation of Western Australian export possibilities. However, renewed exports of Western Australian gypsum appear to be dependent on a rise in world prices to pre-1985 levels and/or a fall in transportation costs.

Domestic gypsum prices reported to DME typically vary appreciably from producer to producer. For example, in 1991, the reported value per tonne ranged from $3.50 to $18.70, with a weighted average of around $8.40 per tonne. In part, this reflects variations in grades for different purposes, but also that values assigned to material in vertically integrated industries appear to be nominal, based on cost of production rather than any 'arms length' sale price. For this reason, reported values have not been included in Table 6.

Imports of raw and calcined gypsum into Western Australia are fairly small, consisting mainly of plasters developed for specialized uses, such as dentistry, or ingredients in pre-prepared stock feeds and fertilizers. Table 8 gives data on these imports for 1987–89. Some or all of these imports of raw or calcined gypsum could be replaced with local production if the market were large enough.

Resources

It is impossible at this time to calculate a total gypsum resource for Western Australia, because most of the deposits have not been properly explored. For example the Lake

MacLeod lake bed contains inferred resources of 1000 to 2000 Mt, based upon sparse drill information from a potash exploration program conducted in the mid-1960s. Follow-up work has only begun recently and results are not yet available. Other deposits are too small, too remote, or apparently too impure to warrant interest by industrial mineral companies or any local agricultural suppliers.

Table 8. Western Australian imports of gypsum (1987–93)

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*
Crude (t) (a)	5	18	1	7	1	na	1
Value ($) (b)	3 625	6 012	253	1 000	1 000	na	2 000
Unit Value ($/t)	725.00	334.00	253.00			na	
Calcined (t) (c)	238	212	106	146	126	137	116
Value ($) (b)	133 167	89 211	39 586	67 000	67 000	75 000	84 000
Unit Value ($/t)	559.53	420.81	373.45	459	532	547	724

Notes: In 1988 the Australian Bureau of Statistics began using the fiscal year for their statistics instead of the calendar year.

na not available
(a) Gypsum and anhydrite
(b) These values are assumed to be CIF and they vary greatly due to the numerous specialty products included such as plasters, powders, coatings, and fillers/extenders
(c) Calcined gypsum and plasters (made of calcium sulfate). Figures do not include plasters specially prepared for dentistry

Total known Western Australian gypsum resources were given by de la Hunty and Low (1958) as approximately 27 Mt. This figure included 58 deposits, of which 36 had been inspected by the authors. The current investigation records some 180 deposits (58 from the earlier investigation) of which 25 were inspected. As a result of the sparse, incomplete data available on most of the deposits, figures for Western Australian resources are approximate and are dominated by the Lake MacLeod deposit. The total gypsum resource of the State is thus 1000–2000 Mt. The inclusion of deposits of bedded anhydrite and gypsum in various sedimentary basins would greatly increase this figure.

Information on the quality of gypsum resources in Western Australia is also very sparse. In general, it can be said Western Australia has some of the purest gypsum in the world due to its recent deposition in an arid environment which restricts the dissolution and contamination of the mineral. Gypsum from the major deposits is commonly above 90% $CaSO_4.2H_2O$ and production is generally in the 95–99% purity range.

Transportation costs in Western Australia

The cost of transporting material from the mine to the point of sale or consumption is probably the single most important economic factor when mining a relatively low-value product. Table 9 gives some examples of Western Australian costs in 1991 of transporting gypsum, iron ore, limestone, dolomite, etc.

Table 9. Examples of transport costs for Western Australian minerals

Carrier	*Distance*	*Cost (trip)*	*Cost (t/km)*
Truck	330 km	$26/t	$0.079
Rail	300 km	$22/t	$0.073
Rail	345 km	$20/t	$0.058
Ship	WA–Eastern States	(a) $40/t	
Ship	Port Hedland–Taiwan	$18/t	

(a) Includes $5/t loading and $5/t unloading charge

It is quite evident from Table 9 that the transport costs vary substantially within and outside Western Australia. The parameters that affect these costs, and may lower charges are: frequency of shipment; distance and mode (for example rail versus ship); quantity of shipment (lower charges for larger cargoes by ship); departure/delivery ports (backloading rates are possible); and the demand versus availability of various modes of transportation.

A final factor which should be mentioned here is that government charges may have a significant effect upon the transportation of materials or minerals. For example, truck transportation charges in 1991 were around $0.07–0.08 t/km (see Table 9), but it has been estimated that the increases in truck registration fees could result in a rise of 12 to 15 per cent in these costs. Such an increase may drive potential truck transport customers to use rail instead, consider ships wherever possible, or to delay or abandon new developments.

Considering the above, it can be seen why current and future transport costs of materials and minerals assumes a pivotal position in the economic viability of any gypsum, or indeed, industrial mineral operation.

Distribution, origin and age of deposits

Gypsum in nature may occur either as the decomposition product of pre-existing minerals, particularly those containing sulfides, or as primary evaporite deposits. Only the latter type has been shown to contain economically significant quantities of gypsum in Western Australia and this study is therefore limited to resources of this type.

It is generally accepted that gypsum, not anhydrite, is the primary depositional mineral from marine and terrestrial brines under arid to semi-arid conditions. There are, however, some workers who believe that anhydrite is the primary depositional mineral (Dickson, 1978). Of further interest is the Persian Gulf coastal sabkha (Arabic for 'salt flat') environment where both gypsum and anhydrite are forming as primary minerals, but this appears to be a unique situation.

Gypsum deposits in Western Australia fall into three broad categories based upon their geological setting. The categories are:

- salt lakes or playas in the arid interior of the State;
- barred basins in present or former coastal inlets and associated saline lagoons; and
- evaporite sequences in sedimentary rocks of Late Proterozoic to Mesozoic age.

Individual deposits are discussed in detail under these headings.

Most deposits are composed essentially of gypsum, although the Lake MacLeod barred basin deposit and some older evaporite sequences contain anhydrite.

Salt lake (playa) deposits

Distribution and origin

The majority of the State's gypsum deposits are related to salt lakes in the arid interior of the State. These features are interpreted as the infilled remnants of once-major drainage systems that were active during the early part of the Tertiary Era. The more important palaeodrainage channels and their respective drainage basins are documented by van de Graaff et al. (1977) and are indicated on Plate 1.

The distribution of salt-lake deposits is also shown on Plate 1. Such deposits are widespread in the State's wheat belt and throughout most of the southwest and goldfields regions. Many other deposits have been noted during regional geological mapping in the State's desert regions, although, because of their remoteness, no evaluation of their commercial potential has been attempted.

Gypsum deposits in the beds of inland salt lakes tend to be scattered, fairly thin, and relatively impure due to the normal impurities in the surface waters and the intermittent stream flows. Lake-bed deposits also redissolve when enough water is available (from either stream-flow, runoff, or groundwater sources). As a result, lake-bed deposits are generally of little interest to major producers. However, gypsum from the beds of salt lakes is important as it supplies material for gypsum dunes, a significant source of production.

Gypsum dunes (also known as lake dunes) are found on the south and southeast shores (also near-shore, a short distance from the shore) and generally trend in a northeasterly direction. This trend is at right angles to the direction of the prevailing wind. The dunes themselves may vary in height from 0.25 m (ridges) up to 20 m or more, and in length from tens of metres to several kilometres. Generally, the dunes are much cleaner than gypsum deposits on the lake beds themselves since most of the impurities have been removed through winnowing and/or leaching.

A characteristic of commercial salt-lake deposits is their occurrence between the present 250 mm and 400 mm rainfall isohyets (de la Hunty and Low, 1958). It appears that a balance existed between evaporation rate and rainfall in these Ca- and SO_4-rich lake systems at the time of gypsum deposition. Although similar evaporation versus rainfall conditions exist in the Pilbara and Kimberley regions, no gypsum deposits of commercial potential have been identified there. This may be due to the better developed drainage systems in these areas, allowing any accumulation of evaporite minerals to be periodically flushed out to sea following cyclonic or monsoonal rain.

Gypsum deposits in salt lakes are still forming today, with precipitation of seed gypsum on lake beds, and lithified rock gypsum below the watertable, being noted during periods of summer evaporation The source of nearly all of the $CaSO_4$ found in gypsum deposits within Western Australia is the ocean. Samples taken from many of the deposits during a separate study and tested for sulfur isotopes showed that even within the heart of the State's interior, 50% or more of the sulfur was ocean-derived. The study reached the conclusion that the sulfur, along with other salts, was carried inland as an aerosol by prevailing winds (Chivas et al., 1991).

Age of the salt lakes

The age of deposition for lake bed and lake dune deposits (called 'inland playas') in South Australia was estimated by Barnes (1990) to be about 18 000 years BP. During the course of the present study, three samples were collected for dating (one of carbonaceous matter and two of shells) from one of the larger dunes being mined on Lake Hillman. These samples were submitted to Dr P. Thorpe of the Hydrogeology Section, GSWA, for radiocarbon dating.

The first sample, composed of carbonaceous matter, was found to be of modern age (30 ± 200 years BP). The second and third samples were composed of non-marine gastropod (*Coxiella*) shells collected from discrete layers within the seed gypsum dune. The second sample furnished sufficient material to give a firm minimum age of 35 900 years BP. Although smaller than desired, the third sample still gave a minimum age of 28 580 years BP but with a larger error term. The results of the dating tests are given in Table 10.

The dates obtained from the *Coxiella* shells indicate that the approximate date for deposition of the gypsum seed dune is at least 28 900 years BP, and, more probably, over 35 900 years BP. No other data are currently available on the age of gypsum deposits in the interior of Western Australia, although it is clear from the occurrence of the mineral on present lake surfaces that it is still being formed in many locations. It therefore appears likely that gypsum has formed at various times in the past (up to at least 35 900 years BP) and continues to form intermittently in the interior of the State.

Table 10. Results of carbon isotope dating of samples from Lake Hillman

Material sampled	*% Modern carbon*	*Date (years BP)*
Tree roots in gypsum and sand	99.6 ± 2.4	(a) 30 ± 200
Coxiella shells from gypsum dune	0.5 ± 0.6	(b) >35 900
Coxiella shells from gypsum dune	0.8 ± 1.3	(c) >28 580

(a) Probably consists of root material from present-day vegetation. Small sample size resulted in large error term

(b) Minimum age reported, as sample was indistinguishable from background

(c) Minimum age reported, as sample was indistinguishable from background. Small sample size (40% of desired amount) resulted in large error term

Barred basin and birrida deposits

Gypsum deposits formed in coastal areas are located in barred basins and birridas, where seawater has been partly or totally cut off from the ocean. Such deposits occur along the north-central coast from near Cliff Head, northward to Lake MacLeod, and include those formerly mined at Shark Bay (Plate 1).

Barred basins are essentially low-lying coastal areas which have been flooded by seawater during a recent sea-level rise. Later deposition of terrestrial sediments then blocked off direct access to the sea. An accompanying drop in sea level may have also occurred. The trapped seawater has gradually evaporated to produce gypsum and other salts.

Shallow coastal depressions, known in Western Australia as 'birridas', have essentially the same origin as the coastal salinas described by Barnes (1990). While these depressions are generally not barred basins, their origins are the direct result of changes in sea level and/or the accompanying rises and falls in the watertable.

Two types of birrida deposits are found in Western Australia. The first of these — essentially gypsum-filled depressions — result from marine incursions into low-lying coastal depressions and interdunal troughs during periods of high sea level. In the Shark Bay area they are thought to be Quaternary, but detailed dating information is sparse. With the subsequent fall in sea level, evaporite minerals were deposited as the water salinity increased.

The second type of birrida appears not to have been flooded by seawater. Instead, saline groundwater in surface ponds and shallow subsurface accumulations (just under the surface of depressions) seems to have been the source of the gypsum. These deposits are generally found in the Shark Bay area. They vary from one to five metres in thickness.

The largest barred basin deposit in Western Australia is in Lake MacLeod, north of Carnarvon. This huge depression was flooded with seawater about 6000 years ago to create the lake. During a period of stable high waterlevel, gypsum began precipitating along the shallower edges of the lake. Precipitation continued during the subsequent restriction of the opening to the sea (on the south) and the accompanying fall in sea level. The deposits on the east, west, and north of the current lake are the result of this precipitation process and are also indicative of the former areal extent and level of the lake. The deposits may still reach 2–3 m in thickness although erosion, dissolution, and burial by sand dunes have severely limited exposures and removed much of the original gypsum (see section on *Deposits related to coastal lagoons and depressions*).

Gypsum continues to be deposited in the lake. The Lyndon and Minilya Rivers, terrestrial groundwater, and marine-incursion groundwater are responsible for maintaining the current lake level and supplying additional dissolved minerals. Significant thicknesses of gypsum (up to 5 m) were noted on the lake surface during a sparse drilling program in the mid-1960s (Alderman, 1967). The gypsum lay beneath bedded halite and saline brine.

A full evaluation of this gypsum deposit has not yet taken place, but, given the areal extent of the lake and the apparently continuous nature of the deposit, Lake MacLeod probably contains something in excess of a billion tonnes of gypsum. In addition, there are large deposits of seed gypsum near the Lyndon River and on the eastern and western margins of the lake. This deposit, therefore, would not only be the largest in Western Australia, but is probably one of the larger near-surface deposits of gypsum in the world. Dampier Salt Pty Ltd, which is currently producing salt (NaCl) by evaporation of the lake brines, has commenced an evaluation of the gypsum in the lake bed.

These barred basin deposits have been recognized since de la Hunty and Low (1958) completed their study and add substantially to the resources calculated by them for the State. For example, the Lyndon River deposit alone has resources of 10 Mt of gypsum, and a huge resource underlies Lake MacLeod.

Evaporite sequences in sedimentary basins

Substantial thicknesses of anhydrite- and gypsum-bearing evaporites have been recorded in the Officer Basin (Late Proterozoic), Canning Basin (Silurian to Devonian), Carnarvon Basin (Silurian to Devonian and Cretaceous) and the offshore Bonaparte Basin (Devonian). Gypsum is also associated with Permian shales in the Perth Basin.

Rifts associated with the opening of the Tethys Ocean during the early Palaeozoic may have provided local arms of the ocean in which circulation was sufficiently restricted during the Silurian and Devonian to allow evaporite minerals to precipitate. It also seems likely that Western Australia was situated nearer the equator at that time, enhancing the opportunities for evaporites to form (Veevers, 1976).

Deposits related to inland salt lakes (playas)

During the early part of the Tertiary Era, probably up until the Oligocene, Western Australia had a moist, temperate to tropical climate (Hocking and Cockbain, 1990). The ocean encroached onto the coastal plains at least twice during this period, firstly in the Palaeocene to Early Eocene, and again in the Middle to Late Eocene. Sea levels during the second incursion probably rose to around 300 m above their present height. Inland, most of the State was drained by a well-developed system of rivers incised into a land surface that had been shaped during the Late Cretaceous or Early Palaeocene (van de Graaff et al., 1977).

The Miocene and Pliocene saw a gradual transition to arid conditions (Hocking and Cockbain, 1990), with consequent drying up and infilling of many of the earlier river valleys. Although there were periodic returns to moister times in the Pleistocene, the greater part of the former Eocene river system now remains only as broad depressions marked by strings of salt lakes. Exceptions occur in parts of the State where tectonic uplift or warping has caused rejuvenation of all or part of the ancient rivers. Such rejuvenation is well documented in the southwest of the State where movement on the Meckering Line has caused renewed erosion along the lower parts of Moore, Avon and Blackwood Rivers.

Van de Graaff et al. (1977) traced the courses of many of the Eocene rivers and recognized a number of palaeodrainage basins. With some slight modifications, these form a convenient means of grouping the salt-lake deposits for description. The distribution of the deposits in relation to the former drainage basins is indicated on Plate 1.

Further information on the distribution, origin and age of salt lake deposits is given above, under the heading *Salt lake (playa) deposits.*

Southwest and Murchison regions

Most of the economic gypsum deposits of the State occur in the southwest region, which is characterized by major west-flowing river systems such as the Avon, Moore, and Blackwood. These rivers formerly had more extensive head-waters which are now represented by chains of salt lakes. The Murchison River also drains a region of salt lakes formed within its former tributaries, and gypsum is recorded from some of these. Any extensive salt lakes that may have occupied former valleys of the Gascoyne, Ashburton, and Fortescue Rivers have apparently been removed during relatively recent down-cutting of these valleys due to tectonic uplift.

Baandee Southwest

Coordinates: 31°37' S, 117°56' E.

Location: 4.8 km southwest of Baandee.

Nature of occurrence: A low ridge of impure seed along the southeast shore of the lake. This seed is overlain by a thin veneer of kopi, underlain by clay, and attains a maximum thickness of 40 cm.

Production and usage: 95 268 t to the end of 1961 (Table 6). Used for plaster. Has possible agricultural uses now.

Estimated resources: Seed — 500 000 t of 85% purity (ridge or old dune).

Sample results: See reference.

Remarks: Deposit has NaCl problems. See also 'Hines Hill'.

Reference: de la Hunty and Low (1958).

Baandee North

Coordinates: 31°22' S, 118°01' E.

Location: 24 km north of Baandee.

Nature of occurrence: Seed dune reaching 11 m in height composed of 9+ m of seed capped by kopi. Some seed is also found in the southeast corner of the lake against the dune.

Production and usage: None reported. Possible agricultural uses.

Estimated resources:

Seed — 20 000 t of 90% purity (dune);

Seed — 2500 t of 70% purity (lake and dune).

Sample results : See reference.

Remarks: Small clean deposit with good potential. See also 'Burran Rock South' and 'Hines Hill North-northeast'.

Reference: de la Hunty and Low (1958).

Bodallin

Coordinates: 31°12' S, 120°22' E.

Location: 19.3 km northeast of Bodallin.

Nature of occurrence: Kopi patches on a low ridge at the southeast edge of an old clay pan.

Estimated resources: Occurrence only.

Reference: de la Hunty and Low (1958).

Boodarockin

Coordinates: 31°00'36" S, 118°44'28" E.

Location: 65 km northeast of Merredin.

Nature of occurrence: Gypsum occurs in a dune following the southern edge of a small salt lake. The dune is about 2 m high, 15 to 20 m wide, and about 2 km long and consists of seed gypsum with a covering of kopi. The floor of the deposit is about level and about one metre above the high-water level of the salt lake.

Production and usage: None, but production of 5 000 t per annum is planned for agricultural use.

Estimated resources: 36 000 t of 88% purity.

Relevant tenement: Mining Lease 77/421.

Boondi

Coordinates: 31°12' S, 120°22' E.

Location: About 12 km east of Boorabbin.

Nature of occurrence: Up to 20 cm of gypsum occurs on an unnamed lake south of the former Boondi railsiding.

Estimated resources: Unknown.

Reference: Chivas et al. (1991).

Burran Rock

Coordinates: 31°17'36" S, 117°59'23" E.

Location: 3.7 km south of Burran Rock townsite.

Nature of occurrence: Unknown.

Production and usage: 34 762 t in 1989–90.

Estimated resources: Unknown.

Remarks: Gypsum mining tenement, no details.

Relevant tenement: Mining Lease 70/251.

Burran Rock South

Coordinates: 31°20'57" S, 117°59'13" E.

Location: 10 km south of Burran Rock townsite.

Nature of occurrence: Unknown.

Production: 23 060 t between 1986 and 1991.

Estimated resources: Unknown.

Remarks: Gypsum mining tenement, no details.

Relevant tenement: Mining Lease 70/207.

Carnamah

Coordinates: 29°36'30" S, 115°47'45" E.

Location: 8 km southeast of Three Springs.

Nature of occurrence: Gypsum occurs in a low bank on the eastern shore of a small lake. The surface area is 900 m by 60 m and the approximate thickness of gypsum is 0.6 m.

Production and usage: 11 144 t produced between 1988 and 1991, for local agricultural purposes (Table 6).

Estimated resources: Not known.

Relevant tenement: Mining Lease 70/344.

Chandler

Coordinates: 31°06' S, 118°27' E.

Location: 1.5 km northeast of Chandler townsite.

Nature of occurrence: Lake Chandler, Lake Chandler East and Red Lake each have two marginal lunettes; the westernmost is seed gypsum, and the eastern one is seed overlain by a veneer of kopi. One pit in the seed dune reached nearly 7 m in depth.

Production and usage: de la Hunty and Low (1958) referred to production of 60 269 t in 1951–1952. From 1968 to 1978 production totalled 49 282 t from MCs 42 and 43H.

Estimated resources: The dunes have a resource of 2.0 Mt, of at least 85% purity.

Remarks: See also 'Lake Brown' and 'Lake Campion'.

Reference: de la Hunty and Low (1958); Chivas et al. (1991); Freeman (in prep.).

Relevant tenements: MCs 42 and 43H. Refer to Freeman (in prep.) for further details.

Cookernup Siding

Coordinates: 33°00' S, 115°52' E.

Location: 4.4 km west of Cookernup Siding.

Nature of occurrence: Crystals up to 8 cm long were taken from a clay belt 4–4.8 km from the siding. This belt had a northerly trend.

Estimated resources: Occurrences only.

Reference: de la Hunty and Low (1958).

Coorow Siding

Coordinates: 29°57' S, 116°05' E.

Location: Approximately 11.3 km southeast of Coorow Siding, next to the Midlands Road, midway between Coorow and Marchagee.

Nature of occurrence: Kopi occurs in two clay pans about 20 m apart on each side of the highway. The east pan has 5 cm of seed overlying 20 cm of clayey kopi, and the west pan has kopi banks reaching one metre in height.

Production: None reported.

Estimated resources: Kopi/seed — 26 000 t of 64% purity (mostly kopi).

Sample results: See reference.

Reference: de la Hunty and Low (1958).

Cowcowing Lakes North

Coordinates: 30°56' S, 117°26' E.

Location: 2 km north of Dukin, along the lake edge; and 4.5 km west of Dukin, in the southern part of the lake.

Nature of occurrence: Several low ridges in this area contain seed with a capping of kopi. The northern area contains a ridge along the southeastern shore of the northernmost of the lakes. The western ridge occurs in the northern part of the southernmost of the lakes.

Production and usage: 495 t mined in 1924 (Table 6), probably for plaster.

Estimated resources: Seed/kopi — 300 000 t of 70% purity (ridge or old dune).

Sample results: See published reference.

Remarks: De la Hunty and Low (1958) called this deposit 'Dukin Siding'. Prospecting tenement P70/612 covers the northern area mentioned above. See also 'Cowcowing Lakes South'.

Reference: de la Hunty and Low (1958);

Relevant tenements: Prospecting Licences 70/612, 70/657.

Cowcowing Lakes South

Coordinates: 31°02' S, 117°20' E.

Location: 8 and 13.5 km west of Nalkain Siding.

Nature of occurrence: Two discontinuous ridges of seed, trending slightly east of north, occur on the main lake flat at 8 km and the other at 13.5 km east of Nalkain Siding. The westerly ridge rises to 9 m above the lake and is capped with 0.5–1.0 m of kopi. The other ridge to the east is slightly higher and has about the same thickness of capping kopi. Dirty compact kopi up to one metre in depth also covers most of this side of the lake and is sometimes underlain by up to one metre of seed forming small ridges.

Production and usage: 387 687 t to the end of 1991(Table 6) for use in the plaster and cement industries.

Estimated resources:

Seed — 1.2 to 1.5 million t of 94% purity (ridge or old dune);
seed/kopi — 1 million t of 80% purity (ridge/lake bed).

Sample results : See references.

Remarks: Tenements P70/453 and M70/174 cover the westerly ridge mentioned above. See also 'Cowcowing Lakes North' and 'Nalkain'.

Reference: de la Hunty and Low (1958); Chivas et al. (1991).

Relevant tenements: Prospecting Licence 70/453 and Mining Leases 70/137, 70/171–74, 70/264.

Cunderdin

Coordinates: 31°39' S, 117°18' E.

Location: North of the Great Eastern Highway, 6.4 km east of Cunderdin.

Nature of occurrence: Small intermittent lake covered with 5–50 cm of gypsum crystals up to 5 cm in length. These are densely packed in places and loose in others. Crystals are pink in colour due to iron impurities and some clay. Kopi dune near the southeast shore is covered with thick sand.

Estimated resources:

Seed — 7000 t of 80% purity (lake);
kopi — five t of 69% purity (dune).

Sample results : See reference.

Remarks: Possible agricultural value after grinding. See also 'Cunderdin East' and 'Cunderdin East-northeast'.

Reference: de la Hunty and Low (1958)

Cunderdin East

Coordinates: 31°38' S, 117°18' E.

Location: A little north of the Cunderdin deposit.

Nature of occurrence: Fine seed on the floor of a small clay pan with an average depth of 45 cm. Some clay and silt impurities. Small kopi dune to the southeast of the clay pan has one metre of seed overlain by one metre of kopi.

Production and usage: None reported. Small pit in dune.

Estimated resources:

Seed — 24 000 t of 89% purity (clay pan);

kopi/seed — small amount of 64% purity (dune).

Sample results : See reference.

Remarks: Deposit may have too much NaCl for agricultural uses. See also 'Cunderdin' and 'Cunderdin East-northeast'.

Reference: de la Hunty and Low (1958)

Cunderdin East-northeast

Coordinates: 31°36' S, 117°20' E.

Location: About 9.7 km east-northeast of Cunderdin on the Great Eastern Highway.

Nature of occurrence: On the southeast side of a small clay pan is a patch of 15 cm-thick seed, overlain by 3 cm of gypsum crystals; and two kopi dunes with an average height of less than 60 cm.

Estimated resources:

Seed — 1400 t of 90% purity (clay pan or old dune);

kopi — 1500 t of 90% purity (dune).

Sample results : See reference.

Remarks: Possible agricultural value. See also 'Cunderdin' and 'Cunderdin East'.

Reference: de la Hunty and Low (1958).

Damboring Lake

Coordinates: 30°33' S, 116°41' E.

Location: Approximately 10 km west-northwest of Ballidu Siding. Site coordinates taken from map in reference.

Nature of occurrence: Gypsum layer is found under a salt crust on the smaller Damboring Lake.

Estimated resources: Unknown.

Reference: Chivas et al. (1991).

Elphin Siding

Coordinates: 30°50'52" S, 116°35'22" E.

Location: 8.5 km west of Elphin Siding or 14 km northwest of Wongan Hills.

Nature of occurrence: Unknown.

Production and usage: 3714 t mined to the end of 1988 (Table 6) probably for use in agriculture.

Estimated resources: Unknown.

Remarks: Gypsum mining tenement, no details.

Relevant tenement: Mining Lease 70/012.

Gunyidi

Coordinates: 30°07' S, 116°17' E.

Location: 22.5 km east of Gunyidi on a gravel road.

Nature of occurrence: Kopi, with clay impurities, about 15 cm thick in banks (?ridges).

Production and usage: None reported.

Estimated resources: Occurrence only.

Sample results :

Gypsum	90.00%
insoluble in water	8.50%.

Remarks: Referred to as 'Marchagee East' in reference. See also 'Pinjarrega Lake'.

Reference: de la Hunty and Low (1958).

Hines Hill

Coordinates: 31°31'15" S, 118°04'49" E.

Location: From just north, to about 2 km north, of Hines Hill townsite.

Nature of occurrence: Seed, crystals, and kopi and granular gypsum occur in association with several clay pans. Dunes, ridges, islands, and surface deposits have been described in the references.

Production and usage: 2743 t (worth $4762) produced from 1924 to 1928, 16 325 t (worth $25 176) from 1949 to 1957, and 30 260 t (worth $89 148) from 1983 to 1990 for use in the plaster and cement industries. Table 6 gives the combined production and value data for the two producers in the Hines Hill area.

Estimated resources:

Seed — 15 000 t of 85% purity (dune);
seed/granular — 20 000 t of 95% purity (dune);
seed — 20 000 t of ?80% purity;
seed/kopi/crystals — 20 000 t of 71% purity (bank/dune, samples G123–124);
seed — 16 000 t of 59% purity (dune, samples G116–117);
kopi/granular — 3000 t of 94% purity (dune);
crystals — 700 t of ?85% purity.

Sample results : See Table 5 of de la Hunty and Low (1958).

Remarks: Tenement M70/055 probably covers the area sampled as G116 and 117, and tenement M70/294 probably covers the area sampled as G123 and 124. See also 'Hines Hill North–northeast'.

Reference: de la Hunty and Low (1958).

Relevant tenements: Mining Leases 70/006, 70/055, 70/293, 70/294.

Hines Hill North-northeast

Coordinates: 31°24'45" S, 118°04'46" E.

Location: About 14 km north of Hines Hill townsite.

Nature of occurrence: A small clay pan has a very small bank of impure seed at its southeast edge.

Production and usage: 29 125 t with a reported value of $54 301 for 1957–73, and 6580 t worth $39 480 for 1989–90 (Table 6).

Remarks: Mining tenement M70/331 covers the deposit referred to by de la Hunty and Low as 'Hines Hill (North)'. See also 'Hines Hill North' and 'Baandee North'.

Reference: de la Hunty and Low (1958).

Relevant tenements: Mineral Claim 485H and Mining Lease 70/331.

Hines Hill North

Coordinates: 31°23' S, 118°03' E.

Location: About 17.5 km north of Hines Hill townsite.

Production and usage: 320 t in 1987.

Remarks: Gypsum prospecting tenement, no details. See also 'Hines Hill North-northeast' and 'Burran Rock South'.

Relevant tenement: Prospecting Licence 70/652.

Jilakin Lake

Coordinates: 32°41' S, 118°23' E.

Location: About 21 km east of Kulin townsite.

Nature of occurrence: Reported occurrences of surface deposits, small dunes, and crystals of gypsum from several small lakes 1 to 7 km southeast of Jilakin Lake.

Sample results : Some samples were submitted by Mr A.G. Carmody, Kulin, from this locality in 1987. The results are given in Table 11.

Remarks: The author made brief visits to several localities and was unable to identify any gypsum deposits.

Table 11. Analytical results for gypsum samples from Jilakin Lake

	Sample	$CaSO_4.2H_2O$	*NaCl*	*MgO*	SiO_2	Al_2O_3
K2/No. 1	Near fence and road	82.6	0.64	0.56	13.40	2.20
K2/No. 2	Jack No. 1 ram paddock	86.0	1.64	0.76	7.48	4.61
K2/No. 3	Jack No. 2 near lake	96.0	0.04	0.97	2.05	0.79
K2/No. 4	Pits — Lucchesi No. 7	86.2	0.10	0.48	11.50	1.54
K2/No. 5	Lucchesi — near fence in lake	99.1	0.36			
K2/No. 6	On bank — near No. 5	94.0	0.23	0.99	4.29	0.41

Note: Results provided by Mr A. G. Carmody, Kulin

Kellerberrin

Coordinates: 31°41' S, 117°41' E.

Location: 8 km south of Kellerberrin.

Nature of occurrence: Hard, buckled mat of crystals 5 cm thick on lake. Seed on a dune is 30 cm thick and overlies kopi and coarse sand. Dune becomes sandy at 1.5 m.

Production and usage: 150 t to the end of 1974 (Table 6), probably used in the agriculture and/or plaster industries.

Estimated resources:

Crystals — 1000 t of 93% purity (lake);
seed — 6400 t of 81% purity (dune).

Sample results : See de la Hunty and Low (1958).

Remarks: See also 'Woolundra'.

Reference: de la Hunty and Low (1958).

Kondinin

Coordinates: 32°34'45" S, 118°24'15" E.

Location: 16 km southeast of Kondinin railway station.

Nature of occurrence: Three small dunes, one of seed and two of kopi underlain by granular gypsum, form this deposit. The seed dune reaches 1.2 m in height whereas the kopi/granular dunes reach 1 m (northern dune) and 1.5 m (southern dune) in height.

Production and usage: 9681 t (Table 6), probably for agricultural uses.

Estimated resources:

Kopi/seed — 9000 t of 83% purity (dune);
kopi/seed — 118 000 t of 84% purity (dune);
seed — 35 000 t of 71% purity (dune).

Sample results : See de la Hunty and Low (1958).

Reference: de la Hunty and Low (1958).

Relevant tenement: Mining Lease 70/04.

Koorda

Coordinates: 30°45'07" S, 117°24'24" E.

Location: 50 km north of Wyalkatchem.

Nature of occurrence: Seed gypsum overlain by kopi is found in a dune 800 m long by 40 m wide on the southeast shore of a salt lake.

Production and usage: 5000 t extracted in 1988 for agricultural purposes (Table 6).

Relevant tenement: Mining Lease 70/229.

Koorda Southwest

Coordinates: 30°51' S, 117°29' E.

Location: 3.2 km southwest of Koorda townsite.

Nature of occurrence: Gypsum crystals reaching 5 cm in length, 1.5 cm in width, and 5 cm in thickness are found on the bed of a lake.

Production and usage: 6559 t reported to the end of 1929 (Table 6), used for plaster production.

Estimated resources: Crystals — 100 t or more.

Remarks: Deposit exhausted in 1929. In 1921–22, the only source of gypsum in Western Australia. See also 'Koorda Northwest', 'Cowcowing Lakes' and 'Lake Wallambin'.

Reference: de la Hunty and Low (1958).

Koorda Northwest

Coordinates: 30°44' S, 117°21' E.

Location: 16 km northwest of Koorda.

Nature of occurrence: 1.3 m of seed underlies 0.3 m of kopi on this lake.

Estimated resources: Seed — 6000 t of 80% purity (lake).

Sample results : See reference.

Reference: de la Hunty and Low (1958).

Relevant tenement: Mining Lease 70/241.

Lake Annean

Coordinates: 26°52' S, 118°17' E.

Location: From the map in the reference, it appears to be on the north-central shore of the lake.

Nature of occurrence: Gypsum in lake sediments beneath 2–6 cm of playa sediments.

Estimated resources: Unknown.

Reference: Chivas et al (1991).

Lake Austin

Coordinates: 27°37' S, 117°53' E.

Location: 50 km north of Mt Magnet on the Great Northern Highway.

Nature of occurrence: Kopi (5 cm) overlies seed gypsum (0.5–1 m) on the lake surface. Ridges on the lake (25–125 cm thick) are composed of: kopi/soil; then a cemented gypseous crust; which is underlain by fine-medium, off-white seed gypsum. Dunes, capped with kopi, occur sporadically along the southern shore, rising from 3–10 m above the lake bed. One prominent dune is exposed in a road cutting for the Great Northern Highway close to the northern margin of the lake. Figure 5 gives details of a measured section and channel sample from one of these shoreline dunes.

Production and usage: None reported. Some local extraction for road surfacing material has taken place.

Estimated resources: Unknown.

Sample results: Analytical results of three samples collected by the author from location 27°34' S, 117°46'20" E, are given in Appendices 1 and 2. See also Figure 5. Blockley and Driessen (1962) reported partial analyses for two samples cut from dunes on the surface of Lake Austin. Calculated gypsum contents were 89% and 83% respectively, whereas Na and Cl results indicate levels of about 0.7% and 8.4% salt.

Remarks: References indicate possible NaCl problems. The above data are summarized from the references and the author's brief inspection in October 1989.

References: de la Hunty and Low (1958); Blockley and Driessen (1962); Chivas et al. (1991).

Lake Baladjie

Coordinates: 30°58' S, 118°55' E.

Location: Just north of Baladjie Siding.

Nature of occurrence: A thickness of 5 cm of gypsum crystals found under a salt crust on a lake.

Production and usage: None reported.

Remarks: No apparent economic value. Also referred to as 'Lake Deborah'.

Reference: de la Hunty and Low (1958).

Lake Brown

Coordinates: 31°05'39" S, 118°18'30" E.

Location: About 20 km northeast of Elabbin Siding.

Nature of occurrence: Major occurrence is on the lake floor, and is up to 1.5 m thick. Seed dunes also occur along the southeast shore of the lake, up to 15 m in height. These dunes, which are contaminated with quartz sand, have a surficial covering of kopi.

Production and usage: Includes 564 120 t produced between 1935 and 1991 for plaster. To 1992, a total of 60 269 t have come from the lunette, and 716 182 t from the playa lake floor. Mining is currently from the lake bed.

Estimated resources: Seed — 3.4 Mt of 90–95% purity (dunes). Lake floor resources unknown, but economically significant.

Sample results: See de la Hunty and Low (1958); Freeman (in prep.).

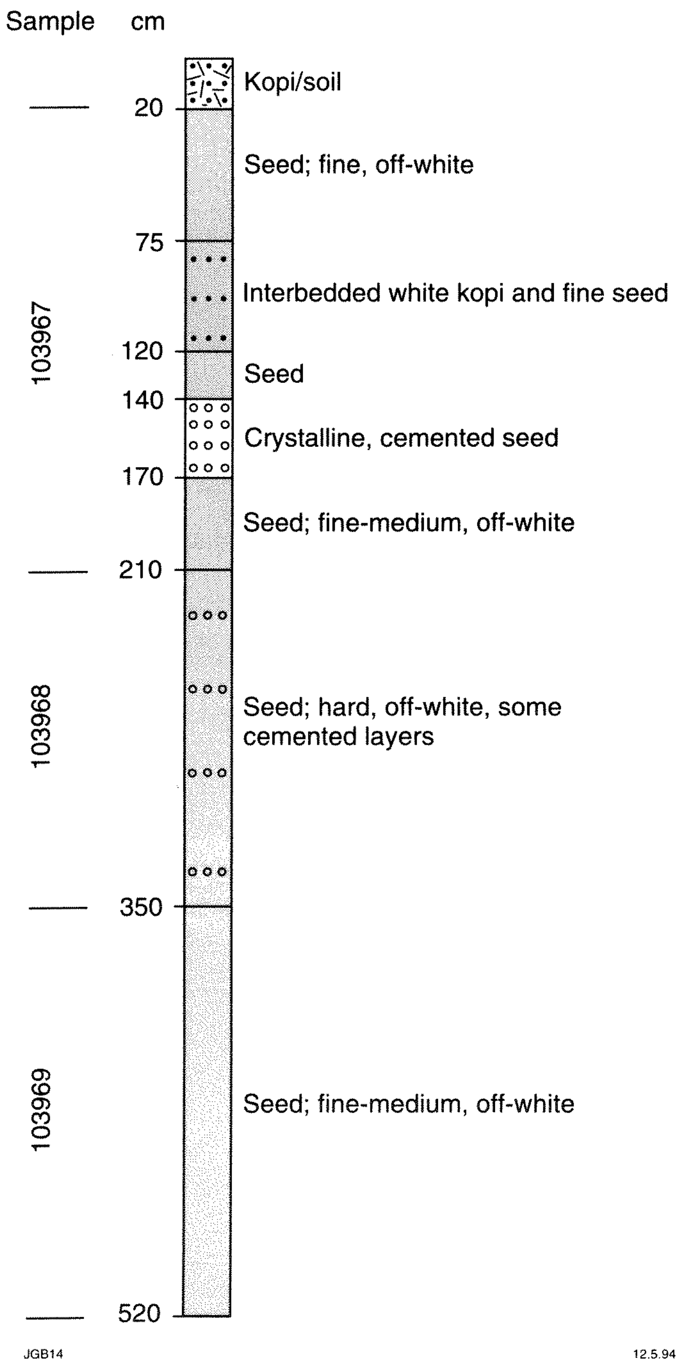


Figure 5. Measured section and sample intervals, Lake Austin

Remarks: The lake floor provides excellent material for plaster manufacture. Tenement M77/41 covers most of the resource. See also 'Lake Campion' and 'Chandler'.

References: de la Hunty and Low (1958); Chivas et al. (1991); Freeman (in prep.).

Relevant tenements: MC 51–52H, M77/41. For further details see Freeman (in prep.).

Lake Buchan

Coordinates: 33°09' S, 119°05' E.

Location: About 5 km south-southeast of Newdegate townsite.

Nature of occurrence: On the southeast shore of Lake Buchan are dunes and samphire flats containing gypsum. A belt of seed dunes on the edge of the lake reaches 2.7 km in length, 100 m in width, and averages 1.5 m in height. Immediately southeast of the dunes is a flat with 5 cm of kopi overlying 45 cm of seed. A second flat further southeast has 45 cm of kopi overlying 1.2 m of seed. A third, smaller flat, to the north, contains 75 cm of seed overlain by 45 cm of kopi.

Production and usage: None reported.

Estimated resources:

Seed — 129 000 t of 82% purity (dune);
seed/kopi — 210 000 t of 60% purity (first flat) (the seed alone averages 70%);
seed — 310 000 t of 78% purity (second flat).

Sample results: See de la Hunty and Low (1958).

Reference: de la Hunty and Low (1958).

Lake Burkett

Coordinates: 33°06'06" S, 119°02'30" E.

Location: 50 km east of Lake Grace.

Nature of occurrence: Gypsum on a lake bed.

Relevant tenement: Mining Lease 70/246.

Lake Camm

Coordinates: 32°59'17" S, 119°33'03" E.

Location: About 5.7 km southwest of Lake Camm townsite on the southern end of Lake Camm.

Nature of occurrence: Several low dunes, 1–1.5 m high, occur on this lake. They are composed of 0–0.5 m of sand or soil overlying 1–1.5 m of fine to coarse seed gypsum. A small mining operation was removing this seed gypsum down to the watertable at the time of inspection (1990).

Production and usage: 6790 t produced between 1988 and 1991 (Table 6), probably for local agricultural use. Remaining resources may reach 4000–5000 t.

Estimated resources: Unknown.

Sample results: A sample supplied by Messrs. A. R. and K. J. Hewson was found to contain:

CaO	26.0%
SO_3	38.4%
Cl	0.18%
LOI	19.8%
Moisture	2.34% (45° C)
SiO_2	10.0%

On a dry basis, these results indicate 82.0% gypsum, 0.3% salt, and +10% quartz. Analytical results of one gypsum sample collected by the author are also given in Appendices 1 and 2 (Sample No 103986; location 32°59' S, 119°33' E).

Remarks: Mining tenement, but few details. The author visited the deposit in May 1990.

Relevant tenement: Mining Lease 70/208.

Lake Campion Nature Reserve

Coordinates: 31°09' S, 118°25' E.

Location: 6.5 km south of Chandler townsite.

Nature of occurrence: Small clay pan with belts of dunes in the southeast quadrant. Seed gypsum reaches 6 m in height. Covered by M77/2 and M77/21.

Production and usage: Between 1984 and 1990 10 257 t were mined from M77/2.

Estimated resources: A total resource of 6 Mt occurs in and adjacent to the Reserve. Within this, an unnamed lake (7.5 km south of Chandler) has 190 000 t at 95% purity on former M77/2 and M77/21; Wolfe Lake, 6.5 km south of Chandler (de la Hunty and Low, 1958, Plate II), has 230 000 t.

Sample results : See Freeman (in prep.).

Remarks: There are about forty lakes within the Nature Reserve, many with gypsum potential. See also 'Chandler' and 'Lake Brown'.

Reference: de la Hunty and Low (1958); Freeman (in prep.).

Relevant tenements: Mining Lease 77/2 and M77/21.

Lake Chidnup

Coordinates: 33°22' S, 119°53' E.

Location: 29 km northwest of Ravensthorpe on the north side of the Perth road.

Nature of occurrence: Specimens only of seed and clay–kopi.

Production and usage: None reported.

Estimated resources: Virtually none, occurrence only.

Reference: de la Hunty and Low (1958).

Lake Cobham

Coordinates: 33°26'33" S, 119°16'48" E.

Location: 6 km east of Lake Magenta or 38 km northwest of Fitzgerald townsite.

Nature of occurrence: Medium seed gypsum up to one metre thick occurs on the lake bed, underlain by a grey sand and overlain by one metre of kopi and soil. A thin horizon containing *Coxiella* shells is located roughly centrally in the gypsum layer.

Production and usage: 14 828 t produced between 1984 and 1990 (Table 6), probably for local agricultural use.

Estimated resources: Unknown.

Sample results : Analytical results of one gypsum sample collected by the author are given in Appendices 1 and 2 (Sample 103985; location 33°26'42"S, 119°17'15"E). Chivas et al (1991) also sampled the kopi and gypsum on the lake.

Remarks: Mining tenements cover the centre and southern portions of the lake, but no details are known. The author briefly visited this deposit in May 1990. See also 'Lake Magenta'.

Reference: Chivas et al. (1991).

Relevant tenements: Prospecting Licences 70/123–125, 70/114, Mining Leases 70/219, 70/273, 70/274, 70/600–601.

Lake De Courcy

Coordinates: 30°16' S, 117°08' E.

Location: 4 km northwest of Lake Hillman.

Nature of occurrence: Two old dunes on or near the western side of this lake contain kopi and seed gypsum. They trend northeasterly and are parallel to the dunes on nearby Lake Hillman. The smaller dune, closest to the shoreline, rises 2–3 m above the surrounding lake bed and the larger dune rises 3–8 m above the lake bed. One hand-auger hole was drilled by the author to obtain samples in the smaller dune. Figure 6 illustrates the interbedded kopi and gypsum and indicates the thicknesses sampled.

Production and usage: None reported.

Estimated resources: Unknown.

Sample results : Analytical results of four gypsum samples collected by the author are given in Appendices 1 and 2.

Remarks: Author briefly visited this deposit in May 1990. See also 'Lake Goorly' and 'Lake Hillman'.

Lake Goorly

Coordinates: 29°59'24" S, 117°01'07" E.

Location: Southeast end of Lake Goorly.

Nature of occurrence: Up to 60 cm of kopi overlies up to one metre of seed in a samphire flat. On the east bank of Lake Goorly there is 60 cm of crystals/seed overlain by 15 cm of dirty kopi.

Production and usage: 20 916 t produced from 1988 to 1991 (Table 6) probably for agricultural use.

Estimated resources:

Seed — 500 000 t of 85% purity (flat);
kopi/crystals — 200 000 t of 70% purity (bank).

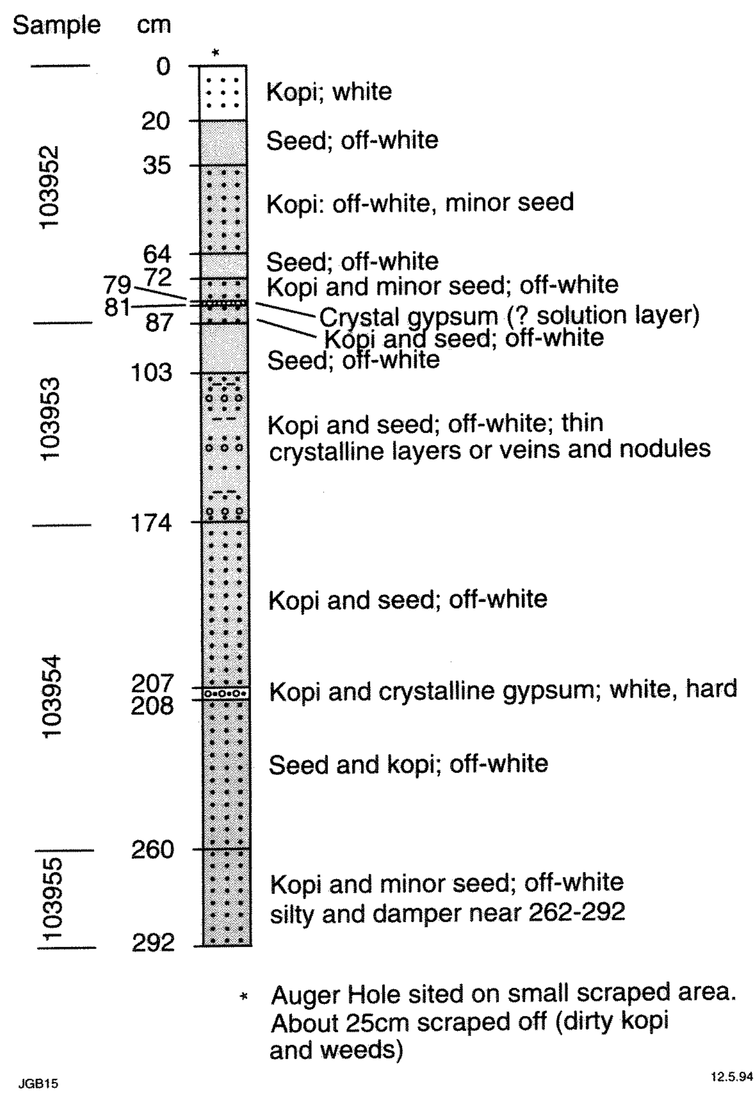


Figure 6. Measured section and sample intervals, Lake De Courcy (lat. 30°17'24"S; long. 117°07'56"E)

Sample results: See reference.

Remarks: Referred to as 'Wubin Downs' in reference. Possible NaCl problems.

Reference: de la Hunty and Low (1958).

Lake Grace

Coordinates: 33°15' S, 118°28' E.

Location: Twenty-four km south of Lake Grace townsite on the southeast shore of Lake Grace South. Gypsum has also been investigated by CSIRO and Kalgoorlie School of Mines (1975) from the lake bed near the northwest end of Lake Grace North (south of railway line).

Nature of occurrence: Minor deposits of seed with dirty kopi were observed in small ridges and dunes near clay pans in this area. Chivas et al (1991) sampled gypsum from the lake sediments.

Production and usage: None reported, though apparently there has been unauthorized extraction of some hundreds of tonnes of seed gypsum from low dune ridges within the Nature Reserve (pers. comm., Freeman, M. J., 1994).

Estimated resources: Ridges of seed, possibly containing thousands of tons.

Sample results : Kopi mixed with clay was found in small dunes. The seed was fairly clean.

Remarks: CSIRO and Kalgoorlie School of Mines (1975) have jointly investigated the deposits from Lake Grace North to determine optimum methods for the recovery and treatment of gypsum from the lake surface to a depth of 1.4 m.

References: de la Hunty and Low (1958); CSIRO and KSM (1975); Chin and Brakel (1986); Chivas et al. (1991), Patterson and Shiner, (1993).

Lake Gulson

Coordinates: 32°49'19" S, 119°27'51" E.

Location: About 4 km west by south of Varley townsite.

Nature of occurrence: Gypsum occurs in low dunes and ridges on the southeast shore of a small lake southeast of Lake Gulson and west of Varley. A typical dune comprises 0–0.3 m of sand/silt overlying 0.2–0.5 m of kopi/fine seed gypsum, which is then underlain by 0.3–1.0 m of fine to medium seed gypsum (down to the watertable).

Production and usage: 17 126 t produced from 1985 to 1991 (Table 6), probably for agricultural use.

Estimated resources: Unknown.

Sample results : Analytical results of one gypsum sample collected by the author are given in Appendices 1 and 2. This sample was of the 0.95 m of fine to medium seed gypsum immediately above the watertable in the small operating pit in a low dune. Sample 103987; location 32°49'01" S, 119°28'42" E.

Relevant tenements: Mining Leases 70/56, 70/256.

Lake Harvey

Coordinates: 30°19' S, 117°33' E.

Location: Just east of the southern tip of Lake Moore.

Nature of occurrence: Small island of seed gypsum, approximately 20 cm thick, which appears to be eroding or dissolving away. Lake Moore, on the other side of the dirt track, has many small seed islands and ridges which appear to be growing. These are mostly wet due to capillary action.

Estimated resources: Negligible.

Remarks: See Lake Moore for location.

Lake Hillman

Coordinates: 30°20' S, 117°10' E.

Location: About 6 km northeast of Kalannie townsite.

Nature of occurrence: Seed gypsum, capped by kopi, has been deposited on the lake bed, in two large dunes on the lake, and in ?old dunes or ridges along the south shore of the lake. Lake bed deposits typically comprise 1–2 m of seed gypsum, underlain by clay and overlain by kopi or soil up to one metre thick. The two northeast–trending dunes near the centre of the lake rise 2–10 m above the lake bed. They are composed principally of seed gypsum, capped by kopi or soil, and they contain the bulk of the resources. Along the south and southeast shore are some small ridges or ?old dunes. These ridges vary between 1 and 3 m in height and are composed of seed gypsum, with some interbedded sand, capped with kopi or soil. Clay, underlying the seed gypsum, is usually found at about the same level as the watertable. An inactive pit on watertable. An inactive pit on ML 70/77 in one of these ridges exposed a thin, conformable layer of *Coxiella* shells in the seed gypsum about one metre above the watertable. Carbon samples (mainly roots) were also obtained from within the seed gypsum in this pit and the radiocarbon dating results are discussed above (see *Distribution, origin and age of deposits*).

Production and usage: 312 299 t produced from 1977 to 1991 (Table 6) for the cement, plaster, and agricultural industries.

Estimated resources:

Seed — 1 000 000 t of +95% purity (dunes, ridges, and lake bed);
kopi — ?100 000 t of 80–95% purity (dunes, ridges, and lake bed).

Sample results : Analytical results of eight gypsum samples collected by the author are given in Appendices 1 and 2. Analyses of two lake-surface salt samples and one clay sample, found beneath the gypsum in this deposit, are also given in Appendix 2. Sample locations are shown in Figure 7.

Remarks: Prospecting and mining tenements cover most of the economically recoverable resources. The author briefly visited this deposit in October 1989. See also 'Lake De Courcy'.

Relevant tenements: Prospecting Licences 70/170 and 70/171, and Mining Leases 70/76–77, 70/170–171, 70/216, 70/248, 70/315, 70/319, 70/342.

Lake Julia

Coordinates: 31°02' S, 119°22' E.

Location: About 24 km north of Southern Cross townsite.

Nature of occurrence: Clean, flat lenses of pale brown, saccharoidal gypsum, are overlain by a surface layer of dirty gypsum and underlain by clayey gypsum which grades rapidly into lake mud. The average thickness is about 0.6 m, but may be up to 3 m in dunes on the eastern side of the lake.

Production and usage: None reported. Possible plaster and agricultural uses.

Estimated resources: Seed — 1 100 000 t of 90% purity (dune).

Sample results : Shown in Table 1 of reference, samples A, C, G, J, K, and M.

Remarks: Only company data are available.

Reference: Katanning Holdings Limited (1973).

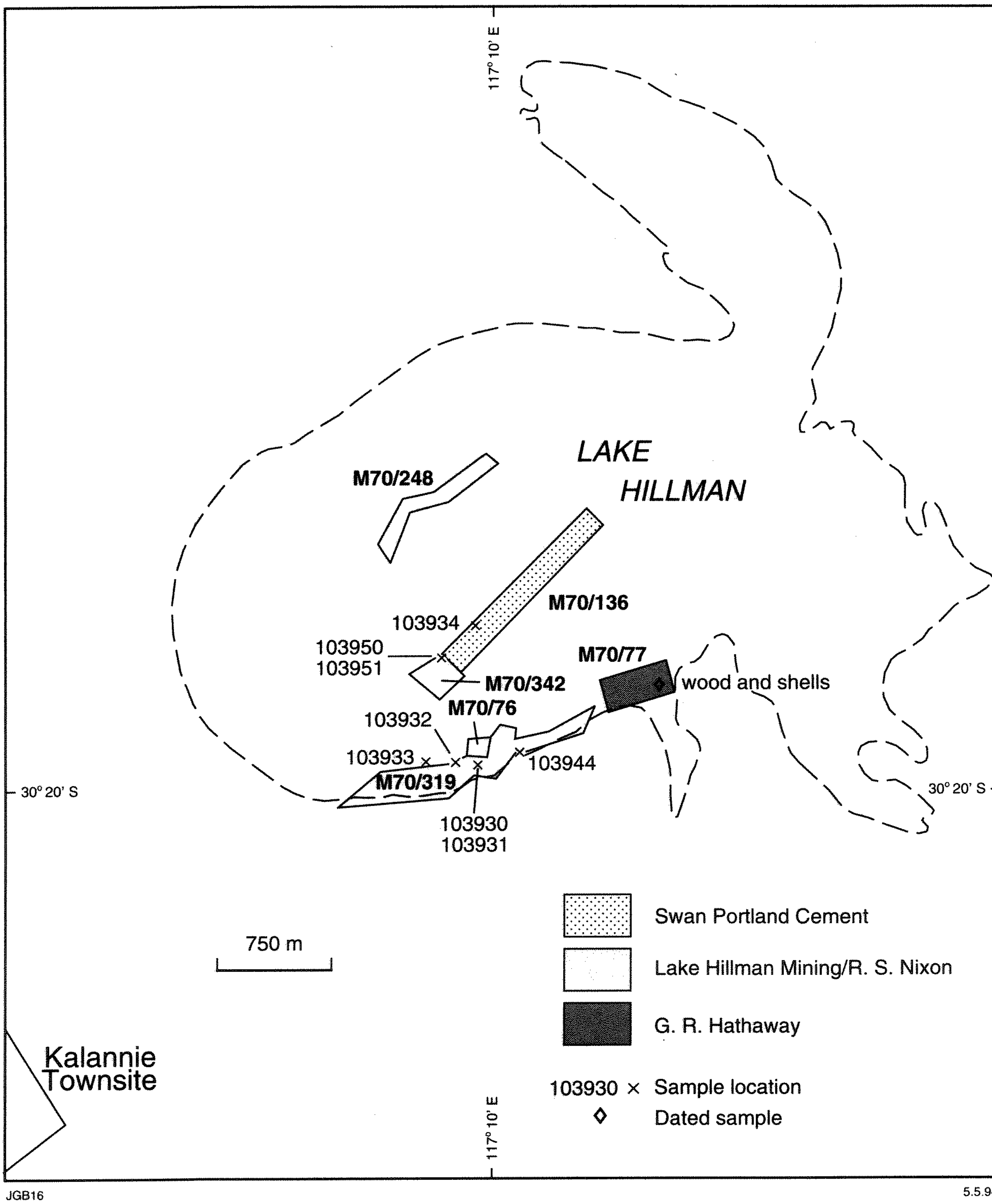


Figure 7. Sample locations and tenement holdings, Lake Hillman

Table 12. Analytical results for Lake Julia gypsum samples

Sample No.	*Sample description*	*CaO*	SO_3	*Gypsum**	*NaCl*	*Insoluble*	*950°C LOI*
				percentage			
A	Fairly clean gypsum; pit 2	26.5	42.0	81.3	0.8	3.1	21.3
B	Surface dirty gypsum; pit 4	28.0	40.5	85.9	5.77	1.0	23.5
C	Clean gypsum, pit 4	25.5	42.2	90.5	1.24	0.5	21.8
D	Surface dirty gypsum; pit 5	26.2	38.6	80.4	4.94	8.4	22.5
E	Lake surface mud zone with selenite crystals; pit 5	17.2	25.0	52.7	4.12	34.3	22.2
F	Surface layer, pit 6	16.9	18.3	51.8	4.12	30.3	21.5
G	Clean gypsum; pit 6	28.7	41.3	88.0	0.8	2.6	21.1
H	Surface layer; pit 7	25.6	39.4	78.5	5.77	5.4	23.7
I	Clean gypsum; pit 7	23.2	40.3	71.2	1.65	8.0	21.4
J	Cemented gypsum layers and nodules; pit 8	29.0	43.5	89.0	0.8	0.2	21.8
K	Surface fairly clean gypsum, pit 8	29.0	42.7	89.0	0.5	1.9	22.9
L	Gypsum with impurities; below sample K; pit 8	26.2	41.1	80.4	1.65	1.1	21.7
M	Moderately clean gypsum; pit 9	27.1	42.9	86.0	0.8	1.8	21.3
N	Selenite crystals in lake surface clay; pit 8	18.7	32.2	57.3	3.30	18.9	20.9

* Calculated from CaO
Source: Katanning Holdings Ltd (1973)

Lake Kathleen

Coordinates: 32°59' S, 119°42' E.

Location: 14.5 km north of Lake King townsite and east of the Hyden–Ravensthorpe road.

Nature of occurrence: Seed about 35 cm thick occurs on the southeast part of the lake under about 30 cm of kopi/clay. Seed dunes on the nearby bank contain up to 2.5 m of seed overlain by 60 cm of kopi. Other dunes in the belt farthest from the lake contain seed under kopi or are composed of kopi/granular gypsum.

Production and usage: None reported. Selective mining is possible for plaster, cement, or agricultural uses.

Estimated resources:

Seed — 660 000 t of 84% purity (lake);
seed — 200 000 t of 77% purity (dune);
seed — 190 000 t of 73% purity (lake);
kopi/seed — 90 000 t of 50% purity (other dunes).

Sample results : See published reference.

Remarks: Above data summarized from de la Hunty and Low (1958). Good potential for selective mining for specific uses.

References: de la Hunty and Low (1958); Ucabs (1986, 1987).

Relevant tenement: Exploration Licence 70/207.

Lake King

Coordinates: 33°07' S, 119°37' E.

Location: About 7.5 km west of Lake King townsite on the Newdegate road.

Nature of occurrence: Kopi and fine seed gypsum up to 0.5 m thick on the lake bed, and ridges and dunes of fine seed gypsum up to 1.5 m thick, capped by kopi, in the east and southeast portions of the lake.

Production and usage: None reported.

Estimated resources: Unknown.

Sample results : Analytical results of two gypsum samples collected by the author are given in Appendices 1 and 2. The first sample, 103981, was collected on the lake bed and the second sample, 103980, was taken from a small pit being worked on Mining Lease 70/348. Sample locations are 33°05'30" S, 119°35'11" E, and 33°05'35" S, 119°33'42" E respectively.

Remarks: Prospecting, exploration, and mining tenements, but no details available. The author briefly visited the deposit in May 1990.

References: Chivas et al. (1991); Ucabs (1986, 1987).

Relevant tenement: Mineral Claim 70/937; Mineral Lease 70/599, Prospecting Licences 70/93–94, 70/221; Exploration Licences 70/202, 70/206, 70/207; and Mining Leases 70/234, 70/347, 70/348.

Lake Kurrenkutten

Coordinates: 32°16' S, 118°05' E.

Location: 13 km southeast of Bilbarin Siding.

Nature of occurrence: Small amount of seed and some clay–kopi banks on the eastern shores of the lake.

Production and usage: None reported.

Estimated resources: Occurrence only.

Reference: de la Hunty and Low (1958).

Lake McDermott

Coordinates: 30°49' S, 117°55' E.

Location: South end of Lake McDermott and north of the Great Eastern Highway.

Nature of occurrence: Several clay pans contain small occurrences of seed, kopi, and clay containing gypsum crystals.

Production and usage: 271 t produced in 1947 (Table 6), probably for plaster production. Possible agricultural uses now.

Estimated resources:

Seed — 1 200 t of 80% purity (dune);
seed — 78 000 t of 60–65% purity (clay pan and dune);
seed — 146 000 t of 34–40% purity;
kopi/seed — 180 000 t of 48% purity.

Sample results : Brown (1984) reported on seven samples from four localities. Grades ranged from 70% to 98% $CaSO_4.2H_2O$. Earlier results are given in de la Hunty and Low (1958).

Remarks: The deposit has also been referred to as 'Marshall Rock' (de la Hunty and Low, 1958), and 'Welbungin'.

References: de la Hunty and Low (1958); Brown (1984).

Lake Magenta

Coordinates: 33°24' S, 119°12' E.

Location: About 39 km southeast of Newdegate on the northeast shore of the lake.

Nature of occurrence: Kopi and ?seed gypsum on the lake bed and several kopi-capped fine seed gypsum dunes on the north end of the lake. These dunes rise 4–5 m above the lake bed. Figure 8 shows the typical composition of these dunes.

Production and usage: None reported.

Estimated resources: Unknown.

Sample results: Analytical results of three gypsum samples collected by the author are given in Appendices 1 and 2 (location 33°24'47" S, 119°11'30" E).

Remarks: Mining tenement, but no details. The author briefly visited this deposit in May 1990.

Reference: Chivas et al. (1991).

Relevant tenement: Mining Lease M70/134.

Lake Moore

Coordinates: 30°10' S, 117°32' E.

Location: West of Mouroubra and Remlap homesteads.

Nature of occurrence: Seed, overlain by kopi, covers most of the eastern half of the lake. It grades into clay at shallow depth. Kopi overlies significant thicknesses of seed in places along the central-eastern and northeastern shore. These deposits appear to be dunes but may be residual lacustrine sediments. Figure 9A gives details from a hand-auger drill hole and Figure 9B illustrates a measured section; both sections are from shoreline gypsum deposits.

Production and usage: None reported.

Estimated resources: An inferred resource of 150 Mt was estimated by Kid Mining Pty Ltd in 1987, comprising:

100 Mt of seed gypsum; and

50 Mt of kopi and rock gypsum.

Sample results : Analytical results of nine gypsum samples collected by the author are given in Appendices 1 and 2. Locations of these and other sightings of gypsum are shown in Figure 10.

Remarks: Exploration tenements cover the deposit but no details are available. The author briefly visited this deposit in October 1989. The deposits were noted by Lipple et al. (1983).

References: Chivas et al. (1991); Kid Mining (1987); Lipple et al. (1983).

Relevant tenement: Exploration Licences 59/065, 59/066, 59/067.

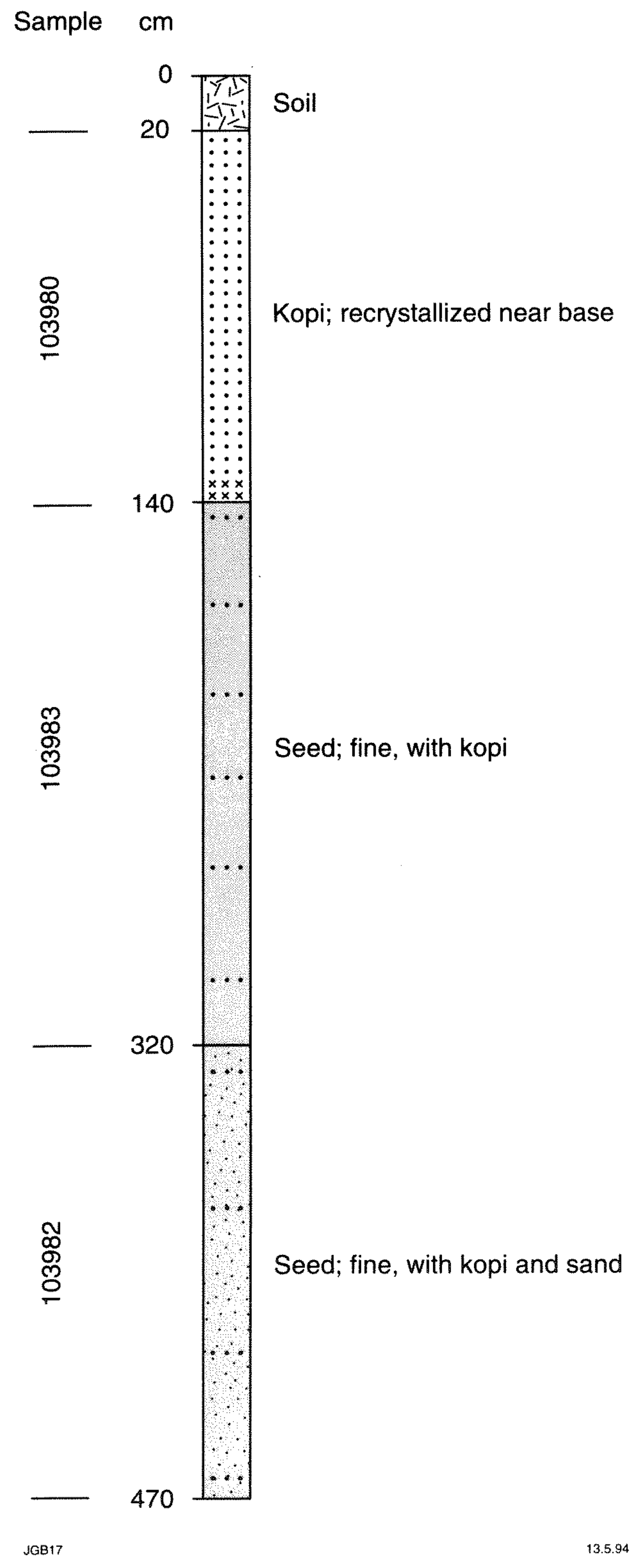


Figure 8. Measured section and sample intervals, Lake Magenta

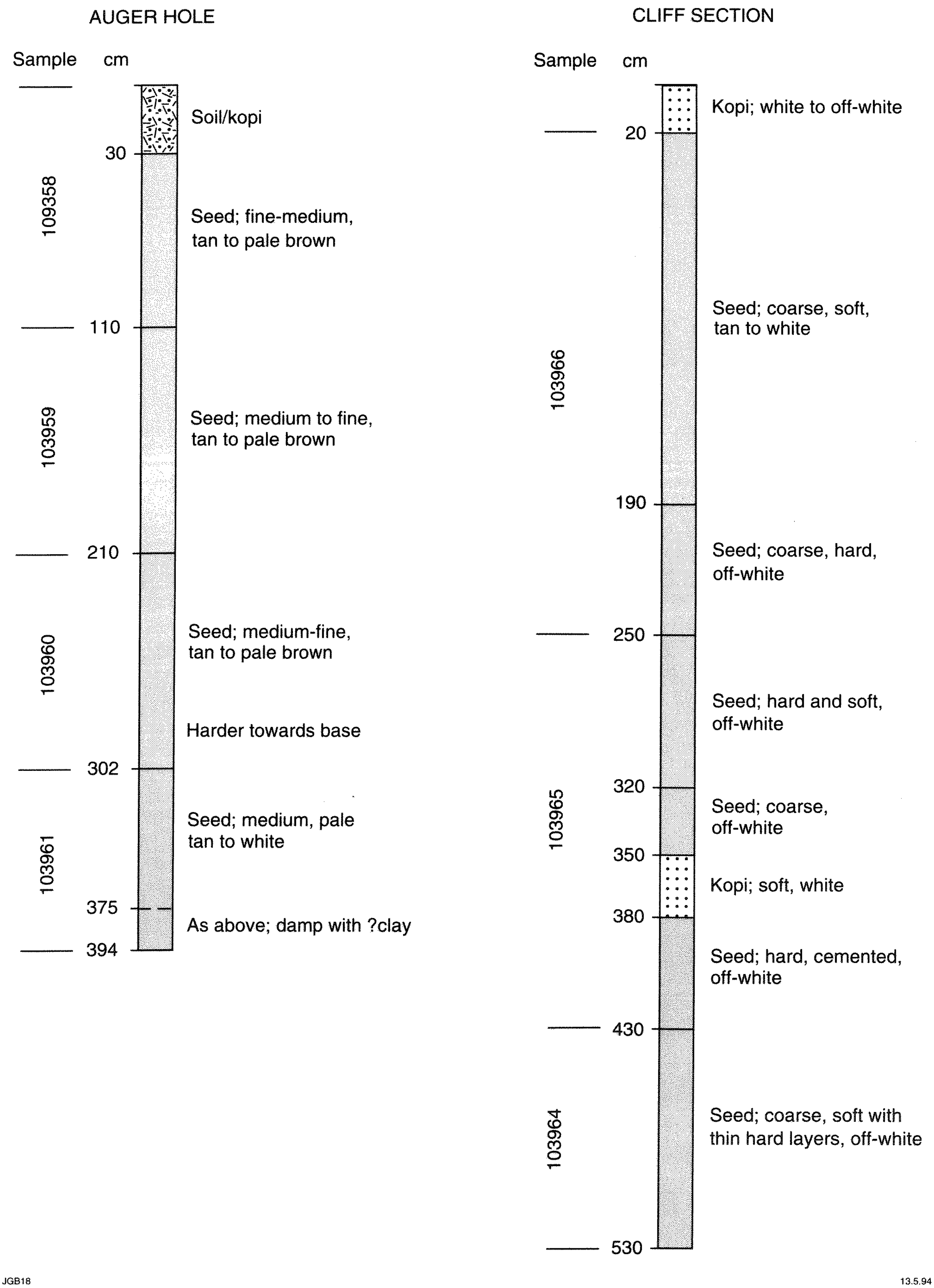


Figure 9. Measured sections and sample intervals, from an auger hole and cliff section, Lake Moore (see Fig. 10 for locations)

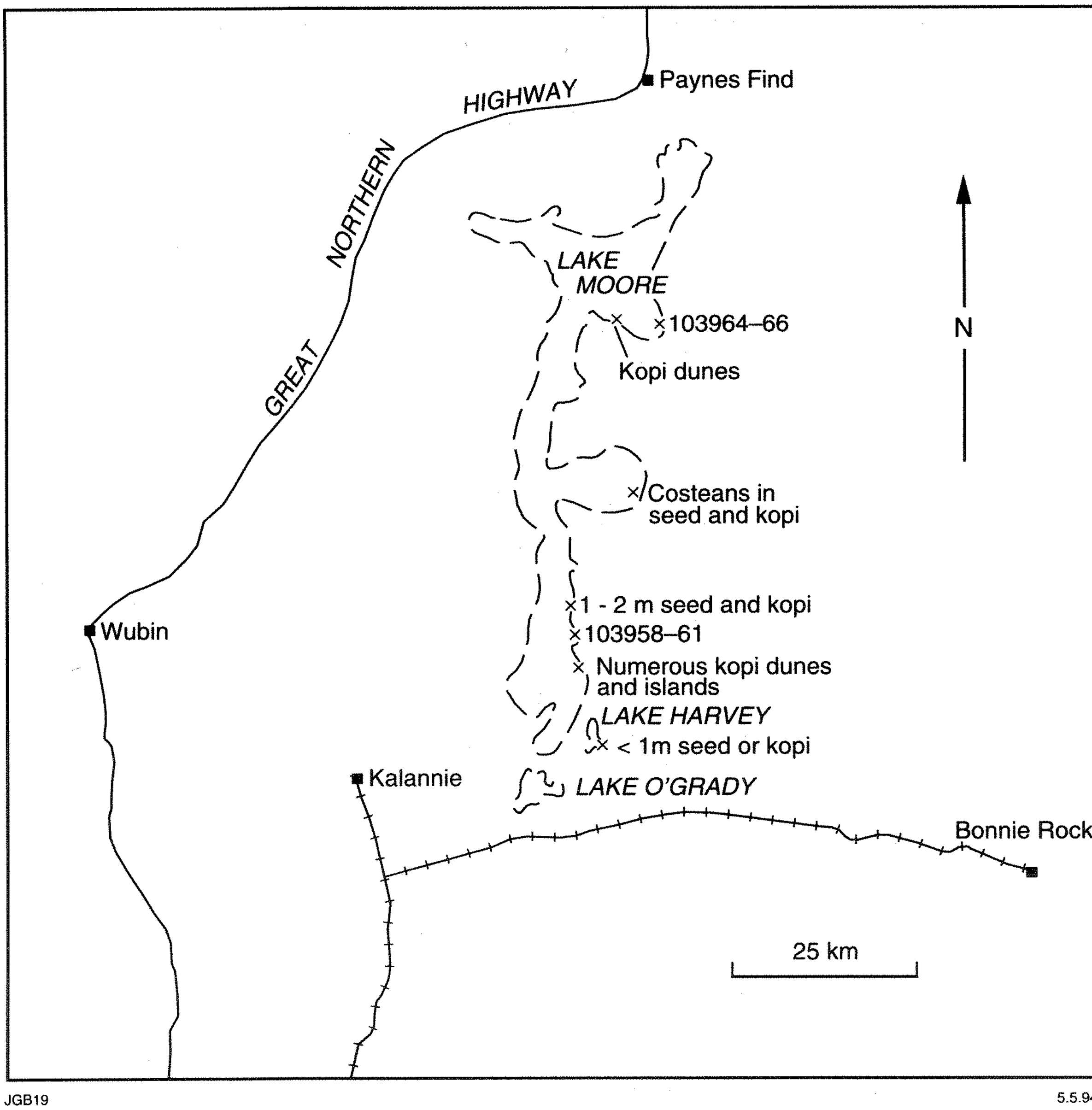


Figure 10. Sample locations and gypsum occurrences, Lake Moore and Lake Harvey

Lake Seabrook

Coordinates: 30°59' S, 119°38' E.

Location: About 35 km north of Yellowdine townsite.

Nature of occurrence: Seed dunes occur over an area 5 km long and of variable width on the western edge of a peninsula which extends northwards into the lake. The height of each dune varies from 0.3 m to 6 m and the width varies from 100 m to 500 m. A layer, up to 30 cm deep, of thumbnail-size crystals on the lake covers an area of more than 8 sq km.

Production and usage: 1 261 306 t produced from 1926 to 1990 (Table 6), principally for the plaster industry.

Estimated resources:

Seed — 1 020 000 t of 95% purity (dune);
crystals — 3 100 000 t of +80% purity (lake).

Sample results : See de la Hunty and Low (1958).

Remarks: Mining tenements but no details.

References: de la Hunty and Low (1958); Chivas et al. (1991).

Relevant tenements: Mining Leases 77/039, 77/048, 77/147.

Lake Wallambin

Coordinates: 30°58'58" S, 117°39'31" E.

Location: 25 km east-northeast of Nalkain.

Nature of occurrence: Mining has taken place on a gypsum dune which was 2–3 m thick and covered by about 25–50 cm of kopi. Most of this dune has been mined but a channel sample was obtained from the 1.5 m of seed gypsum just above the lake/water level. A thin kopi layer (10–30 cm), underlain by red clay, covers the east end of the lake. A low ridge of clay about 1–1.5 m high also projects into the lake bed and appears to be inclined to the south.

Production and usage: 177 863 t produced from 1968 to 1989 (Table 6), probably for agricultural use.

Estimated resources: Nearly mined out.

Sample results : Analytical results of one gypsum sample, 103956, collected by the author, are given in Appendices 1 and 2. Results are also given in Appendix 2 for a sample of clay, 103957, taken from the low clay ridge. Locations for these samples are 30°58'59" S, 117°39'28" E; and 30°58'33" S, 117°40'18" E respectively.

Remarks: Author briefly visited the deposit in May 1990. Mining tenements exist but no further details are available. See also 'Cowcowing Lakes'.

Relevant tenements: Mining Leases 70/107 and 70/108.

Lime Lake

Coordinates: 33°25' S, 117°23' E.

Location: About 1 km northeast of Lime Lake Siding.

Nature of occurrence: 1 to 1.5 m of rock gypsum, clay and gypsum, and gypsum crystals in the lake bed, overlain by marly clay.

Production and usage: None reported.

Estimated resources: Crystals — 10 000 t of 65% purity (lake bed).

Sample results : See de la Hunty and Low (1958).

Remarks: High NaCl and $CaCO_3$ contents.

Reference: de la Hunty and Low (1958).

Mollerin Lake

Coordinates: 30°30' S, 117°39' E.

Location: Along the south and southwest edges of Mollerin Lake.

Nature of occurrence: A narrow bank of kopi, up to 2 m high, skirts two sides of Mollerin Lake.

Production and usage: None reported. Possible agricultural uses.

Estimated resources: Kopi — small tonnage.

Reference: de la Hunty and Low (1958).

Mongers Lake

Coordinates: 29°07' S, 117°15' E.

Location: About 5 km east of Warriedar Station.

Nature of occurrence: 2–5 cm of gypsum occurs on this lake.

Reference: Chivas et al. (1991).

Moorine Rock

Coordinates: 31°23' S, 119°07'30" E.

Location: 25 km southwest of Southern Cross.

Nature of occurrence: Both lake bed and dune gypsum overlain by kopi.

Production and usage: Not known.

Relevant tenement: Mining Lease 77/517.

Moorine Rock South

Coordinates: 31°23' 45" S, 119°08' E.

Location: 9.6 km south of Moorine Rock.

Nature of occurrence: This deposit is on an old dry lake flat and consists of medium– large crystals in the southern part and seed in the northern part. The deposit reaches 1.5 m in the centre of the flat and is overlain by 15 cm of dirty kopi. A kopi dune on the east edge of the flat rises to 3 m in elevation but it is covered by only 0.6 m of kopi.

Production and usage: None reported. Possible agricultural uses.

Estimated resources:

Seed/kopi — 298 000 t of 77% purity (lake);
kopi/seed — 7500 t of 83% purity (dune).

Sample results : See de la Hunty and Low (1958).

Reference: de la Hunty and Low (1958).

Relevant tenement: Mining Lease 77/420.

Mount Palmer

Coordinates: 31°27' S, 119°42'30" E.

Location: Roughly 6 km southeast of Mount Palmer.

Nature of occurrence: Thin seed dune, average thickness 0.5 m, overlying dirty seed and clay on the east shore of a salt lake. The dune is approximately 2000 m long and 320 m wide. In addition, there are possible deposits one km east (P77/583) and 3.5 km southeast (P77/584) of the above coordinates.

Production and usage: None reported.

Estimated resources:

Seed — 310 000 t of +90% purity (dune);
kopi/seed — 100 000 t of ?50% purity.

Sample results : See de la Hunty and Low (1958).

Remarks: Prospecting tenements were for gypsum, but there are no details.

Reference: de la Hunty and Low (1958).

Relevant tenements: Prospecting Licences 77/583–584.

Mount Walker

Coordinates: 32°03'20" S, 118°41'20" E.

Location: About 31 km east of Narembeen, nearly to Mount Walker townsite.

Nature of occurrence: Kopi-capped seed dune on the south shore of a small lake north of the Narembeen–Mount Walker road. The dune appeared to include: a clean, medium-sized seed gypsum layer underlain by a thin recrystallized gypsum layer; both overlain by reddish seed gypsum/kopi; and capped by soil and/or a thin reddish kopi. Total thickness for the recrystallized layer plus the clean and reddish seed gypsum appeared to be about 2–3 m. This deposit appears to be nearly mined out.

Production and usage: 4974 t produced in 1987–88 (Table 6), probably for local agricultural use.

Estimated resources: Unknown, but the deposit appears to be nearly mined out.

Sample results : Analytical results of one gypsum sample collected by the author are given in Appendices 1 and 2. This sample was composed of the clean seed gypsum, the recrystallized gypsum, and the lower portion (2 cm) of the reddish seed gypsum described above. Total thickness sampled was 1.0 m. (Sample 103988; location 32°03'23" S, 118°41'07" E).

Remarks: Mining tenements completely cover the deposit, but no resource details are available. This deposit was visited briefly by the author.

Relevant tenements: Mining Leases 70/312, 70/314.

Mukinbudin

Coordinates: 30°49' S, 118°18' E.

Location: Approximately 13 km northeast of Mukinbudin.

Nature of occurrence: Unknown.

Production and usage: 500 t produced in 1989 (Table 6), probably for testing and local agricultural use.

Estimated resources: Unknown.

Remarks: Prospecting tenement only. No other details known, except that a small quantity was mined for testing purposes.

Relevant tenement: Prospecting Licence 70/653.

Nalkain

Coordinates: 31°02' S, 117°27' E.

Location: 3.2 km northwest of Nalkain Siding.

Nature of occurrence: On a lake flat there are up to 60 cm of gypsum crystals overlain by 15 cm of kopi. An adjacent patch of seed (30 cm thick) is overlain by 45 cm of kopi.

Production and usage: None reported. Possible agricultural uses.

Estimated resources:

Seed — 70 000 t of 60% purity (lake bed);
kopi/seed — 30 000 t of 78% purity (patch).

Sample results : See de la Hunty and Low (1958).

Remarks: Potential NaCl problems. See also 'Cowcowing Lakes South' and 'Cowcowing Lakes North'.

Reference: de la Hunty and Low (1958).

Narembeen

Coordinates: 32°19' S, 118°30' E.

Location: 8 km east of Narembeen.

Nature of occurrence: ?Kopi samples submitted to GSWA.

Production and usage: None reported.

Estimated resources: ?Small tonnage.

Sample results : See de la Hunty and Low (1958).

Reference: de la Hunty and Low (1958).

Parker Range

Coordinates: 31°38' S, 119°37' E.

Location: About halfway between the Parker Range and the Toomey Hills.

Nature of occurrence: The lake was reported to have kopi on the lake bed (30–45 cm thick) and some low kopi/seed dunes on and near the eastern shore. One dune was described as being about 800 m long, 90 m wide and 4 to 6 m in height. On inspection the dunes appeared to be 1–4 m thick and generally comprised 0.5–1.5 m of kopi capping 1–2 m of seed gypsum. There has been some trenching across these dunes to give good exposure.

Production and usage: None reported.

Estimated resources: Unknown.

Sample results : Analytical results of one gypsum sample collected by the author are given in Appendices 1 and 2. This material was a grab sample of seed gypsum/soil at the watertable (about 30 cm under the lake bed). (Sample 103973; location 31°37'30" S, 119°36'32" E).

Remarks: The author briefly visited this deposit in May 1990.

Reference: Gibson (1904).

Pinjarrega Lake

Coordinates: 30°03' S, 115°55' E.

Location: 16 km west of Marchagee.

Nature of occurrence: Gypsum crystals are found in clay beneath bentonite and clay (30 to 60 cm deep). These crystals are found in several clay pans in this area. There also appears to be a small amount of kopi at this locality.

Production and usage: None reported.

Estimated resources: Occurrences only.

Sample results : (kopi)

Gypsum	92.78%
$CaCO_3$	2.21%
Insolubles	1.31%

Remarks: Above data summarized from de la Hunty and Low (1958), and referred to as 'Marchagee West'. See also 'Coorow'.

Reference: de la Hunty and Low (1958).

Pootenup

Coordinates: 34°14' S, 117°42' E.

Location: About 5.5 km east-northeast from Pootenup.

Nature of occurrence: A small dune is located on the east shore of the more westerly of two small salt lakes. The dune is 400 m long, and averages 50 m wide and 2 m high. It is composed of 60 cm of seed, overlain by 60 cm of kopi, and underlain by a reddish clay. A small island of gypsum is situated in the other lake.

Production and usage: None reported.

Estimated resources:

Kopi — 3150 t of 85% purity (dune);
seed — 6000 t of 93% purity (dune).

Sample results : See de la Hunty and Low (1958).

Reference: de la Hunty and Low (1958).

Southern Cross

Coordinates: 31°13' S, 118°02' E.

Location: 600 m northeast of Southern Cross railway station.

Nature of occurrence: A small patch of dirty crystals, varying from 15–75 cm in thickness, occurs on the west side of a small lake flat. On the southeast corner of this flat is a small seed dune averaging 1.2 m in height and 27 m in width.

Production and usage: None reported. Possible agricultural uses.

Estimated resources:

Crystals — 10 000 t of 80% purity (lake);
seed — 9000 t of 75% purity (dune).

Sample results : See de la Hunty and Low (1958).

Reference: de la Hunty and Low (1958).

Stennetts Lake

Coordinates: 33°13' S, 119°58' E.

Location: 3.2 km southwest of Stennetts Lake.

Nature of occurrence: Kopi dune up to 10 m high, 60 m wide, 240 m long, and trending N30°E. Kopi is a clean, white colour and the dune runs through an old sand-covered lake bed.

Production and usage: None reported. Possible agricultural uses.

Estimated resources: Kopi — 19 000 t of 93% purity (dune).

Sample results : See de la Hunty and Low (1958).

Reference: de la Hunty and Low (1958).

Woolundra

Coordinates: 31°39' S, 117°48' E.

Location: 2.4 km south of Woolundra Siding, which is 7 km east of Kellerberrin.

Nature of occurrence: This area contains a small dry lake covered with seed and several dunes usually composed of seed; both are overlain by kopi.

Production and usage: 54 415 t produced from 1924 to 1953 for the plaster industry (Table 6). The remaining resources would suit the cement industry or agricultural users.

Estimated resources:

Seed — 4000 t of 70% purity (lake);
seed/crystals — 5000 t of 70% purity (lake);
seed/crystals — 12 000 t of 65% purity (dune);
kopi/crystals — 12 000 t of 82% purity (dune);
kopi — 3000 t of 79% purity (dune);
kopi — 3000 t of 64% purity (dune).

Sample results : See de la Hunty and Low (1958).

Remarks: Gypsum has been produced from this locality since 1921 (except for 1931). See also 'Kellerberrin'.

Reference: de la Hunty and Low (1958).

Wyola

Coordinates: 31°38' S, 117°22' E.

Location: Just north of the Great Eastern Highway at Wyola; about half way between Cunderdin and Tammin.

Nature of occurrence: Circular bank of pink kopi, with an average thickness of 60 cm, covering about 5 acres (2 ha) in a clay pan.

Production and usage: None reported. Possible agricultural uses.

Estimated resources: Kopi — 10 000 t of 89% purity (bank).

Sample results : See de la Hunty and Low (1958).

Remarks: See also 'Cunderdin', 'Cunderdin East' and 'Cunderdin East-northeast'.

Reference: de la Hunty and Low (1958).

Yarra Yarra Lakes

Coordinates: 29°45' S, 115°48' E.

Location: About 4 km southwest of Carnamah.

Nature of occurrence: Seed, up to 15 cm or more thick, occurs as a surface covering on the lake, with gypsum crystals mixed with clay underlying it and reaching a thickness of one metre. Some low dunes occur around the lake.

Production and usage: None recorded.

Estimated resources:

Seed — 10 000 000 t of 80% purity (lake bed);
crystals — 1 500 000 t of 70% purity (lake bed);
crystals — 700 000 t of 41% purity (lake bed).

Sample results : See de la Hunty and Low (1958).

Remarks: NaCl impurity will cause problems. A feasibility study into using the gypsum to make plaster concluded that the cost would be high because of the need for extensive washing of the material and mining problems due to seasonal flooding of the lake surface.

References: de la Hunty and Low (1958); Downing (1975); Chivas et al. (1991).

Relevant tenement: Mineral Claims 70/13456–13471, and Exploration Licence 70/147.

Youngs Siding

Coordinates: 35°02' S, 117°31' E.

Location: About 33 km west of Albany.

Nature of occurrence: Gypsum crystals are scattered throughout a blue-grey clay, observed in drains near the siding and in the drain crossing the road near the siding.

Production and usage: None reported.

Estimated resources: Occurrence only.

Sample results : Hand-picked crystals from a location 4.8 km north of the siding.

Gypsum	95.94%
$CaCO_3$	0.07%
Insoluble in acid	4.22%

Reference: de la Hunty and Low (1958).

Minor deposits in the southwest and Murchison regions

A number of minor deposits noted during regional geological mapping, or postulated from tenement applications, are listed in Table 13.

Table 13. Minor or poorly documented gypsum deposits in the southwest region

Deposit	*Locality*	*Co-ordinates*		*Map sheet (1:250 000)*	*References*	*Remarks*
Eva Lake	21 km north of Mt Clara	31°03'S	119°49'E	Southern Cross	Gee (1982)	
Hamersley Lakes	Just north of Woongaring Hills	30°26'S	118°55'E	Jackson	Kid Mining (1987)	Brief reconnaissance plus two analyses
Lake Biddy	Tenement covers lake bed	33°01'S	118°56'E	Newdegate	ML70/220	No details available
Lake Wallambin	37 km northeast of Wyalkatchem	30°58'S	117°38'E	Bencubbin	E70/657	Lakebed seed gypsum
Ninghan	36 km northeast of Dallwalinu	30°00'S	116°58'E	Perenjori	P70/592	South margin of Lake Goorly
Yellowdine	4.5 km east of Yellowdine	31°08'S	119°43'E	Southern Cross	Gee (1982)	

Eucla region

The Eucla region, as used in this Record, covers much of the State's Eastern Goldfields, and extends across to the South Australian border, taking in the Eucla and southern Officer Basins. The region is characterized by a system of palaeorivers converging upon the Eucla Basin which, during the Eocene, was a shallow extension of the Southern Ocean. The courses of the former rivers are marked by chains of salt lakes and intervening low country supporting salt-resistant vegetation.

Most of the gypsum deposits known from this region are within its western part, where an active gold and nickel mining industry has encouraged intensive prospecting and geological investigations. At the same time, roads, railways and other infrastructure servicing the mines offer the possibility of commercially exploiting at least the better grade deposits. Further deposits probably exist in the eastern part of the region, but it is extremely remote.

Beete

Coordinates: 32°40' S, 121°29' E.

Location: About 5.5 km northwest of Beete Siding.

Nature of occurrence: Low kopi and seed dunes occur on the east and southeast shores of a salt lake system. The dunes are 1–4 m high and composed of 0–1 m of kopi underlain by 1–4 m of seed. Seed and kopi more than 2 m thick also occur on parts of the lake. Figure 11 shows the general distribution of gypsum dunes and the areas classed as measured and indicated resources, based on the investigations of Poole (1986). Figure 12 illustrates gypsum profiles and sample results in one of the costeans reported by Poole (1986). Some problems with impurities of sand, clay, and recrystallized gypsum were noted.

Production and usage: None reported.

Estimated resources:

Seed — 435 000 t of 94.5% purity (dune; includes 272 000 t of 96% purity, measured);
seed — 100 000 t of 93% purity (dune, measured);
seed/kopi — 600 000 t of ± 95% purity (dune, indicated);
seed/kopi — 4 250 000 t of ± 90% purity (dune and lake, inferred).

Sample results : Analytical results of three samples (103976–8, approximate location shown in Figure 11) collected by the author are included in Appendices 1 and 2. The first and second samples taken were of the small seed gypsum in 5 m- and 2.5 m-high dunes, respectively. Both of these dunes are capped with approximately one metre of kopi. The third sample is from the lake bed itself (0.25–1.8 m deep). Many detailed analyses were also reported in Poole (1986).

Remarks: Deposit is outlined on the Norseman 1:250 000 geological sheet. For detailed mapping of the tenement area, see Poole (1986). The site was briefly inspected by the author in May 1990.

References: Doepel (1973); Poole (1986).

Relevant tenement: Mining Lease 63/083.

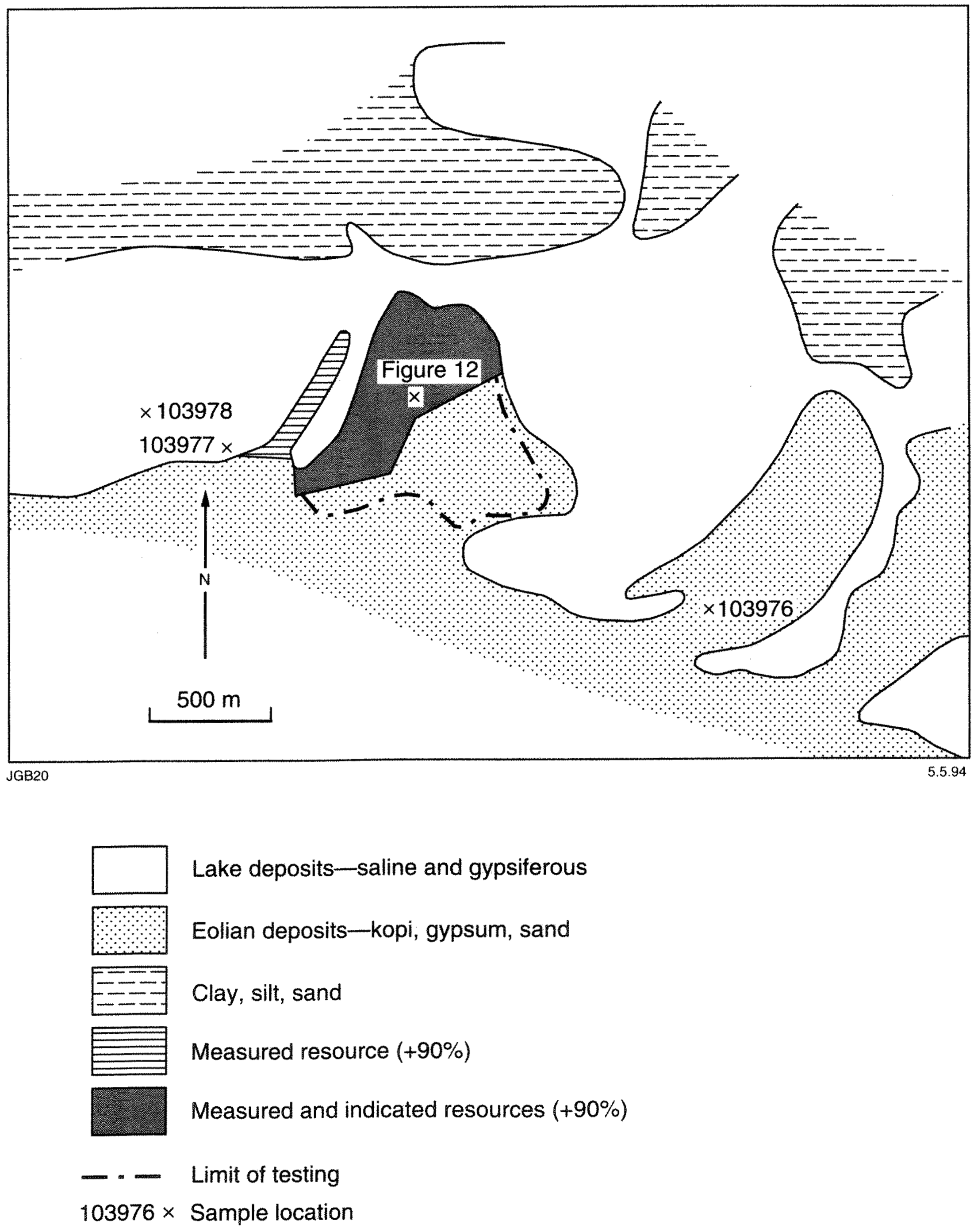


Figure 11. Geological map of the Beete gypsum deposit, showing sample locations and position of measured and indicated resources (after Poole, 1986)

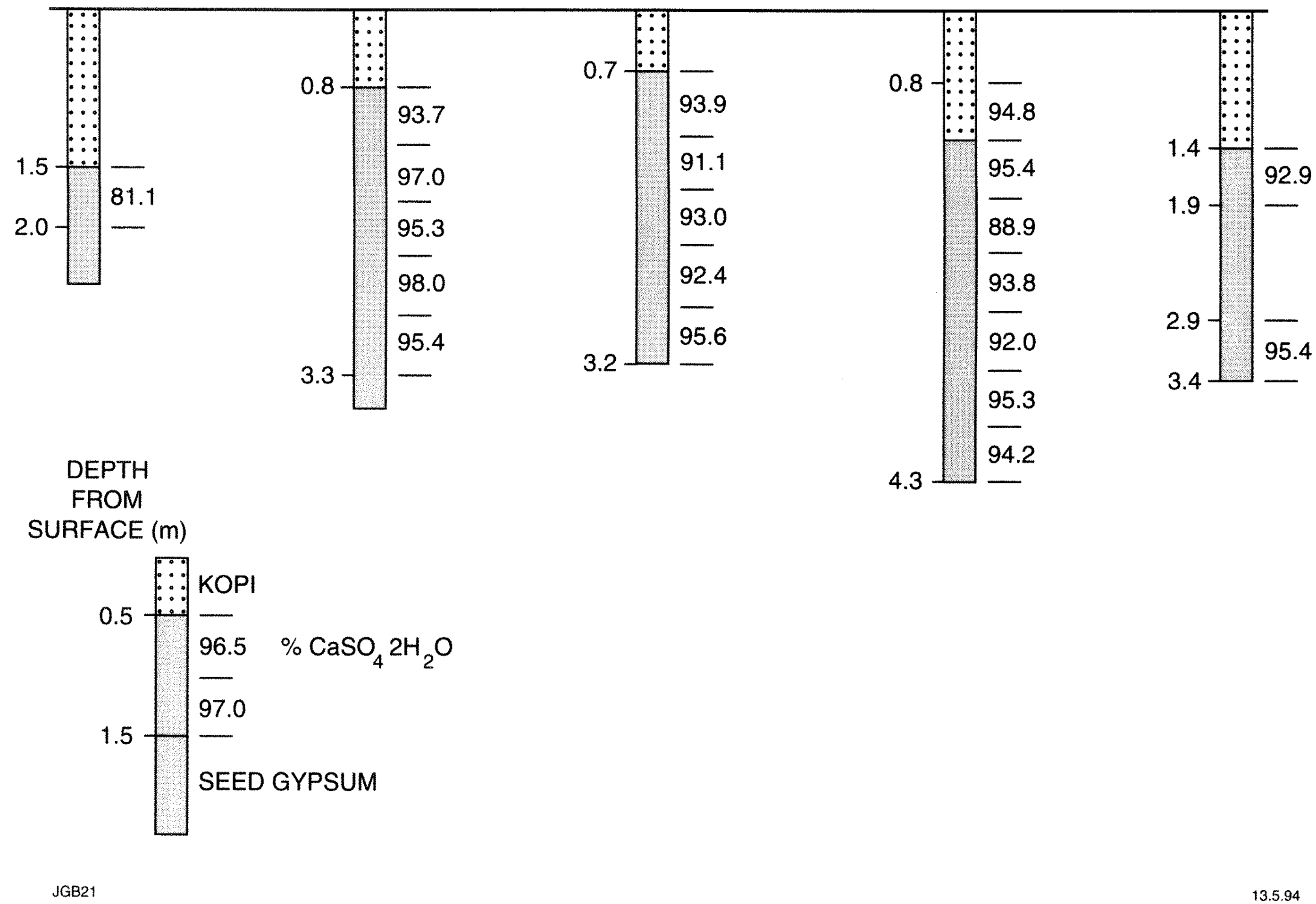


Figure 12. Gypsum profiles and sample results from costeans 1–5, Beete deposit (after Poole, 1986). See Figure 11 for locations of samples

Gidgi Lake

Coordinates: 30°36' S, 121°25' E.

Location: About 16 km north of Kalgoorlie and 2.5 km west of the Kalgoorlie – Broad Arrow road.

Nature of occurrence: Kopi occurs as ridges on the east side of a clay pan. It also occurs as patches amongst the sand from the clay pan to the siding at Gidgi. The average kopi thickness is 60 to 80 cm.

Production and usage: None reported.

Estimated resources: Kopi — 10 000 t of 85% purity (dune).

Sample results : See de la Hunty and Low (1958).

Remarks: Referred to as 'Gidgi Siding' in reference.

Reference: de la Hunty and Low (1958).

Hannan Lake

Coordinates: 30°52' S, 121°32' E.

Location: About 17.5 km southeast of Kalgoorlie and 2 km east of the Kalgoorlie–Kambalda road.

Nature of occurrence: Kopi occurs in dunes and clay pans immediately south and east of Hannan Lake.

Production and usage: None reported.

Estimated resources: Large amount of kopi reported in dunes, otherwise unknown.

Sample results :

Water soluble CaO 29.68%
(equal to gypsum 91.12%)

Reference: de la Hunty and Low (1958).

Kopai Lake

Coordinates: 30°46' S, 121°16' E.

Location: 11.3 km northwest of Kurrawang.

Nature of occurrence: Kopi dune on the east bank of the lake is approximately 1600 m long, 100 m wide, and rises 5 m above the lake surface. Average kopi thickness is about 1 m.

Production and usage: None reported, but possible agricultural uses.

Estimated resources: Kopi — 50 000 t of 84% purity (dune).

Sample results : See de la Hunty and Low (1958).

Remarks: Other lower grade occur dunes farther south.

Reference: de la Hunty and Low (1958).

Relevant tenement: Exploration Licence 15/195.

Lake Cowan

Coordinates: 32°14' S, 121°44' E.

Location: Just west of Norseman.

Nature of occurrence: Seed gypsum occurs on the lake flats and in dunes and banks. Lake flat deposits are laterally extensive, although thin (0.3–0.5 m) and close to the watertable. Dune deposits are less extensive (Figure 13) and are composed of 0.6–4.5 m (average 2 m) of seed gypsum beneath 0.2–0.6 m of kopi. Exploration has not taken place below the current watertable.

Production and usage: Total production is 573 494 t with a reported value of $5 845 761 to the end of 1986 (Table 6). The production recorded from 1982 to 1986 was exported through Esperance. Previous output was primarily for domestic use, probably for cement and plaster products. There has been mining of gypsum from the lake to produce plaster to fill stopes in nearby gold mines.

Estimated resources:

Seed — 5 460 000 t of 95–98% purity (dunes, average 2 m thick);
seed — 1 300 000 t of +95% purity (banks and low dunes, average 1 m thick);
seed — 5 700 000 t of +90% purity (lake flats, average 0.3 m thick);
granular/kopi — 900 000 t of +90% purity (low dunes and cap on banks and thicker dunes).

Sample results : See de la Hunty and Low (1958).

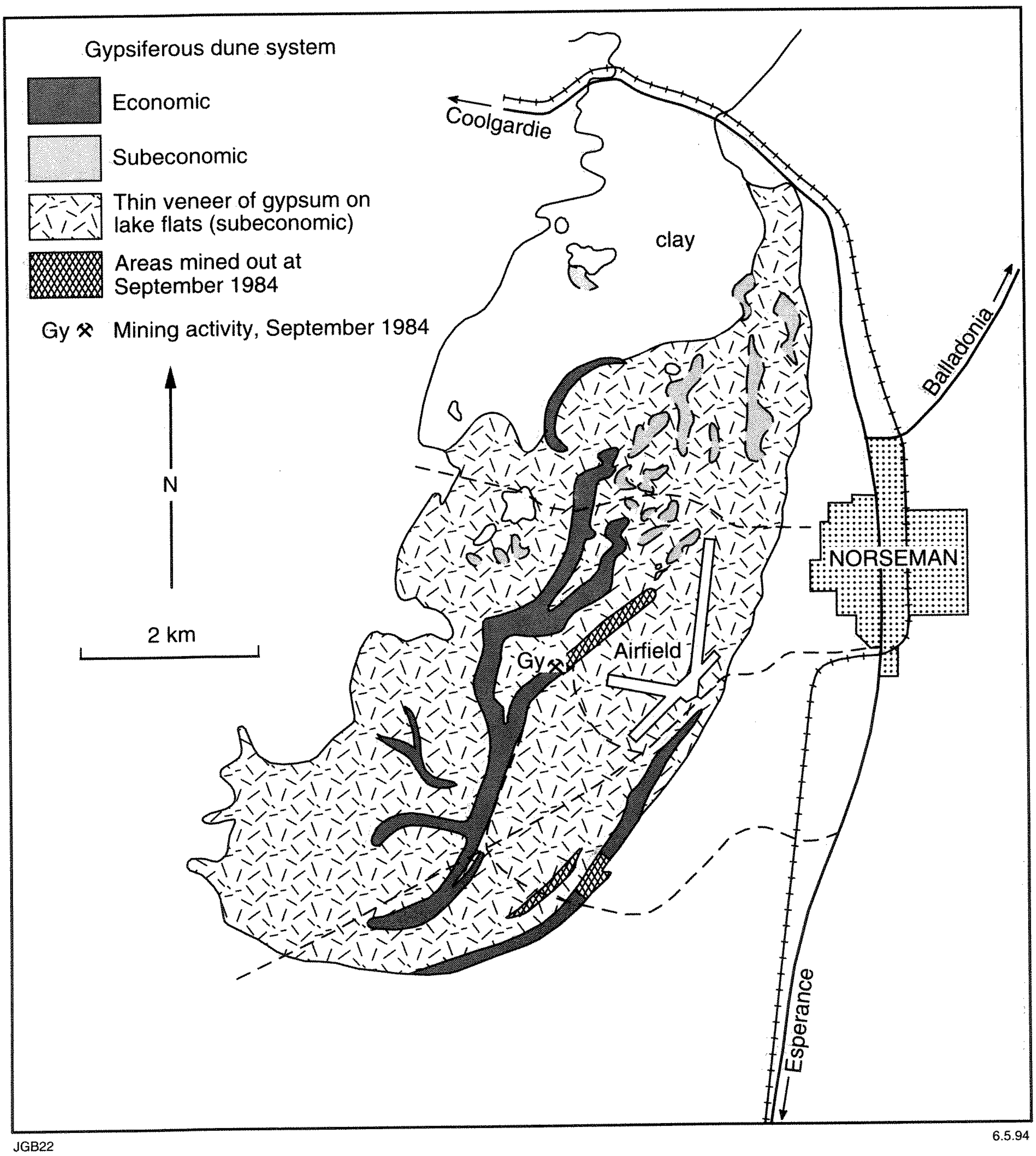


Figure 13. Map of Lake Cowan showing distribution of gypsum deposits and areas mined (after Keats, 1984). Map based on 1971 aerial photography

Remarks: The deposit is outlined on the Norseman 1:250 000 geological sheet. Detailed mapping and resource calculations were reported in de la Hunty and Low (1958) and further delineation of the deposit and calculation of resources was completed by Keats (1984). See also 'Lake Cowan North'.

Reference: de la Hunty and Low (1958); Doepel (1973); Keats (1984); and Chivas et al. (1991).

Relevant tenements: Mining Leases 63/85, 63/87, 63/148, 63/170, 63/237.

Lake Cowan North

Coordinates: 32°06' S, 121°44' E.

Location: Approximately 6 km north of Norseman.

Nature of occurrence: Gypsum in lake sediments 20–40 cm thick.

Production and usage: None reported.

Estimated resources: Unknown.

Remarks: Deposit is shown on the Norseman 1:250 000 geological sheet and mentioned in Chivas et al (1991). See also 'Lake Cowan'.

Reference: Doepel (1973); Chivas et al. (1991).

Lake Douglas

Coordinates: 30°53' S, 121°25' E.

Location: About 1.5 km southeast of White Lake and 6.5 km west of the Hampton nickel smelter.

Nature of occurrence: Several gypsum dunes occur on the east side of some rocky hills. These dunes contain 1–7 m of apparently wind-blown gypsum overlying sand.

Production and usage: None reported, but appears to have many potential uses.

Estimated resources:

Gypsum (?seed) — 800 000 t of 94% purity (average 6% sand).

Sample results : 13 holes drilled with the following results:

Gypsum	85–99%
sand	0–12%
kaolin	0–12%
montmorillonite	0–2%

Remarks: Tenements relinquished because gypsum was no longer required at nickel smelter.

Reference: WMC (1984).

Relevant tenements: Mineral Claims 26/1246–1248.

Lake Dundas

Coordinates: 32°29' S, 121°53' E.

Location: About 24 km east of Bromus Siding or 19 km east of the Coolgardie–Esperance Highway at the turn-off to Bromus Siding.

Nature of occurrence: Tenements are located on the northeast shore of the lake.

Production and usage: None reported.

Estimated resources: Unknown.

Remarks: Several tenements, but no details. Deposit is shown on the Norseman 1:250 000 geological sheet. The lake would seem to have good potential for gypsum deposits, especially the southern half.

Reference: de la Hunty and Low (1958); Doepel (1973).

Relevant tenements: Prospecting Licences 63/124, 63/166, 63/195, 63/196, 63/199, 63/271, 63/272, and Mineral Claims 63/025–035.

Lake Lefroy

Coordinates: 31°17' S, 121°43' E.

Location: About 25.5 km northeast of Widgiemooltha.

Nature of occurrence: Pink to red seed and kopi, with limy crusts, occur on the northwest corner of an island in the lake. Gypsum crystals also occur in clay below the salt crust of the lake. Chivas et al. (1991) reported 25 cm of gypsum in the lake sediments. Elsewhere on the lake mining companies have recorded up to 45 cm of gypsum immediately below a surface crust of salt.

Production and usage: None reported.

Estimated resources: Seed/kopi — a few thousand tonnes on the island.

Sample results : (Crystals from lake bed)

Gypsum	80.16%
$CaCO_3$	2.57%
insoluble in acid	14.40%

Remarks: Analytical data summarized from de la Hunty and Low (1958). There is good potential for gypsum deposits in or near this lake.

Reference: de la Hunty and Low (1958); Chivas et al. (1991).

Lake Perkolilli

Coordinates: 30°33'30" S, 121°42'30" E.

Location: Approximately 6 km northeast of Kanowna on the Kanowna–Kurnalpi road.

Nature of occurrence: Kopi, with some seed and clay, occurs in a 2 km-long dune which reaches 320 m in width and 3 m in height. The average thickness of kopi in the dune is 1 m. Further dunes among the lakes to the north were not investigated.

Production and usage: A few tonnes quarried for road surfacing.

Estimated resources: Kopi — 28 000 t of ?90% purity (dune).

Sample results : See de la Hunty and Low (1958).

Remarks: Deposit called 'Kanowna' by de la Hunty and Low (1958); and Chivas et al. (1991). It is shown on the Kurnalpi 1:250 000 geological sheet.

Reference: de la Hunty and Low (1958); Williams (1970); Chivas et al. (1991).

Lake Rebecca

Coordinates: 30°17' S, 122°45' E.

Location: Approximately 16 km east-northeast of Yindi Homestead.

Nature of occurrence: Cliff exposures of fossil lake sediments show significant amounts of gypsum along the north shore of the lake at approximately 30°17' S, 122°48' E. These cliffs show 2–4 m of dirty seed gypsum capped by 0–1 m of kopi and underlain by gypsiferous muds. The cliffs rise to about 4–5 m above the current lake-bed surface.

Production and usage: None reported.

Estimated resources: Unknown.

Sample results : See Appendices 1 and 2 for two samples collected by the author: samples 103974–5; location 30°17'25" S, 122°48'20" E and 30°16'55" S, 122°48'20" E respectively.

Remarks: Deposit shown on the Kurnalpi 1:250 000 geological sheet. The area was briefly inspected by the author in May 1990 to obtain samples. An unusual exposure of a horizontal, slickensided, bedrock surface was observed at approximately 30°18' S, 122°48' E (at the intersection of the fence line and the lake shore).

Reference: Williams (1970).

Lake Tay

Coordinates: 33°00' S, 120°47' E.

Location: Along the southeast and east shores of Lake Tay.

Nature of occurrence: Seed and kopi occurs as lacustrine sediments (lake bed deposits) and eolian sheets, hummocks and dunes along the southeast lake shore (Figure 14). The gypsum in units 1 and 3 contains high salt and clay/silt contamination. Unit 1 is also brine-saturated and shows relatively high potassium, magnesium, and calcium values. High-quality seed is found in Unit 2 with only minor contaminants (clay/silt, sand, kopi, and tree roots). Unit 4 appears to be of similar origin to Unit 2 but contains variable amounts of sand. Older dunes in Unit 4 are capped by up to one metre of kopi and show cyclical development as evidenced by one or more layers of kopi or sandy material within the dune. Detailed descriptions of these units are contained in Watts (1987).

Production and usage: 6518 t with a reported value of $22 000 was produced in 1990, apparently destined for the export market. See Table 6.

Estimated resources: (not including resources below the watertable)

Seed — 1 540 000 t of 95.5% purity (dune, average 0.13% NaCl and 3.7% insolubles);

seed — 373 000 t of 98.5% purity (dune, average 0.3% NaCl and 0.9% insolubles);

seed/kopi — 1 700 000 t (estimating 1-m thickness for areas not sampled).

Sample results : See Figure 15 for thicknesses and analytical values (gypsum, salt and insolubles) from costean and hand auger samples.

Remarks: Exploration tenements, but limited details. Deposit also shown on the Ravensthorpe 1: 250 000 geological sheet. See also 'Lake Tay East' and 'Three Star Lake'.

Reference: Thom et al. (1977); Watts (1987).

Relevant tenements: Exploration Licences 74/45, 74/49–50, 74/61, 74/67, 74/76–78, 74/104 and Mining Leases 74/07, 74/49, 74/61.

Lake Tay East

Coordinates: 32°55' S, 120°50' E.

Location: Along the eastern shore and on the lake bed of the eastern portion of Lake Tay.

Nature of occurrence: Unknown, but presumably as at 'Lake Tay'.

Production and usage: None reported.

Estimated resources: 160 000 t.

Remarks: Exploration tenements, but limited details. See also 'Lake Tay' and 'Three Star Lake'.

Relevant tenement: Exploration Licence 74/104.

Lake Throssell

Coordinates: 27°38' S, 124°05' E.

Location: Approximately 36 km northeast of Yamarna.

Nature of occurrence: Gypcrete, gypsum (10–20 cm thick) in sandy lake sediments, gypsum cement (5–10 cm) and gypsum dunes.

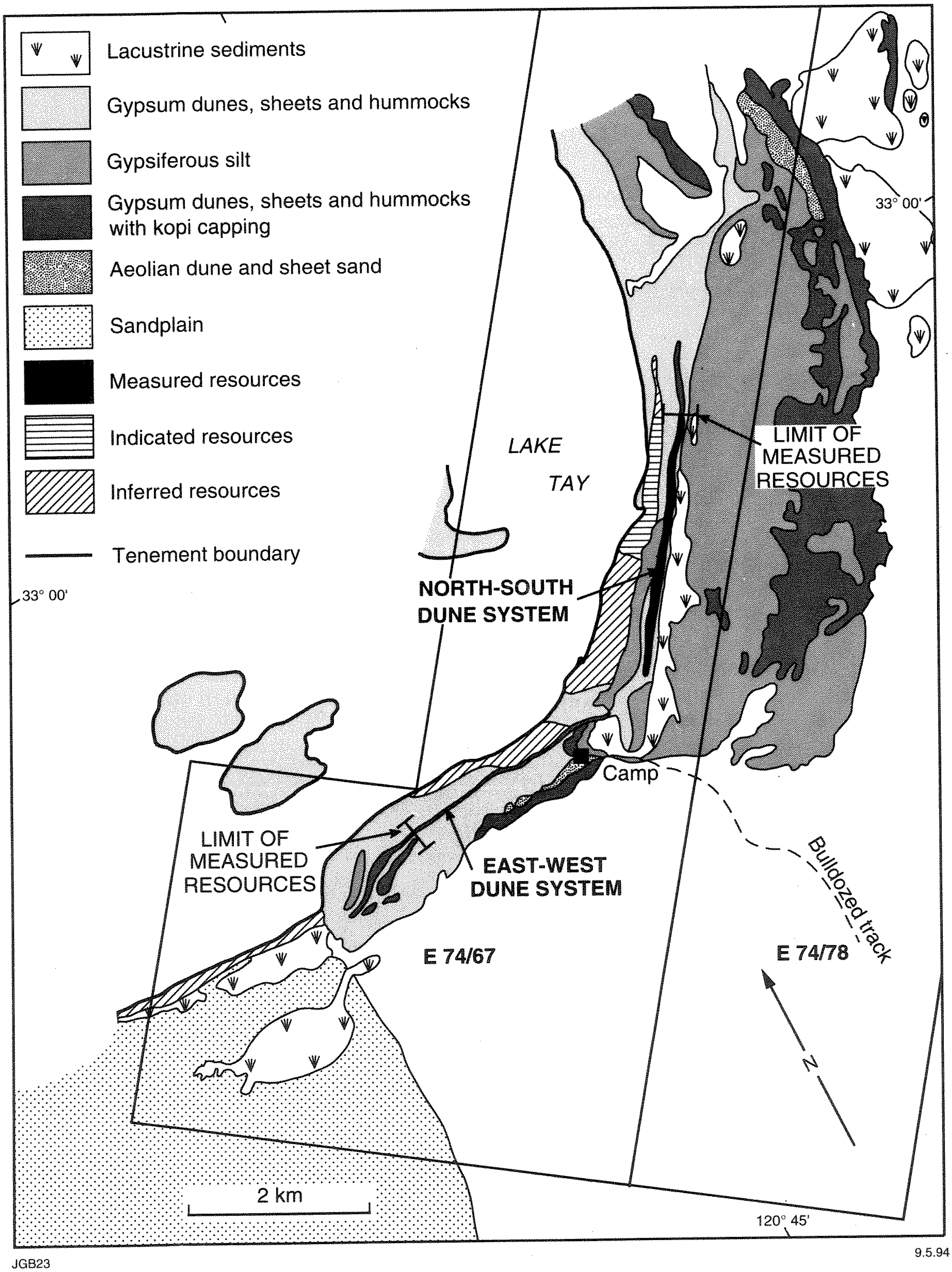


Figure 14. Geological map of Lake Tay showing gypsum deposits (after Watts, 1984)

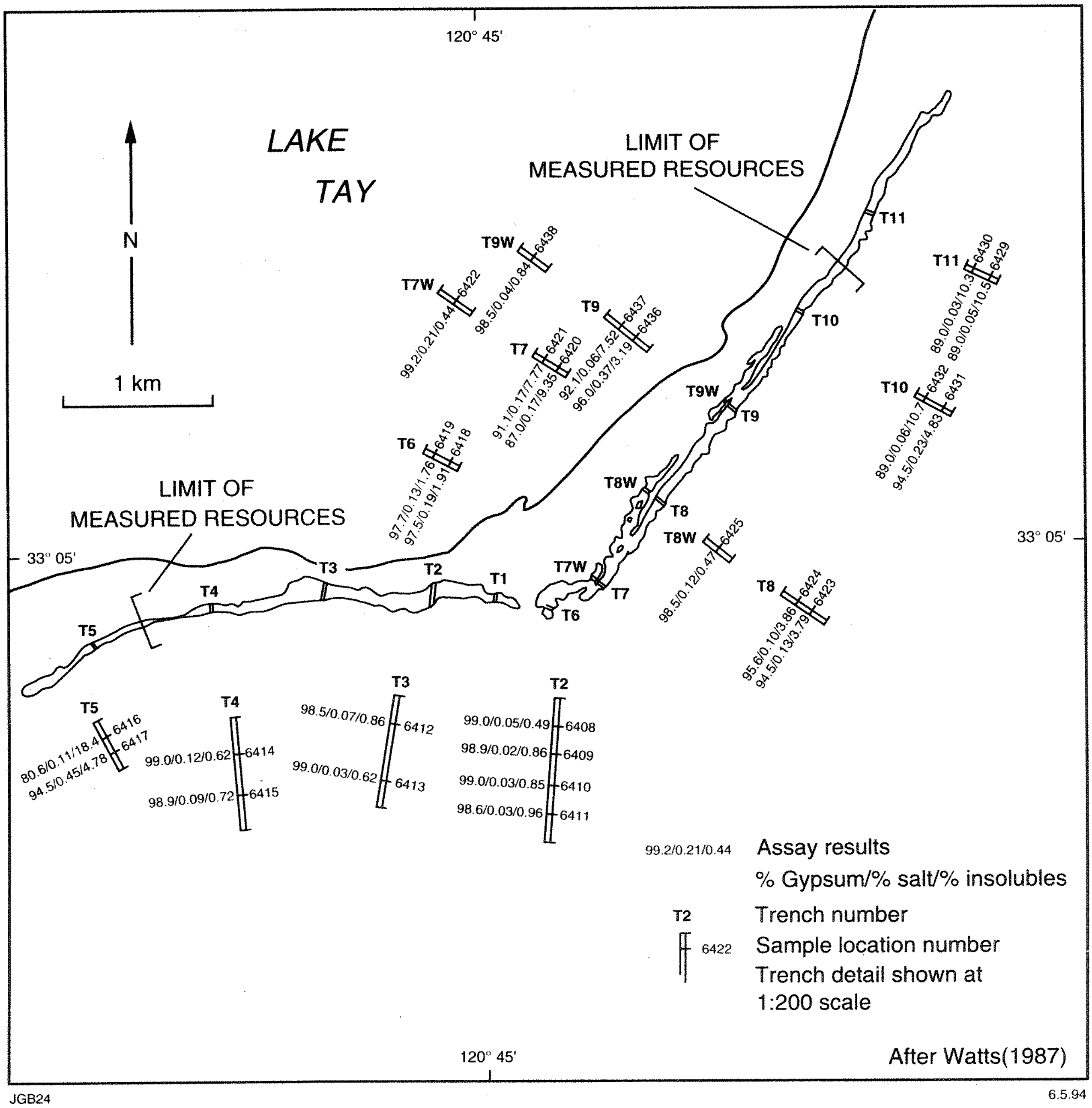


Figure 15. Locations of costeans and sample results used to define gypsum resources, Lake Tay (after Watts, 1987)

Estimated resources: Unknown.

Remarks: Deposit shown on the Throssell 1:250 000 geological sheet.

Reference: Bunting et al. (1978); Chivas et al. (1991).

Lakewood

Coordinates: 30°49' S, 121°33' E.

Location: About 2.5 km southeast of Lakewood townsite along an old timber tram track.

Nature of occurrence: Gypsum crystals occur on an island in a clay pan. The crystals are mixed with red clay to a depth of 4.5 cm and kopi and clay dunes, up to 1.2 m high, also cover about 10% of the island. A kopi dune located southeast of the clay pan has a hard limy caprock and is contaminated with clay and limonite.

Production and usage: None reported.

Estimated resources: Crystals — 2000 t of 63% purity (island).

Sample results : See de la Hunty and Low (1958).

Remarks: A map of the deposit is included in de la Hunty and Low (1958). See also 'Hannan Lake'.

Reference: de la Hunty and Low (1958).

Pyramid Lake

Coordinates: 33°10' S, 120°57' E.

Location: Along the north and east shores of Pyramid Lake.

Nature of occurrence: Unknown.

Production and usage: None reported.

Estimated resources: ?Seed/kopi — 1 700 000 t of unknown purity (lake).

Remarks: Exploration tenement, but no details. Deposit is shown on the Ravensthorpe 1:250 000 geological sheet.

Reference: Thom et al. (1977).

Relevant tenement: Exploration Licence 74/77.

Red Lake

Coordinates: 30°59' S, 121°24' E.

Location: About 5 km southeast of Red Lake and 9.5 km southwest of the nickel smelter at Hampton.

Nature of occurrence: Unknown, although presumably similar to the deposits at Lake Douglas.

Production and usage: No tonnage reported, but a small amount was removed for testing at the smelter.

Estimated resources: Unknown.

Remarks: Tenements were relinquished because gypsum was no longer required at the nickel smelter. See also 'Lake Douglas'.

Relevant tenements: Mineral Claims 15/3576, 15/3790.

Scaddan

Coordinates: 33°24' S, 121°44' E.

Location: About 8 km north of Scaddan townsite and adjacent to the Coolgardie–Esperance railway tracks.

Nature of occurrence: Dry lake bed with 0–1.5 m of sand/soil/kopi overlying 0.5–2 m of clean, medium-coarse seed gypsum. Watertable lies at about 3 m below lake bed surface. Some seed gypsum removed from the north end of M63/157 for testing by tenement holder.

Production and usage: 20 902 t produced between 1988–91 (Table 6).

Estimated resources: Unknown.

Sample results : See Appendices 1 and 2 for testing of one sample collected by the author: sample 103979; location 33°22'S, 121°43'30"E is of the top one metre of the clean seed gypsum.

Remarks: Prospecting, exploration, and mining tenements, but no details available. Author visited locality briefly in May 1990.

Relevant tenements: Prospecting Licences 63/191, 63/424, 63/453; Exploration Licences 63/79–80; and Mining Leases 63/84, 63/150, 63/154, 63/157.

Three Star Lake

Coordinates: 33°00' S, 120°38' E.

Location: Along the southeast and northeast shores of Three Star Lake.

Nature of occurrence: Unknown, but presumably similar to the deposits at 'Lake Tay'.

Production and usage: None reported.

Estimated resources: ?Kopi/seed — 373 000 t of 98.5% purity (lake).

Sample results : None available.

Remarks: Exploration tenement, but no details available. Deposit shown on the Ravensthorpe 1:250 000 geological sheet. See also 'Lake Tay' and 'Lake Tay East'.

Reference: Thom et al. (1977).

Relevant tenement: Exploration Licence 74/76.

Other occurrences in the Eucla region

In addition to those deposits described above, a further forty-nine gypsum occurrences have been noted during various regional surveys of the Eucla region. In most cases there is little information on the occurrences beyond the fact that gypsum is present. Available details are shown in Table 14. Given the general lack of economic incentive to develop gypsum in this region, it is possible that appreciable (but unknown) resources exist in some of the occurrences listed.

Deposits in the remoter regions of the State

Gypsum has been recorded in a number of inland salt lakes during regional geological surveys in the remoter parts of Western Australia. Most occurrences are related to a series of palaeorivers that formerly flowed to the Indian Ocean through the Canning Basin. Others, referred to in Table 15 as the *Eastern desert* deposits, are in areas where drainage appears to be entirely internal. The remaining two deposits lie in the upper part of tributaries of the Fitzroy River in the Kimberley region.

None of these deposits has been the subject of commercial assessment, and, for most, the only available details are brief references in the explanatory notes accompanying 1:250 000 scale geological maps. Details are summarized in Table 15.

Ten Mile Lake

Coordinates: 24°47' S, 120°20' E.

Location: Approximately 32 km east of Beyondie.

Nature of occurrence: Gypsum occurs as a layer under a salt crust and as islands in this lake. It also forms dunes and benches (up to 5 m thick) along the shore. Evaporation has produced up to 0.3 m of unusual 'flower gypsum'.

Estimated resources: Unknown.

Remarks: Deposit indicated on Bullen 1:250 000 geological sheet and described briefly in the notes.

Reference: Leech and Brakel (1980).

Terminal Lake

Coordinates: 24°29' S, 120°37' E.

Location: Approximately 72 km northeast of Beyondie.

Nature of occurrence: Gypsum occurs as a layer under a salt crust and as islands in this lake. It also forms dunes and benches (up to 8 m thick) along the shore. Evaporation has produced up to 0.3 m of unusual 'flower gypsum'.

Estimated resources: Unknown.

Sample results : Two random samples taken:

Hardened crust — 94.2% gypsum, 0.3% calcite;

granular material — 93.3% gypsum, 0.2% calcite.

Remarks: Deposit indicated on Bullen 1:250 000 geological sheet and described briefly in the notes.

Reference: Leech and Brakel (1980).

Table 14. Minor or poorly documented gypsum deposits in the Eucla region

Deposit	*Locality*	*Co-ordinates*		*Map Sheet (1:250 000)*	*References*	*Remarks*
Blue Lagoon	30 km northeast Mt Zephyr	28°15' S	122°00' E	Laverton	Gower (1976)	
Boomerang Lake	7 km south Menangina Homestead	29°53' S	121°53' E	Edjudina	Williams et al. (1976)	
Carlisle Lake	30 km east Jubilee Lake	29°14' S	127°05' E	Jubilee	Lowry (1970)	
Davyhurst	Lights of Israel gold mine	30°02' S	120°39' E	Kalgoorlie	Chivas et al. (1991)	20 cm layer gypsum in soil
Emu Road	Near Trig Station 428	28°13' S	127°15' E	Vernon	van de Graaff (1977)	
Forrest Lakes	165 km north-northwest Deakin Siding	29°20' S	128°45' E	Mason	van de Graaff (1974)	
Geordie Rock	7 km north Geordie Rock	32°52' S	121°23' E	Lake Johnston	P63/1–2; M63/28	No details available
Grass Patch	9.5 km east Grass Patch Siding	33°14' S	121°49' E	Esperance	MC63/3186–9; M	63/252, M63/575 No details available (check tenements)
Hope Campbell Lake	13 km east Hope Campbell Hill	29°10' S	123°22' E	Minigwal	Bunting and Boegli (1977)	
Jubilee Lake	30 km east Lake Gidgi	29°05' S	126°35' E	Jubilee	Lowry (1970)	
Lake Ballard	20 km north Menzies	29°35' S	121°05' E	Menzies	Chivas et al. (1991)	Kopi dune
Lake Barlee	20 km east Cashmere Downs	28°58' S	119°47' E	Barlee; Youanmi	Walker and Blight (1983); Stewart et al. (1983)	
Lake Carey	20 km northeast Mount Keith	29°00' S	122°15' E	Edjudina; Laverton	Williams et al. (1976); Gower (1976)	
Lake Darlot	9 km southeast Banjiwarn	27°47' S	121°35' E	Duketon; Sir Samuel	Bunting and Chin (1979); Bunting and Williams (1979)	
Lake Gidgi	88 km south Neale Junction	29°03' S	126°01' E	Jubilee	Lowry (1970)	
Lake Gillen	12 km southwest Mount Worsnop	26°13' S	124°38' E	Yowalga	Kennewell (1977c)	
Lake Gilmore West	5 km west Lake Gilmore	32°38' S	121°31' E	Norseman	Doepel (1973); Chivas et al. (1991)	
Lake Gilmour	Near Daniell Siding	32°36' S	121°38' E	Norseman	Doepel (1973); Chivas et al. (1991)	50 cm gypsum in lake and kopi dunes
Lake Goongarrie	Near Goongarrie Hill	30°00' S	121°10' E	Kalgoorlie; Menzies	Chivas et al. (1991)	30 cm gypsum in lake sediments
Lake Gwynne	25 km northeast Kalgoorlie	30°33' S	121°38' E	Kurnalpi	Chivas et al. (1991)	50 cm gypsum in lake sediments
Lake Ilma	180 km north-northeast Mundrabilla Siding	29°15' S	127°45' E	Mason	van de Graaff (1974)	
Lake Kirk	Just west of Lake Kirk Siding	31°13' S	121°44' E	Norseman	Doepel (1973); Chivas et al. (1991)	
Lake Marmion	Just south Mendleyarri Homestead	29°45' S	121°35' E	Edjudina; Menzies	Kriewaldt (1970), Williams et al. (1976)	
Lake Mason	23 km east-southeast Birrigrin	27°34' S	119°45' E	Sandstone	Tingey (1985)	
Lake McInnes	14 km north Dr Hicks Range	28°22' S	124°15' E	Rason	Gower and Boegli (1977)	
Lake Mends	9 km northeast Pyramid Lake	33°04' S	121°02' E	Ravensthorpe	Thom et al. (1977)	
Lake Minigwal	5 km northeast Elora Homestead	29°31' S	122°52' E	Edjudina; Minigwal	Williams et al. (1976); Bunting and Boegli (1977)	
Lake Miranda	5 km south Yakabindie	27°40' S	120°33' E	Sir Samuel	Bunting and Williams (1979); Chivas et al. (1991)	Gypcrete ridges, kopi dunes and seed
Lake Noondie	7 km north to 16 km west Bulga Downs	28°35' S	119°20' E	Youanmi	Stewart et al. (1983)	
Lake Raeside	30 km east Yerilla Homestead	29°31 S	122°05' E	Edjudina	Williams et al. (1976)	

Table 14. *(continued)*

Deposit	*Locality*	*Co-ordinates*	*Map Sheet (1:250 000)*	*References*	*Remarks*
Lake Rason	17 km south Hicks Range	28°45' S 124°25' E	Rason; Neale	Gower and Boegli (1977); van de Graaff and Bunting (1975)	
Lake Roe	11 km east Mount Charnleigh	30°43' S 122°38' E	Kurnalpi	Williams (1970)	
Lake Way	40 km southeast Wiluna	26°50' S 120°20' E	Wiluna	Chivas et al. (1991)	Gypsum in lake sediments and dunes
Lake Yeo	10–15 km northeast Turkey Hill	28°00' S 124°30' E	Rason; Throssell	Gower and Boegli (1977); Bunting et al. (1978)	Gypsum on south and east shores of lake
Lake Yindana	11 km east Lake Roe	30°43' S 122°52' E	Kurnalpi	Williams (1970)	
Lake Yindarlgooda	9 km east Hampton Hill Homestead	30°45' S 121°55' E	Kurnalpi	Williams (1970)	
Lightfoot Lake	18 km south Hope Campbell Hill	29°25' S 123°15' E	Minigwal	Bunting and Boegli (1977)	
Neale Junction	10 km north Neale Junction	'28°13' S 125°53' E	Neale	van de Graaff and Bunting (1975)	
Neale Junction South	35 km south Neale Junction	28°40' S 125°50' E	Neale	van de Graaff and Bunting (1975)	
Neale Junction West	28 km west Neale Junction	28°20' S 125°30' E	Neale	van de Graaff and Bunting (1975)	
Norseman East	7 km east Norseman	32°12' S 121°51' E	Norseman	Doepel (1973); Chivas et al. (1991)	
Plumridge Lake	35 km east Salt Creek Homestead	29°30' S 125°15' E	Plumridge	van de Graaff and Bunting (1977)	
Salt Creek	West of Plumridge Lake	29°30' S 124°57' E	Plumridge	van de Graaff and Bunting (1977)	
Shay Cart Range	East and southeast margins of range	28°45' S 123°07' E	Rason	Gower and Boegli (1977)	
Shell Lakes	190 km north Mundrabilla Station	29°11' S 127°32' E	Jubilee; Mason	Lowry (1970); van de Graaff (1974)	
Wangine Lake	2.5 km west-southwest Bora Rocks	30°10' S 120°52' E	Kalgoorlie	Cullen (1963)	Brief reconnaissance only
Wanna Lakes	Many deposits in 50 km radius	28°30' S 128°50' E	Wanna	Kennewell (1977a)	
Woodhouse Lagoon	5 km southeast Mount Worsnop	26°12' S 124°48' E	Yowalga	Kennewell (1977c)	
Yeelirrie	28 km southeast Yeelirrie Homestead	27°26' S 120°20' E	Sir Samuel	Bunting and Williams (1979); Chivas et al. (1991)	Kopi on bed or claypan

Table 15. Gypsum deposits reported from the remoter regions of Western Australia

Deposit	*Locality*	*Co-ordinates*		*Map Sheet*	*References*	*Remarks*
CANNING REGION						
Gregory Salt Lake	15 km W Mt Wilson	S20° 10'	E127° 31'	Cornish and Lucas	Crowe (1978); Crowe and Muhling (1977)	
Gwenneth Lakes	75 km S Newberry Peaks	S20° 58'	E124° 47'	Dummer	Wyborn (1977)	
Lake Bremner	22 km N Mt Boucaut	S25° 06'	E123° 15'	Herbert	Kennewell (1974)	
Lake Buchanan	20 km WSW Mt Archie	S25° 37'	E123° 05	Herbert	Kennewell (1974)	
Lake Burnside	13 km SW Mt Boucaut	S25° 25'	E123° 07'	Herbert	Kennewell (1974)	
Lake Carnegie	25 km E Prenti Downs	S26° 30'	E123° 05'	Robert	Chivas et al. (1991)	Gypcrete on lake shore
Lake Disappointment	Near No. 21 Well	S23° 20'	E122° 57'	Gunanya	Chivas et al. (1991)	Gypcrete and kopi on lake shore
Lake Keene	50 km NNW Mt Nossiter	S25° 00'	E123° 38'	Herbert and Madley	Kennewell (1974, 1975)	
Lake Nabberu	10 km S Hawkins Knob	S25° 32'	E120° 14'	Nabberu	Chivas et al. (1991)	Kopi in lake, gypcrete in dune
Lake Waukarlycarly	60 km NE Telfer	S21° 15'	E121° 50'	Paterson Range	Chivas et al. (1991)	Kopi in lake bed
Lake Wells	37 km NE Lake Wells Hstd	S27° 00'	E123° 20'	Robert and Throssell	Jackson (1978); Bunting et al. (1978)	
Lake Wilderness	10 km E Dean Hills	S24° 17'	E121° 08'	Bullen	Leech and Brakel (1980)	
Linke Lakes	33 km S Mt Archie	S25° 53'	E123° 15'	Herbert	Kennewell (1974)	
Percival Lakes	Vicinity of Thompson Hills	S21° 20'	E124° 50'	Percival	Chivas et al. (1991)	Gypsum alongside lake
Prescott Lakes	48 km SE Newberry Peaks	S20° 45'	E125° 10'	Dummer	Wyborn (1977)	
Watrara Creek	15 km E Three Sisters	S22° 31'	E122° 08'	Rudall	Hickman and Bagas (in prep.)	1–2m gypsum in Tertiary lake
Weelarrana Hill	Abt 6 km WSW Trig Stn	S24° 07'	E119° 52'	Collier	Chivas et al. (1991)	Kopi in claypan
KIMBERLEY REGION						
Nicholson Swamp	15 km NW Dean Hill	S19° 02'	E125° 54'	Crossland	Towner (1977)	
Nicholson Swamp West	8 km W Nicholson Swamp	S19° 02'	E125° 48'	Crossland	Towner (1977)	
EASTERN DESERT						
Christopher Lake	11 km N Flint Hill	S24° 45'	E127° 30'	Cobb	van de Graaff (1975)	
Lake Cobb	45 km WSW Hickey Hills	S24° 09'	E126° 10'	Cobb	van de Graaff (1975)	
Lake Dennis	28 km S Tomahawk Hill	S20° 57'	E128° 57'	Lucas	Crowe and Muhling (1977)	
Lake Farnham	12 km NW Three Hills	S24° 49'	E127° 15'	Cobb	van de Graaff (1975)	
Lake Farnham North	38 km NW Three Hills	S24° 37'	E127° 12'	Cobb	van de Graaff (1975)	
Lake Lucas	27 km SW Tomahawk Hill	S20° 57'	E128° 50'	Lucas	Crowe and Muhling (1977)	
Lake MacDonald	8 km N Bonython Range	S23° 30'	E128° 55'	MacDonald	Wells (1968); Chivas et al. (1991)	Gypsum in lake sediments
Lake Newell	22 km SW Clutterbuck Hills	S24° 45'	E126° 09'	Cobb	van de Graaff (1975)	
Van Der Linden Lakes	28 km WSW Three Hills	S24° 57'	E127° 05'	Cobb	van de Graaff (1975)	

Deposits related to coastal lagoons and depressions

Deposits formed in coastal areas are located in lagoons and depressions (birridas), where seawater has been partly or totally cut off from the ocean and its salts concentrated by evaporation. Such deposits occur along the north-central coast from near Cliff Head, north to Lake MacLeod, and include gypsum formerly mined at Shark Bay (Plate 1). In terms of potential resources, they far outstrip the salt-lake deposits of the interior, but until recently, their distance from the more populated parts of the State has either prevented development, or restricted production to supplying the competitive export market. This situation changed in 1991 when the Dooka deposit was opened up to supply gypsum used in treating mineral sands at Eneabba.

By far the largest resources occur in and around Lake MacLeod, where gypsum is a component of the evaporite sequence within the main lake bed, and also forms bedded deposits in nearby lakes as well as appearing as kopi in fringing dunes.

Further discussion on the geology of the deposits is presented above, in the section *Barred basin and birrida deposits*.

Description of deposits

Bibby Giddy

Coordinates: 26°18'30" S, 113°26'30" E.

Location: Approximately 7 km south of the southern end of the Useless Loop birrida.

Nature of occurrence: The irregularly shaped Bibby Giddy birrida is approximately 3.1 km long, reaches 1.8 km in width, and contains north-northeast-trending dunes, which form a number of interdunal depressions. The better quality seed gypsum (2–3 m or more thick) found in the dunes is capped by kopi (about 1 m) and underlain by rock gypsum similar to that in the Useless Loop deposit. Dunes in the western arm of the birrida were found to contain the best and thickest seed gypsum and these were investigated down to the watertable.

Production and usage: None reported, but could be used for export or domestic consumption when washed to remove impurities.

Estimated resources: Seed — 1 100 000 t of 92–98% purity (dune, 1.6–3.0 m high).

Remarks: Mining lease surrendered, but exploration information forms part of a larger report covering leases still held and is consequently still confidential.

Reference: Butler (1981).

Relevant tenement: Mining Lease 09/05.

Brown Inlet

Coordinates: 26°31' S, 113°30' E.

Location: Approximately 6 km northwest of Mount Elliot and 40 km south-southeast of Useless Loop.

Nature of occurrence: The Brown Inlet deposits are located in two north-trending depressions or birridas. The eastern birrida is about 6 km long and 0.6 km wide. The western birrida is approximately 2 km long and is separated into two smaller arms by north-trending vegetated dunes. The eastern arm is about 0.25 km wide and the western arm is about 0.6 km wide. A typical profile through these deposits is 0.5–1 m of kopi or gypsite overlying 2–5 m of seed gypsum on the birrida floor. The origin of the gypsum is probably similar to the origin of other deposits of the Shark Bay area of Pleistocene to Holocene age. Rock gypsum is found in some places below the watertable but it is not continuous even within the same area. The main impurities are clay and carbonate sand in the kopi, and calcium carbonate in the seed gypsum.

Production and usage: None reported, but quality and deposit size may qualify it (after washing and screening) for the export market.

Estimated resources:

Seed — 5 000 000 t of 93% purity (birrida floor, 2–5 m thick);
seed — 200 000 t of 87.3% purity (birrida floor, 1–3 m thick).

Sample results: Results from a bulk sample are given in Table 16.

Remarks: Most data are still confidential.

Reference: Butler (1983).

Relevant tenements: Prospecting Licences 09/07–09, 09/81–82; Mining Leases 09/25–26.

Table 16. Bulk-sample results, Brown Inlet

	Blended %	*Fine* %	*Coarse* %
Gypsum	93.8	96.9	94.4
Sulfate, SO_3	43.63	45.05	43.88
$CaCO_3$	3.61	1.91	3.25
Salt, NaCl	0.77	0.16	0.28
Acid insolubles	0.17	0.14	0.66

Source: Butler (1983)

Cape Peron

Coordinates: 25°36'30" S, 113°29'00" E.

Location: Near the northern end of the Peron Peninsula.

Nature of occurrence: The main Cape Peron birrida is the largest such feature in the Shark Bay area. It is approximately 9 km long, up to 3 km wide, and trends in a northerly direction. Gypsum was deposited in this complex depression which consists of a marine embayment and several on-shore interdunal depressions. It occurs as rock gypsum (at or below the water level), seed (on or near the surface and in dunes), and kopi (usually capping any exposed gypsum outcrop). The thickness of the rock gypsum has not been investigated, but the seed gypsum varies from 1–5 m on the birrida surface and from 1–3 m in dunes, and the kopi varies from 0.3–1.5 m.

Production and usage: No reported production, although tested quality and estimated resources indicate good export potential.

Estimated resources: (old northerly trending dunes within the birrida)
Seed — 8 800 000 t of 96% purity (dune);
seed — 5 500 000 t of 98% purity (dune).

Sample results : None available, although it is known that impurities may consist of clay/silt, SiO_2, NaCl, and $CaCO_3$.

Remarks: Most of the detailed deposit information is still confidential as it is contained in the mining lease reports. The deposit now lies in a recently proclaimed World Heritage Area, thus development is unlikely in the foreseeable future.

Reference: Butler (1985).

Relevant tenement: Mineral Claims 09/25, 09/35–36; Exploration Licence 09/60; Mining Leases 09/07–09.

Cliff Head

Coordinates: 29°31'47" S, 114°49'41" E.

Location: About 400 m east of Cliff Head on/near a north-trending dirt track.

Nature of occurrence: Between a north-trending limestone ridge (on the west) and a densely vegetated flat (on the east) lies a small area of fossiliferous limestone which is overlain locally by crystalline gypsum. This whole area is then overlain by kopi, which is covered in places by sand.

Production and usage: Approximately 9396 t produced between 1989 and 1991 (see Table 6 for reported production and value).

Estimated resources:

Crystalline — 5000 t of 94% purity;
kopi — 16 000 t of 85% purity (north area);
kopi — 10 000 t of 75% purity (south area).

Sample results : de la Hunty and Low (1958) gave analyses for six samples ranging from 74.60% to 96.46% $CaSO_4.2H_2O$ (gypsum).

Remarks: de la Hunty and Low (1958) presented a map and additional data on this deposit.

Reference: de la Hunty and Low (1958); McMath (1951).

Dooka

Coordinates: 29°20'47" S, 114°59'02" E.

Location: About 11.3 km southeast of Dongara.

Nature of occurrence: The deposit is in a depression between two sets of north-trending sand dunes about 1.2 km apart. Crystalline gypsum, exposed in two pits and several shafts, is overlain by kopi, sand, and lime sand. The two pits reached 3 and 4 m in depth and were still in crystalline gypsum. Kopi covers the crystalline gypsum and may reach one metre in thickness. Figure 16 illustrates the outline of the deposit, the drill hole locations with gypsum intervals intersected, and isopachs for the deposit.

Production and usage: Production of 8242 t was reported in 1991, believed to have been used mainly for settling clays in the Eneabba heavy-mineral sands mines.

Estimated resources: Potential resources were estimated by de la Hunty and Low (1958) to be 60 000 t of 90–95% purity, and by Denman (1986) as approximately 1 200 000 t of plaster-manufacturing and agricultural quality. Drilling of one of Denman's (1986) three prospective areas yielded the following data (from Denman, 1987):

Block 1 — 68 000 t of 93.6% purity (+4 m thick);
Block 2 — 138 000 t of 89.0% purity (2–4 m thick);
Block 3 — 93 000 t of 88.3% purity (0–2 m thick).

Sample results : Average analyses (from Denman, 1987) for individual resource blocks as indicated on Figure 16 (140 samples collected and 80 analysed) are given in Table 17.

A representative sample was given to the author in 1989 by Mr Giles, holder of the (then) current tenement. The analytical results on this single sample are given in Appendices 1 and 2.

Remarks: The full extent of this deposit remains unknown as only one area of outcrop was drilled and described. See also 'Cliff Head'.

Reference: de la Hunty and Low (1958); Denman (1986); Denman (1987).

Relevant tenement: Prospecting Licence 70/426; Mining Lease 70/321.

Table 17. Average analyses for the Dooka deposit

	Block 1 %	*Block 2* %	*Block 3* %
Gypsum	93.6	89.0	88.3
Total Sulfur	17.5	16.6	-
Limesand	6.1	10.4	11.1
Iron Oxide	0.02	0.02	0.02
Silica	0.08	0.08	0.08
Salt (NaCl)	0.06	0.12	0.12

Source: Denman (1986)

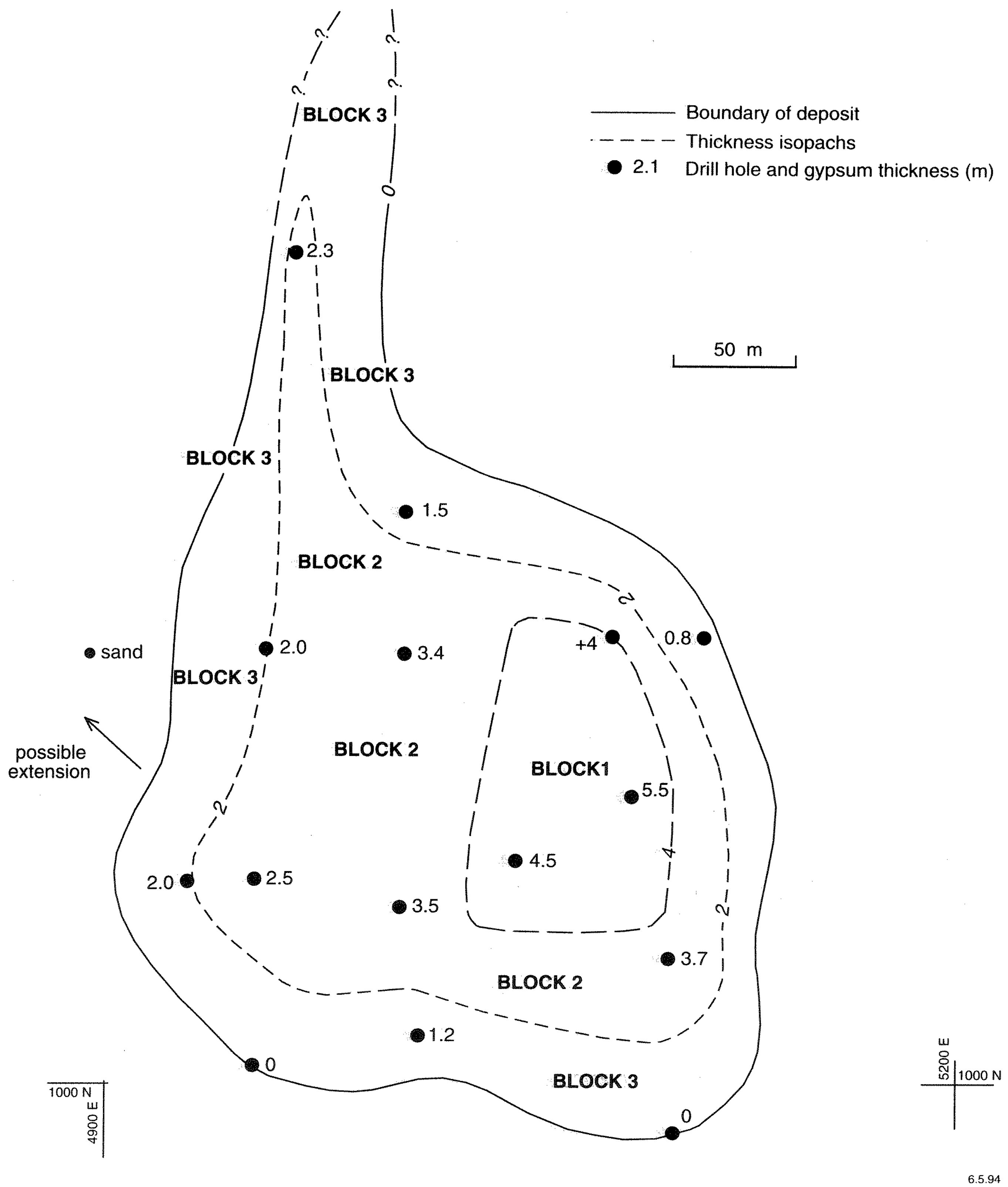


Figure 16. Plan of the Dooka deposit showing gypsum isopachs, drill-hole locations, and resource blocks (modified after Denman, 1987)

Jurien Bay North

Coordinates: 30°12' S, 115° 00' E.

Location: Approximately 12 km north of Jurien.

Nature of occurrence: Gypsum is present in a salt lake occupying a former lagoon in a belt of coastal sand dunes. Drilling on the lake indicates that it is occupied by a thin sequence of gypsiferous and shell-bearing Holocene muds resting on calcreted Pleistocene limestone. In the central-northwestern third of the lake, these sediments are overlain by crystalline gypsum, comprising an upper 25 to 50 cm of finely crystalline material, overlying well-crystallized gypsum that extends to a maximum depth of 5 m below the surface. The gypsum contains appreciable clay towards its base, and overlies grey carbonate/gypsum mud that becomes shelly near the underlying calcrete.

Production and usage: None as yet.

Estimated resources: Based on drilling and surface measurements, the following resources have been calculated:

Measured	1 200 000 t;
indicated	945 000 t;
inferred	660 000 t.

Sample results: Results of three drillhole samples reported by Woods (1991) are listed in Table 18. Results indicate that after washing and drying, the crystalline material contains from 97.2% to 98.5% gypsum, 0.100% to 0.130% salt, and negligible silica.

Remarks: The deposit is being investigated as a source of gypsum for plaster manufacture and agriculture.

Reference: Woods (1991).

Table 18. Analytical results from the Jurien Bay North deposit

Element	*Sample numbers*		
	4	*18*	*19*
		Percent	
Ca (as $CaSO_4.2H_2O$)	98.5	97.2	97.6
Cl (as soluble NaCl)	0.13	0.10	0.10
Si (as SiO_2)	0.20	0.20	0.32
C (as CO_3)	0.75	0.75	0.95
Total	**99.58**	**98.25**	**98.97**

Source: Woods (1991)

Lake MacLeod

Coordinates: 24°10' S, 113°40' E.

Location: Approximately 30 km east of Cape Cuvier (Figure 17).

Nature of occurrence: Gypsum occurs on the surface and within the sediments of a saline playa, formed by the barring of a former marine embayment (Hocking et al., 1987, p. 14). The estimated thickness of the evaporite sequence is reported to reach 12–15 m and includes predominantly gypsum and halite. Gypsum was reported to occur in granular, crystal, recrystallized and bedded forms. Dunes formed alongside the lake and on the lake surface also contain varying amounts of gypsum as kopi (Figure 17).

Production and usage: None reported. Potential production would need to be for export as this location is too remote for the domestic market.

Estimated resources: Unknown because a full evaluation has never been conducted. Data from 13 core holes drilled along the centre of the southern portion of the lake (Figure 17) indicate that between 1–5 m of gypsum occurs on or near the surface of the lake (Figure 18). If an average thickness of 2 m of gypsum is assumed to underlie only 260 km^2 of the lake surface then the potential resource would be in excess of 1 000 Mt. Potential halite resources could also approach 1 000 Mt. Further resources of gypsum may occur in the dunes marginal to the lake, but again, the potential of these has not been assessed.

Sample results : Six samples of gypsum taken at random from just below the lake bed by Dampier Salt Pty Ltd were tested by the Chemistry Centre (W.A.). The tests were aimed at determining whether the high chloride content could be reduced by simple washing procedures. The samples were treated firstly in bore water obtained from near Lake MacLeod, then in tap water, and finally in distilled water. It was found that washing in bore water alone could reduce the initial chloride content from an average 1.68% (equivalent to 2.75% salt) to between 300 to 600 ppm chloride (500 to 1000 ppm salt). Further treatment with tap water followed by distilled water lowered the chloride content to less than 200 ppm. A composite sample of splits washed in bore water alone was found to contain 31.3% CaO (96% gypsum) and 0.24% silica. The silica content could be lowered if the minus 300 micron fraction was removed during washing. Trace element analyses indicated that the gypsum contains from 1000 to 1700 ppm strontium and 150 to 300 ppm zirconium. X-ray diffraction analyses on six samples showed them to consist predominantly of gypsum, with less than one percent quartz.

Remarks: Connolly (1960b) referred to Lake MacLeod as 'Salt Marsh salt lake'. Alderman (1967) investigated the lake brines for potential potash, phosphate, and salt production and a commercial facility for salt production was eventually established. Further information on the origin of this deposit is given in the section *Barred basin and birrida deposits*.

Reference: Connolly (1960b); Alderman (1967); Low (1976); Denman and van de Graaff (1981).

Relevant tenements: Temporary Reserves 70/3420, 70/3491, 70/4202 and Special Agreement M 245SA.

Lake MacLeod East

Coordinates: 24°17' S, 113°48' E.

Location: Approximately 33 km east of Cape Cuvier on the southeastern shore of Lake MacLeod.

Nature of occurrence: Gypsum deposits occur at three locations near the east shore of Lake MacLeod (Nos. 1–3, Fig. 17). These deposits appear to be the result of a previously developed lake pattern, now re-exposed. The following descriptions are taken from Connolly (1960a).
Deposit No. 1 has +0.6 m (limit of hand-auger drilling) of crystalline gypsum, overlain by a thin layer of kopi or soil, over an area of about 710 685 m^2.
Deposit No. 2 has approximately one metre of kopi, overlain by soil and vegetation, and underlain by an unknown thickness (?1–2 m) of crystalline gypsum. The area of kopi coverage, for resource estimation purposes, is about 2 926 000 m^2.
Deposit No. 3 appears to occupy a former north-trending drainage depression and is described as one metre of consolidated kopi overlying ?+2 m of bedded crystalline gypsum. This deposit has an areal extent of about 2 300 000 m^2.

Production and usage: None reported, although a small pit was opened for use on nearby access tracks.

Estimated resources: The following resource estimates are taken from Connolly (1960a) and based on a one-metre average thickness.

Deposit No. 1 — 960 000 t of ?85% purity (bedded crystalline, average 0.6 m thick);
Deposit No. 2 — 4 000 000 t of ?78.8% purity (bedded crystalline, average 0.6 m thick);
Deposit No. 3 — 4 500 000 t of 97.9% purity (bedded crystalline, thickness over 1 m).

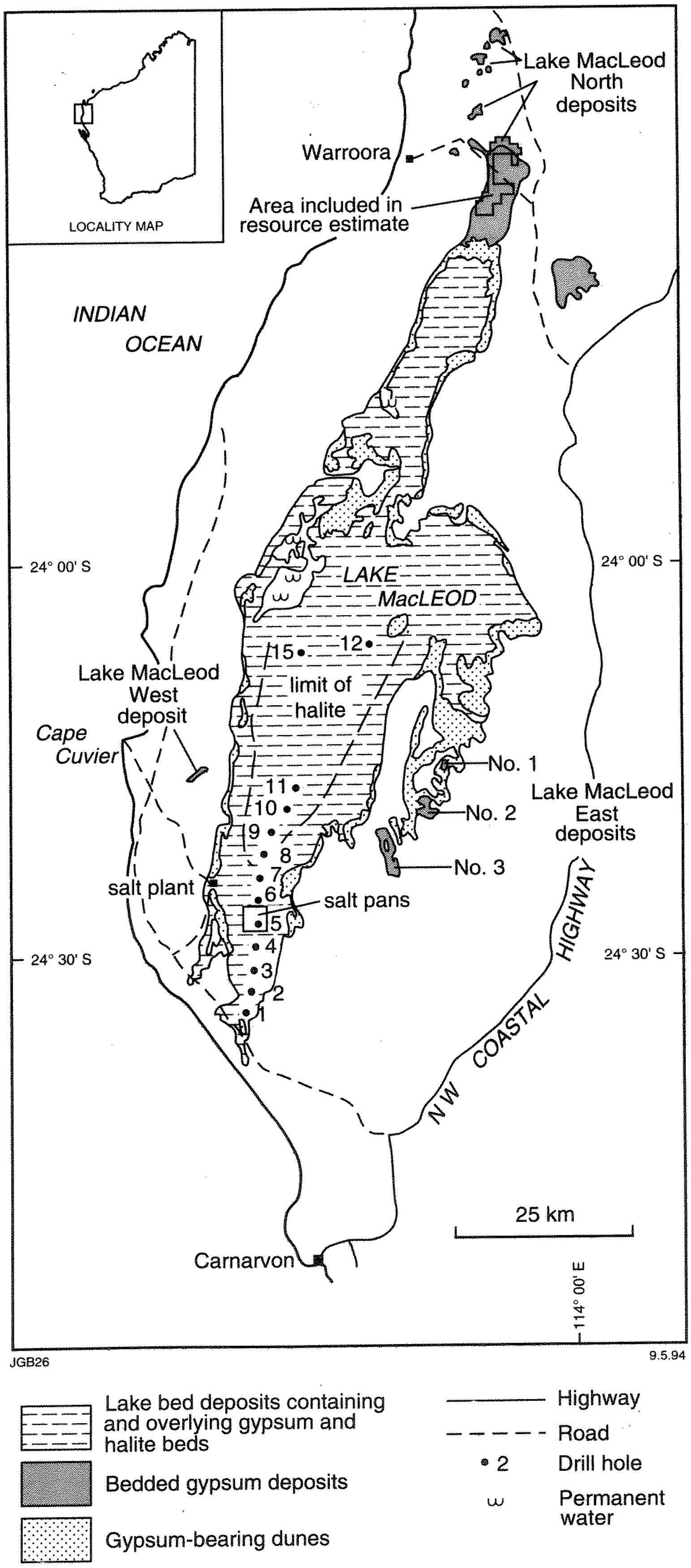


Figure 17. Map of the Lake MacLeod region showing distribution of gypsum deposits and areas tested by drilling

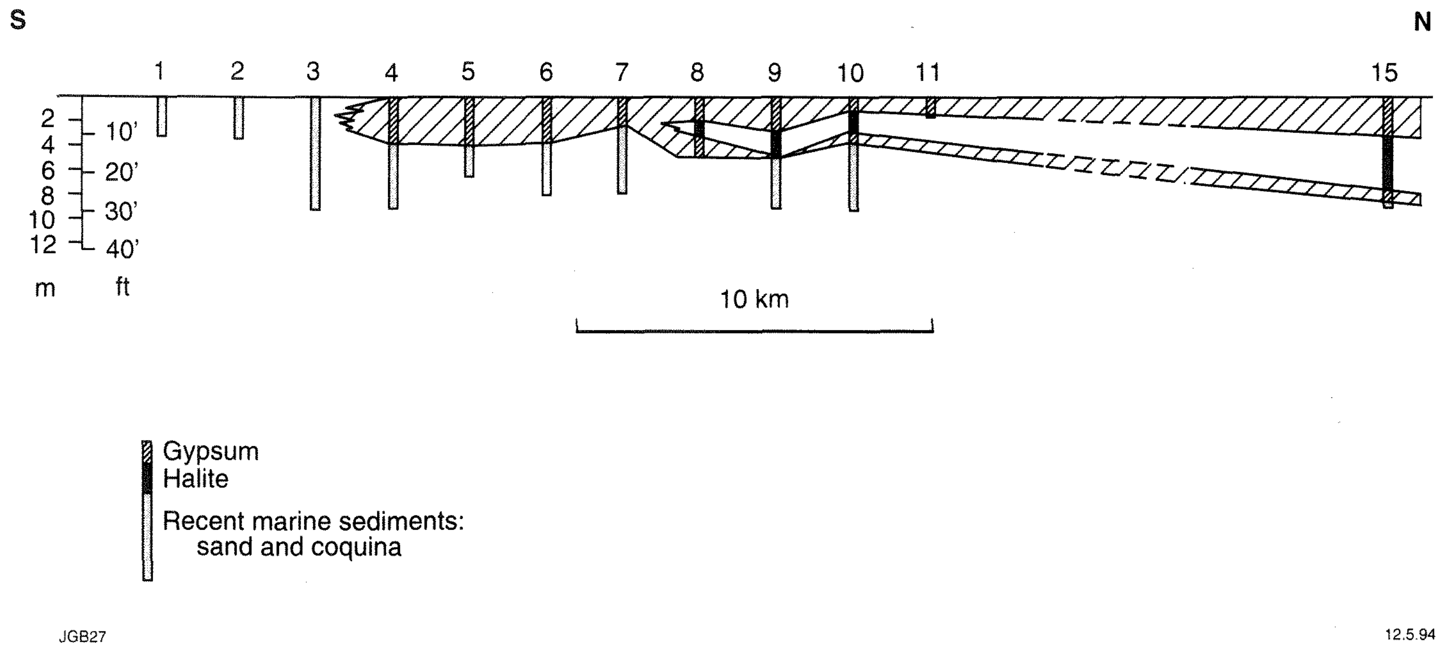


Figure 18. North–south cross section through the Lake MacLeod sediments (after Alderman, 1967)

The 1987 report of Cape Cuvier Exploration and Mining gives an indicated resource of 146 Mt for Deposit No 1. Low (1976) stated that 'gypsum ranges down to about 3.5 m below the ground surface; but the average thickness of the better quality material is probably much less than this'.

Sample results: Results of samples collected by Connolly (1960a) are given in Table 19.

Remarks: Connolly (1960a) investigated these occurrences and his report forms the bulk of the available information. The deposits are also indicated on the Quobba 1:250 000 geological sheet.

Reference: Connolly (1960a); Low (1976); Denman and van de Graaff (1981); Cape Cuvier Exploration and Mining (1984–89).

Relevant tenements: Exploration Licences, 09/53, 09/54; Mining Lease 09/16.

Table 19. Analytical results from the Lake MacLeod East deposit

	Deposit No. 1		*Deposit No. 2*		*Deposit No. 3*	
	A	*B*	*A*	*B*	*A*	*B*
	%		%		%	
Gypsum	84.2	90.5	78.8	94.7	95.0	97.9
CaO	30.2	31.4	29.1	32.0	32.6	32.2
NaCl	0.14	0.03	0.08	0.29	0.07	0.06
Acid insolubles	6.30	3.60	11.3	0.94	0.75	0.56
Fe	0.63	0.33	–	–	–	–

Source: Connolly (1960a)

Lake MacLeod North

Coordinates: 23°29' S, 113°56' E.

Location: The largest deposit is approximately 11 km east of Warroora Station, at the northern end of Lake MacLeod (Fig. 17). A smaller deposit is located to the southeast and nine much smaller deposits lie west, northwest, and north of the major deposit.

Nature of occurrence: Information is unavailable for all except the largest of these deposits. Connolly (1960a) gave a description of gypsum exposed in a pit located approximately 4.8 km west of the Lyndon River crossing on the Minilya–Warroora Road. He observed one metre of mixed kopi and crystalline bedded gypsum, underlain by a dark-red clay, and overlain by 0.3 m of gypsiferous clay. Another investigator, Wolzak (1985), mentioned the northern portion of this deposit as consisting of 0.5–1.0 m of shallow bedded gypsum composed of equal parts of weathered bedded gypsum overlying medium- to coarse-grained crystals. The most extensive study recorded was conducted by Great Boulder Mines Limited in about 1970 and concluded that there was 0.2–1 m of soil cover over 0.9 – +1.5 m of gypsum (the hand-auger drilling was limited to 1 m).

Production and usage: None reported, although several small pits have been noted which probably supply material for surfacing tracks.

Estimated resources: (the resource study area is indicated on Fig. 17)

Crystalline — 32 000 000 t of 93.5% purity (bedded);
crystalline/seed — 10 800 000 t of +90% purity (bedded);
?seed — 45 000 000 t of 87.3% purity (?dune);
?kopi/seed — 1 000 000 t of 92.6% purity (dune).

Sample results:

Gypsum ($CaSO_4.2H_2O$)	95.5%
total lime (CaO)	31.4%
sodium chloride (NaCl)	1.15%
acid insolubles	1.33%

Analyses conducted on air-dried sample and reported by Connolly (1960b).

Remarks: Connolly (1960b) referred to Lake MacLeod as 'Salt Marsh salt lake'. The group is also known as the Lyndon River deposits.

Reference: Connolly (1960b); Hocking et al. (1984); Wolzak (1985).

Relevant tenements: Mineral Claims 08/1076–1115, 08/1272–1274, 08/1313–1318, Exploration Licence 08/56, 08/275, 08/386, 08/442, 08/453, Mining Leases 08/42–44.

Lake MacLeod West

Coordinates: 24°15' S, 113°29' E.

Location: On Quobba Station approximately 12.5 km southeast of Cape Cuvier and the Texada Jetty used by Dampier Salt Pty Ltd to load salt for the export market.

Nature of occurrence: Gypsum occurs near the west shore of Lake MacLeod at one reported location (Fig. 17). It has formed in a large sink hole, approximately 460 m long, 30 m wide, and 2.4 m deep, and comprises one metre of consolidated kopi overlying 1.4 m of hard-packed granular gypsum. Hand-auger drilling down to the watertable, 1.2 m below the bottom of the sink hole, showed gypsum (?bedded crystalline) extending the full depth. The groundwater was highly saline.

Production and usage: None reported.

Estimated resources: A 2 Mt indicated resource was considered 'conservative' by Unimil Pty Limited in 1983.

Sample results : One channel and auger sample of kopi, and granular and bedded gypsum. Tests were done on an air-dried sample.

Gypsum ($CaSO_4.2H_2O$)	91.1%
total lime (CaO)	32.4%
sodium chloride (NaCl)	1.60%
acid insoluble	1.17%

Remarks: Deposits are indicated on the Quobba 1:250 000 geological sheet. Connolly (1960b) referred to Lake MacLeod as 'Salt Marsh salt lake'.

Reference: Connolly (1960b); Low (1976); Denman and van de Graaff (1981).

Relevant tenement: Prospecting Licences 09/51–52, 09/264; Exploration Licences 09/53, 09/477; Mining Lease 09/17.

Useless Loop

Coordinates: 26°13'15" S, 113°25'15" E.

Location: Approximately 9 km south of Useless Loop township.

Nature of occurrence: The Useless Loop birrida trends northerly and is approximately 4 km long and 2 km wide. It contains rock gypsum (at or below the watertable), seed gypsum (on the birrida floor and in truncated dunes), and kopi (capping the dunes and birrida floor). Interbedded, underlying or overlying calcareous sand, travertine, silica sand, clay, and iron complicated the mining of this deposit and formed most of the impurities in the raw gypsum.

Production and usage: Total reported production is 2 494 282 t (Table 6), all exported. To meet buyers' requirements, the seed and rock gypsum had to be washed and screened before shipping.

Estimated resources (pre-mining):

Seed — 1 100 000 t of 90–99% purity (dune and birrida floor down to the watertable, between 2.4 and 4.0 m thick).

Remarks: The deposit has been mostly mined out and the mining leases have been surrendered.

Reference: Butler (1981).

Relevant tenements: Mining Leases 09/06, 09/22–24.

Bedded evaporites in Phanerozoic basins

(by R. M. Hocking)

Introduction

Evaporites occur in the Officer, Bonaparte, Canning, and Carnarvon Basins, either as bedded intervals or as diapiric structures sourced from deeper bedded evaporites. Little attention has been paid to gypsum and anhydrite contents of these, although in the Carnarvon and Canning Basins the potential of the evaporite-bearing sequences for economic potash reserves has been investigated.

Late Proterozoic evaporites are present in the Officer Basin at two stratigraphic levels, and widespread diapiric activity has occurred. Silurian–Devonian evaporites are present in the Bonaparte, Canning, and Carnarvon Basins, and probably all are synchronous. The most extensive and thickest evaporitic sequence is in the Canning Basin, with lesser developments in the Carnarvon and Bonaparte Basins. All the evaporitic sequences contain some anhydrite, but the principal evaporite mineral in salt beds is halite. The evaporites in the Bonaparte Basin are not discussed further because they occur solely in the offshore, northern portion of the Bonaparte Basin (Mory, 1988; Gunn, 1988).

Gypsum occurs in Cretaceous black shales in the Carnarvon Basin, as an oxidation product from pyrite and perhaps as primary bedded gypsum. Permian black shales also contain disseminated and fibrous secondary gypsum, but are not discussed further because of the small quantity of gypsum involved.

Carnarvon Basin

Silurian–Devonian

Stratigraphic interval: Bedded evaporites occur within the Upper Silurian–?Lower Devonian Dirk Hartog and Sweeney Mia Formations (Figs 19, 20, 21), which extend through the western half of the onshore Carnarvon Basin in the subsurface. Their occurrence was described by Wells (1980) and summarized by Hocking et al. (1987). Anhydrite has been reported from most petroleum exploration wells that intersected the unit, but thick intersections of evaporite minerals are restricted to the Yaringa Evaporite Member, which occurs within the upper Dirk Hartog Formation in the

Hamelin Pool area (Fig. 20). Hocking et al. (1987) revised Silurian stratigraphic nomenclature, so that some evaporite occurrences which are recorded as from the Dirk Hartog Formation (Playford et al., 1975; Wells, 1980) are actually from the Sweeney Mia Formation. This includes virtually all occurrences north of Shark Bay. Salt flowage has not been detected on seismic profiles, but, nevertheless, may still be present because seismic data in the Shark Bay area is old and of poor quality.

Location: The Yaringa Evaporite Member has been intersected by Yaringa 1, Hamelin Pool 1 and 2, and Tamala 1 in the Shark Bay area. Wells which intersected the Dirk Hartog Formation and Sweeney Mia Formation are shown in Figure 22.

Depth and extent: On the eastern side of Hamelin Pool, the top of the Sweeney Mia Formation is 150 to 200 m below the surface. The top of the Dirk Hartog Formation is at depths of 700 to 800 m, and the top of the Yaringa Evaporite Member is at 1100 to 1200 m depth. Between Hamelin Pool and the Murchison River to the south, the Dirk Hartog Formation and thus the Yaringa Evaporite Member (if it extends south of Shark Bay) should subcrop at progressively shallower depth. Wells (1980) considered that significant evaporites were only present in a closed basin centred on Hamelin Pool (Fig. 22), based on thinning of the Yaringa Evaporite Member to the southeast.

Quality: The only major exploration program — unsuccessful — has been for potash rather than gypsum or anhydrite, and was conducted in the early 1970s, after halite was discovered in Yaringa 1 (Pendery et al., 1969). Anhydrite occurs mostly as nodules and fracture fillings (Hocking et al., 1987), rather than as beds. Analytical results are not available.

Cretaceous

Stratigraphic interval: Large laths and plates (up to 50 cm across and 1 to 3 cm thick) of translucent gypsum weather out of the Gearle Siltstone in the core of the Giralia Anticline.

Location: Although the Gearle Siltstone outcrops, or is present immediately beneath surficial dirt, over much of the Carnarvon Basin north of the Gascoyne River, gypsum is only noticeable in the core of the Giralia Anticline, on Cardabia Station east of Coral Bay.

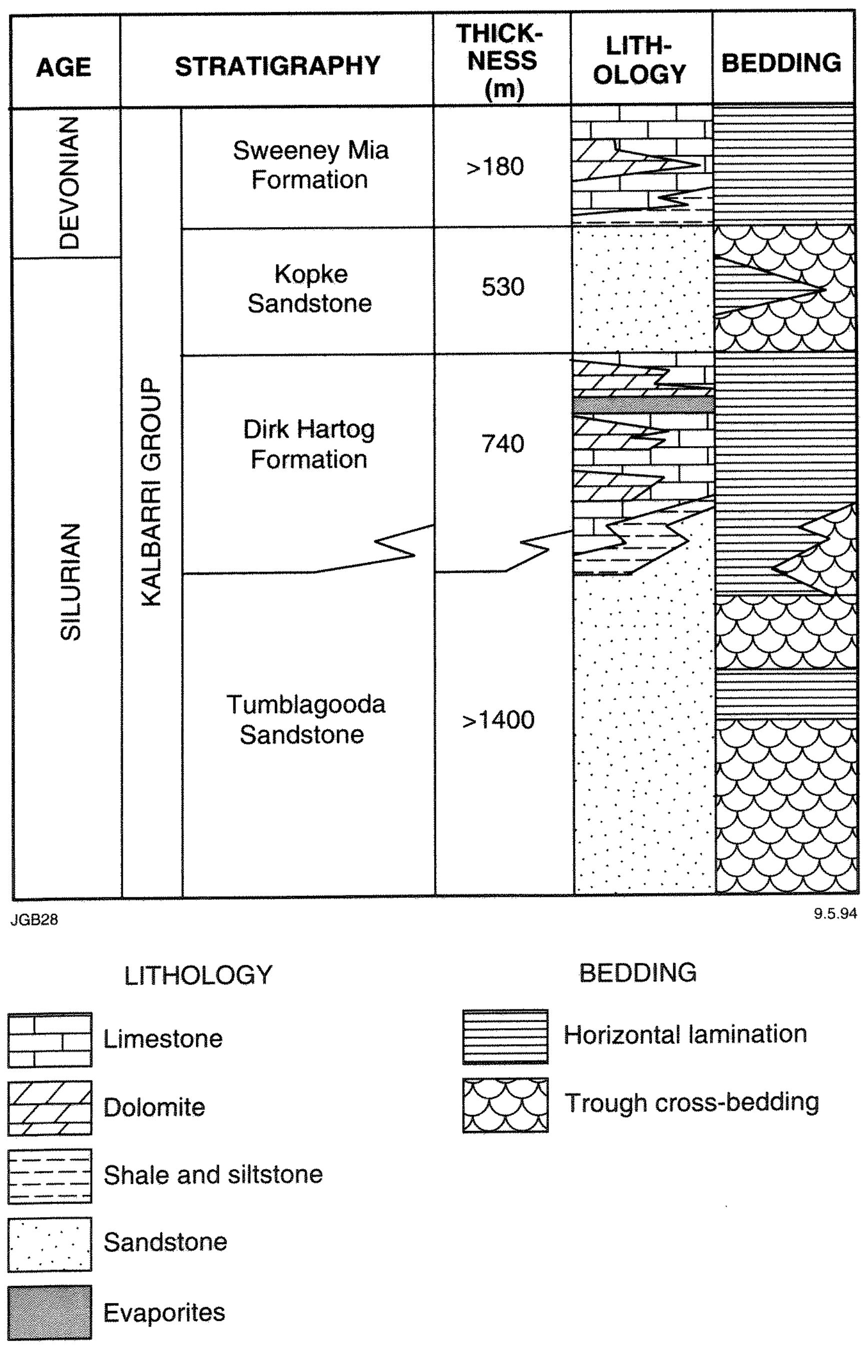
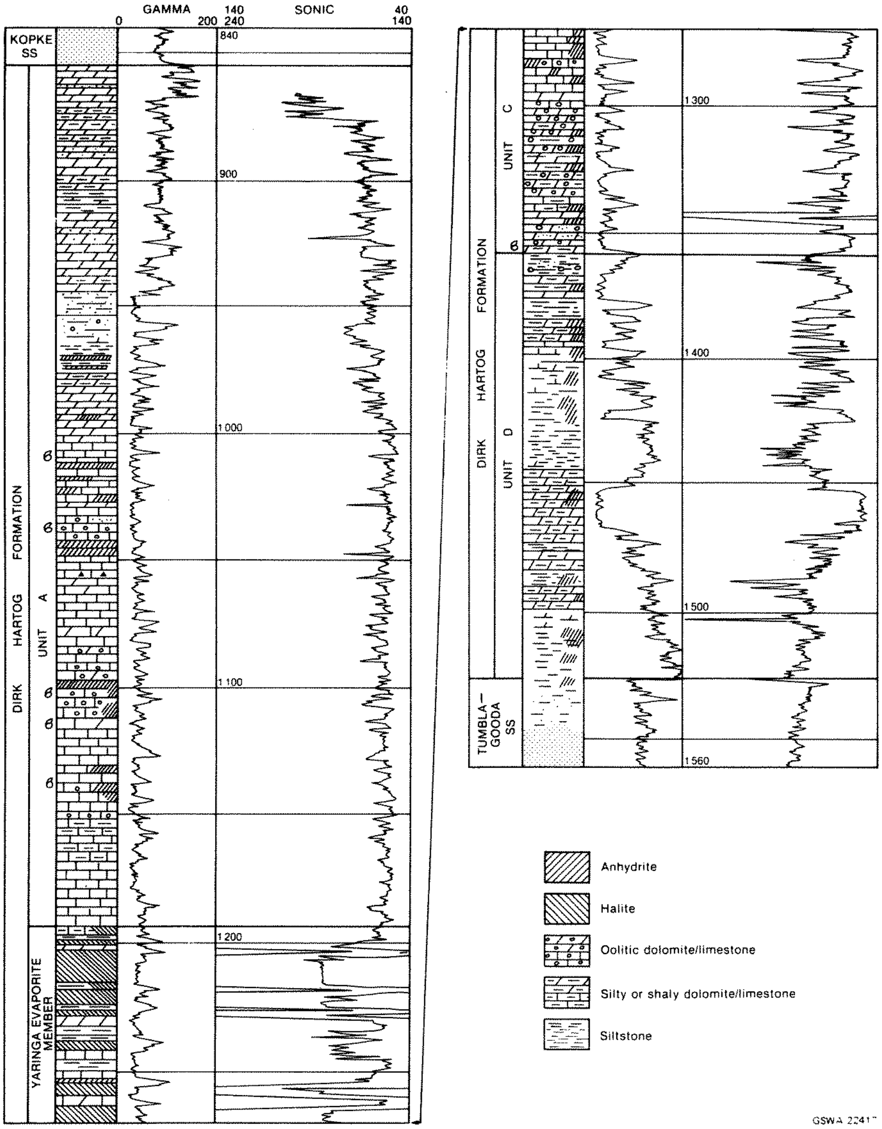


Figure 19. Summary of the Silurian to ?Early Devonian stratigraphy in the Carnarvon Basin (from Hocking, 1991)



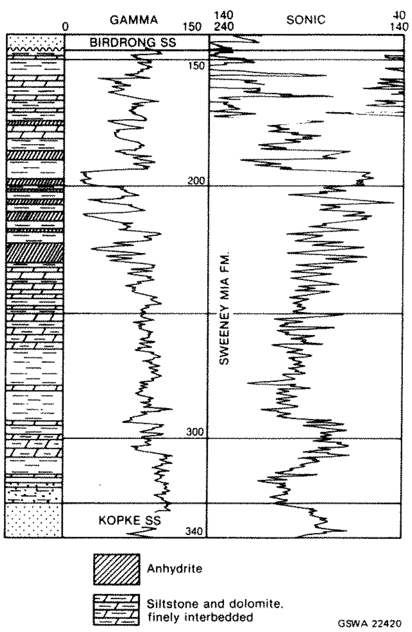


Figure 20. **(top) Dirk Hartog Formation in Yaringa 1 (from Hocking et al., 1987)**

Figure 21. **(left) Type section of the Sweeney Mia Formation in Yaringa 1 (from Hocking et al., 1987)**

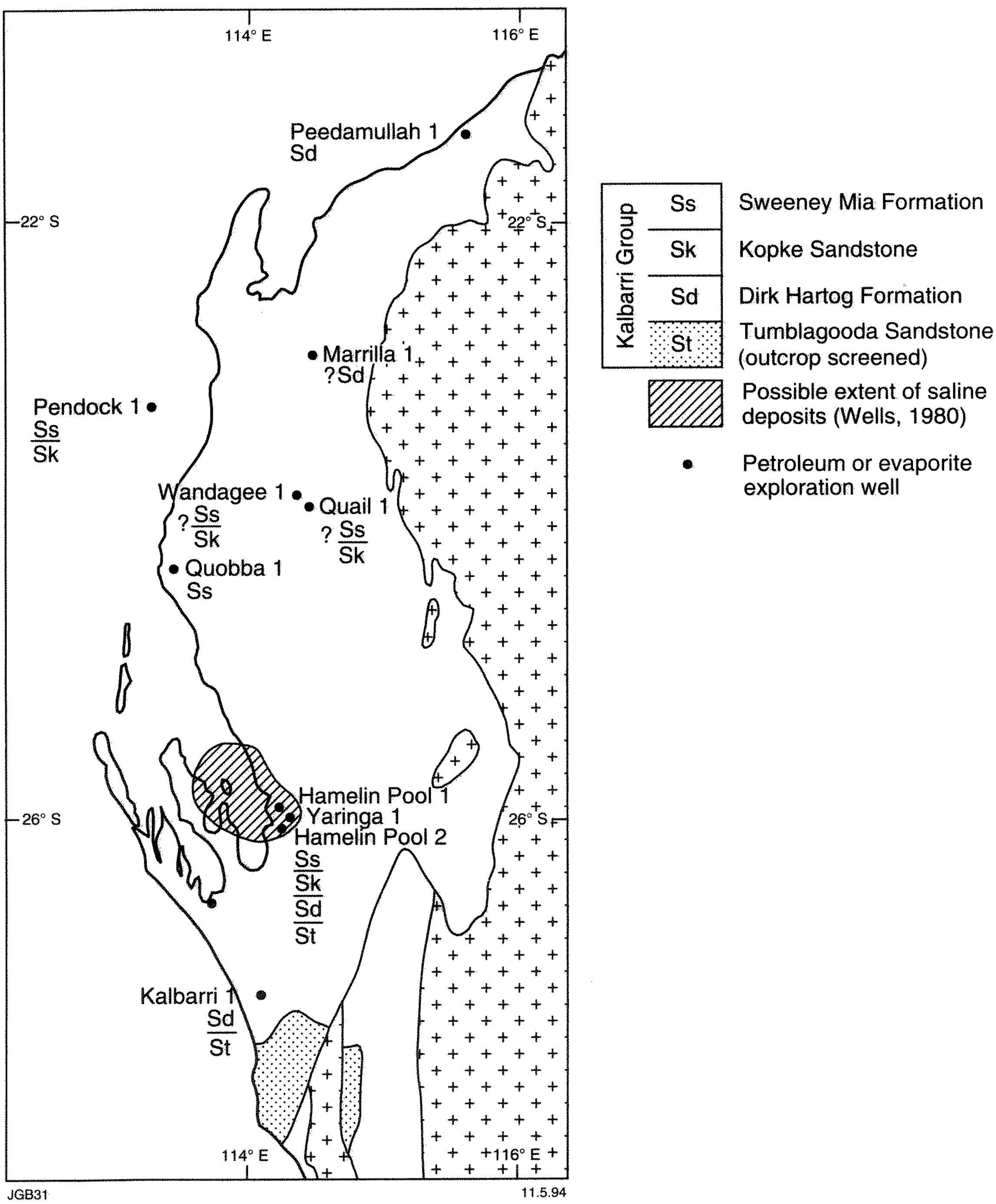


Figure 22. Location of Silurian intersections in wells in the Carnarvon Basin, and extent of evaporites (after Wells, 1980)

Mode of occurrence: Some gypsum plates are secondary fracture fillings, but some follow bedding and may be primary bedded gypsum. Alternatively, they may have crystallized out along bedding plane partings. The best exposures are in dams and similar excavations. As well, barite geodes with gypsum cores are present in some dams in the core of the anticline.

Quality: No analytical results are known, and the estimated resources are small, because of the mode of occurrence.

Canning Basin

Silurian–Devonian

Stratigraphic interval: Bedded evaporite minerals occur in the Upper Silurian to Lower Devonian Carribuddy Group. The evaporites were described by Wells (1980), and the Carribuddy Group by Lehmann (1984). The group contains two evaporite units, the Minjoo and Mallowa Salts (Lehmann, 1984). These are separated, overlain and underlain by red-bed carbonate and argillaceous deposits (Fig. 23). The Mallowa Salt is Australia's largest known halite deposit, and was described and interpreted by Cathro et al. (1992). Significant salt flowage has occurred in some areas (Wells, 1980).

Location: The most complete intersections of the Carribuddy Group are in Kidson 1, Sahara 1, Willara 1, and McLarty 1. These wells lie in the Kidson or Willara Sub-basins, or the adjacent part of the Broome Platform. This area is in the central– southern Canning Basin, remote from any major settlements (Fig. 24).

Depth and extent: The Carribuddy Group has not been intersected north of the Fenton Fault System (in the Fitzroy Trough and Lennard Shelf), but is probably present at depth. In the key wells, the top of the group ranges from 600 to 2700 m depth, and the top of the salt-bearing portion of the group from 675 to 2950 m depth. The depth increases to the southeast from the Broome Platform into the central Kidson Sub-basin.

Quality: Anhydrite occurs as nodules and fracture fillings throughout most of the Carribuddy Group. The Mallowa and Minjoo Salts are dominated by halite. Cathro et al. (1992) noted that the Mallowa Salt contains about 1% anhydrite, typically in beds less than 4 cm thick.

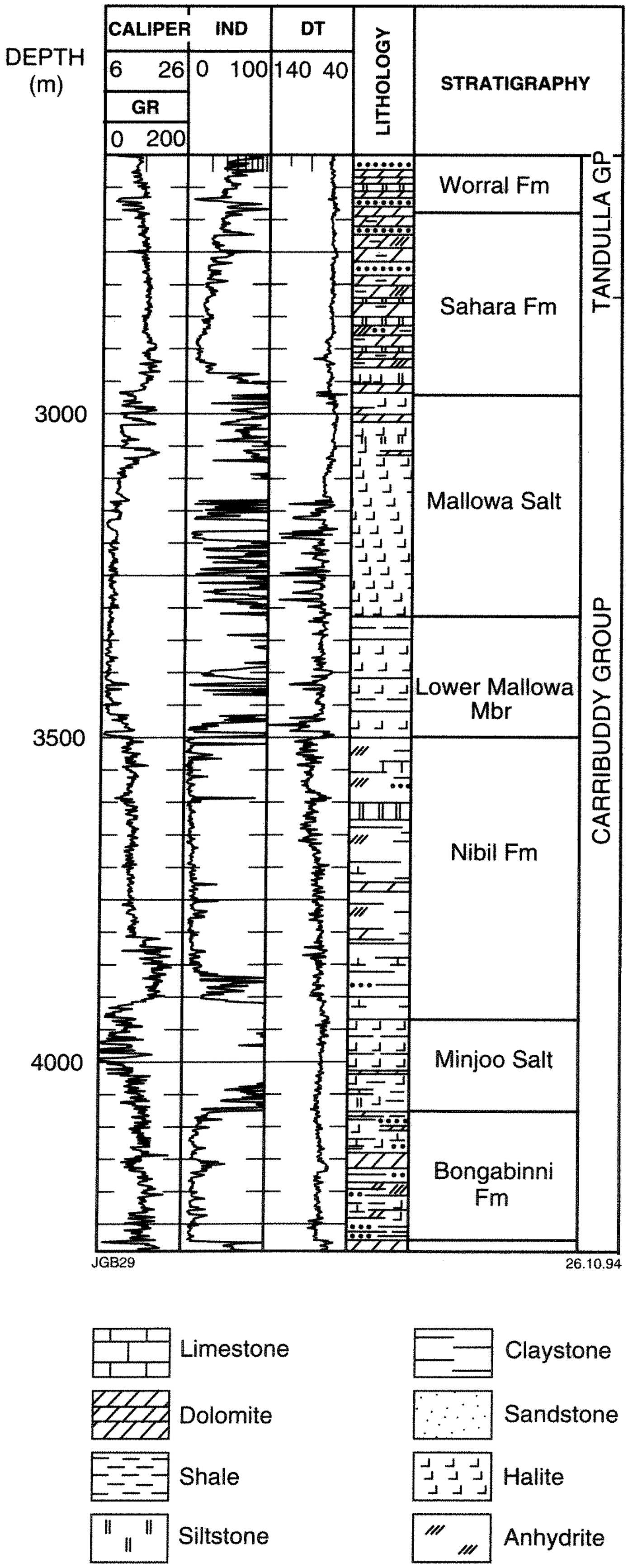


Figure 23. Pre-Devonian sequence in Kidson 1

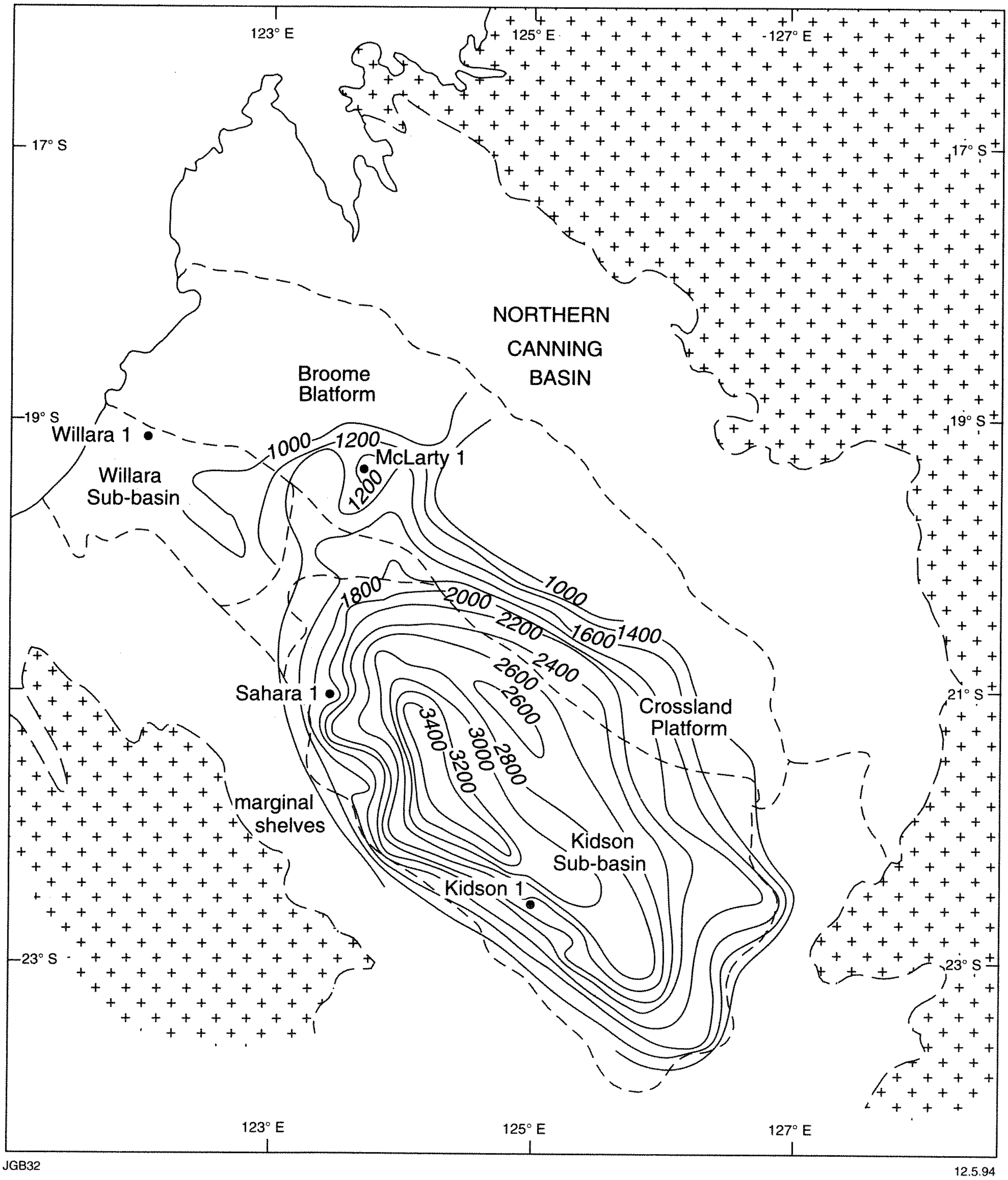


Figure 24. Subdivisions of the onshore Canning Basin, key intersections of Carribuddy Group, and isopach contours of Carribuddy Group (after Wells, 1980)

Officer Basin

Stratigraphic interval: Diapiric structures are widespread in the Officer Basin, and have been described in varying detail by Wells (1980) and Jackson and van de Graaff (1981). Phillips et al. (1985) and Townson (1985) described the northern and central Officer Basin respectively, and included some details of the evaporites. Wells (1980) considered that the cores of the diapirs were sourced from the Late Proterozoic Browne Formation and, to a lesser extent, the Neoproterozoic–Cambrian Babbagoola Formation. Anhydrite and gypsum are present in the diapirs (Wells, 1980; Jackson and van de Graaff, 1981).

Location: The host sequences for the evaporites are exposed only in the Woolnough Hills, and Browne and Madley Diapirs, in the northwestern Officer Basin (Fig. 25). Other diapirs are present near the surface, based on seismic profiles. Most petroleum exploration wells have intersected the evaporite-bearing sequence, within which gypsum is present.

Quality: Because of the comparative isolation of the Officer Basin, there has been little exploration interest in evaporite minerals. Gypsum and/or anhydrite are present throughout the evaporite sequence, and the reader is referred to Wells (1980), who described each evaporite occurrence in detail and presented the available analytical data.

Editor's note: The descriptions presented above predate the Western Australian Basins Symposium (held in Perth in 1994) at which new data regarding the age of the Carnarvon and Canning Basin sequences were presented. The Proceedings of the Symposium have been published in full (Purcell and Purcell, 1994).

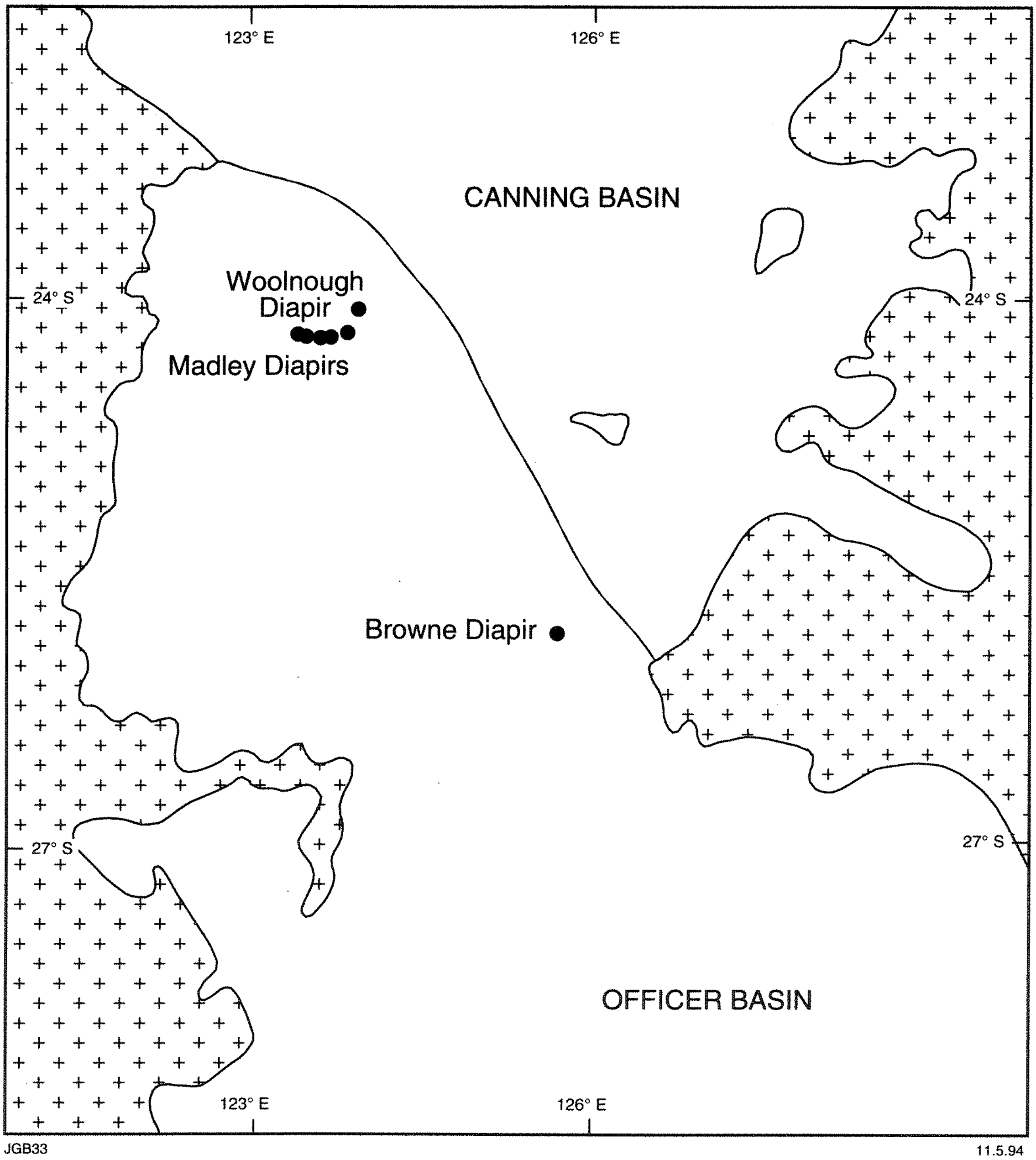


Figure 25. Location of diapirs in Officer Basin

Resource potential

The total known resources of potentially economic gypsum in Western Australia is approximately 1.5 Gt and consists of lake dune, barred basin and birrida deposits. Lake MacLeod hosts the largest single deposit of about 1 Gt and the associated deposits on the east, west, and north of this lake contain another 10–20 Mt. These deposits, and those of the Shark Bay area, could be mined and exported economically if markets existed.

Some of the Shark Bay deposits occur within the recently declared World Heritage Area, and most production from these deposits would have to be loaded at new port facilities proposed at locations also within this protection zone. Consequently, prospects for development are poor at present.

Deposits north of Esperance may also be mined and exported although high land-transport costs make this somewhat unlikely.

In addition to the deposits formed in surface features such as salt lakes, barred basins and birridas, there are very large resources of anhydrite and gypsum contained in various evaporite sequences within older sedimentary rocks. Due to their remoteness and depth, none of these has economic potential at the present time.

Known resources, although by no means fully evaluated at most locations, are of sufficient quality and quantity to supply the local market for hundreds of years (at the current rate of usage) and to allow resumption of gypsum exports when markets permit. Shipments to the Eastern States may also be possible if acceptable transport costs can be negotiated.

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Appendix 1. Chemical analyses of gypsum samples

Deposit	*GSWA No.*	*Analysis (%)* CaO	MgO* (Acid soluble)	SO_3	CO_2	Cl as NaCl	*Calculated composition (%)* $CaSO_4.2H_2O$	$CaCO_3$	NaCl	CaO (Residue by difference)	SO_3	Sand, etc*	*Sample form*
Lake Hillman	103930	25.0	1.02	36.2	0.02	5.23	76.8	0.04	5.23	n	0.5	16.1	kopi
	103931	30.0	0.27	43.4	0.02	2.73	92.1	0.04	2.73	n	0.6	4.3	seed
	103934	31.5	0.19	44.5	0.10	0.32	95.8	0.23	0.32	0.2	n	3.2	seed
	103935	31.6	0.25	43.9	0.74	0.13	94.3	1.68	0.13	n	0.1	3.5	kopi
	103936	31.3	0.28	43.1	0.89	1.10	92.7	2.02	1.10	n	n	3.9	re-xl
	103937	31.7	0.16	45.2	0.11	0.08	97.0	0.25	0.08	n	0.1	2.4	seed
	103950	32.2	0.15	45.0	0.14	0.20	96.8	0.32	0.20	0.5	n	2.0	seed
	103951	30.2	0.15	42.9	0.11	0.88	92.2	0.25	0.88	n	n	6.5	seed
Lake DeCourcy	103952	2.5	1.75	30.3	2.27	0.32	65.2	5.16	0.32	0.4	n	27.2	seed/kopi
	103953	1.7	3.08	20.8	1.76	1.10	44.5	4.00	1.10	n	0.1	47.2	seed/kopi
	103954	1.6	3.23	20.8	1.47	1.69	44.2	3.34	1.69	n	0.2	47.3	kopi/seed
	103955	9.2	4.23	11.3	0.99	2.56	24.3	2.25	2.56	n	n	66.7	sand/seed
Lake Wallambin	103956	31.5	0.07	44.8	0.03	0.43	96.6	0.03	0.43	0.1	n	3.1	seed
Lake Moore	103958	16.9	1.61	21.3	1.43	0.01	45.8	3.25	0.01	0.2	n	49.1	kopi/silt
	103959	14.7	2.05	19.1	0.87	0.01	41.1	1.98	0.01	0.2	n	54.7	seed
	103960	17.1	2.16	23.0	0.60	0.07	49.5	1.36	0.07	0.2	n	46.7	seed/xls
	103961	14.5	1.58	19.4	0.57	0.45	41.7	1.30	0.45	0.2	n	54.8	seed/soil
	103962	29.7	0.52	40.1	0.94	0.70	86.2	2.14	0.70	0.4	n	10.0	kopi
	103963	31.8	0.32	44.1	0.23	0.45	94.8	0.89	0.45	0.4	n	3.1	kopi
	103964	28.1	1.18	39.5	0.23	0.61	84.9	0.52	0.61	0.2	n	12.6	seed
	103965	28.6	0.86	39.9	0.11	0.11	85.8	0.25	0.11	0.5	n	12.5	seed
	103966	24.5	1.30	34.8	0.06	0.03	74.8	0.14	0.03	0.1	n	23.6	seed
Lake Austin	103967	27.3	0.13	38.5	0.09	0.87	82.8	0.20	0.87	0.2	n	15.8	seed
	103968	23.7	0.30	33.2	0.15	1.27	71.4	0.34	1.27	0.3	n	26.4	seed/xls
	103969	26.2	0.29	36.8	0.07	0.61	79.1	0.16	0.61	0.3	n	19.5	seed
Parker Range	103973	28.1	0.22	39.8	0.26	0.01	85.3	0.59	0.01	n	0.1	14.0	kopi/seed
Lake Rebecca	103974	28.0	0.55	38.6	0.64	0.91	83.1	1.45	0.91	n	n	15.1	kopi
	103975	27.6	0.24	39.6	2.20	0.02	83.8	0.45	0.02	n	0.6	15.1	seed
Beete	103976	25.5	0.28	36.3	0.41	2.03	76.8	0.93	2.03	n	0.6	19.6	seed
	103977	31.2	0.06	45.1	<0.01	0.16	95.8	<0.01	0.16	n	0.6	3.4	kopi/seed
	103978	30.4	0.28	43.6	0.04	2.42	93.1	0.09	2.42	n	0.3	4.1	seed/silt
Scadden	103979	30.3	0.05	43.3	0.14	0.02	92.4	0.32	0.02	n	0.3	7.0	seed
Lake King	103980	30.6	0.54	44.2	0.05	1.03	93.6	0.11	1.03	n	0.6	4.7	kopi
	103981	30.6	0.06	43.7	0.36	0.18	92.4	0.82	0.18	n	0.7	5.9	seed
Lake Magenta	103982	22.7	0.78	20.9	6.62	0.11	43.7	15.50	0.11	n	0.7	40.5	seed/sand
	103983	24.9	0.97	32.2	2.40	0.28	67.0	5.45	0.28	n	1.0	26.3	seed/kopi
	103984	32.0	0.28	37.6	5.00	0.49	78.7	11.40	0.49	n	1.0	8.4	kopi
Lake Cobham	103985	30.6	0.26	43.3	0.43	0.24	92.1	0.98	0.24	n	0.5	6.2	seed
Lake Camm	103986	31.2	0.13	44.6	0.02	0.88	95.8	0.05	0.88	n	n	3.3	seed
Lake Gulson	103987	30.6	0.20	44.2	0.11	0.98	93.6	0.25	0.98	n	0.6	4.6	seed
Mt Walker	103988	19.9	0.08	28.6	<0.01	<0.01	61.1	<0.01	<0.01	n	0.2	38.7	seed
Cliff Head	103989	32.6	0.11	43.3	2.13	0.04	91.8	4.84	0.04	n	0.6	2.7	inter xls

n = not detected; xls = crystals; inter = intergrown; re-xl = recrystallized; * = The acid soluble MgO in the analysis does not figure on its own in the calculated composition. It is included in the 'sand, etc' residue by difference column

Technique — Crushed material was treated with dilute hydrochloric acid and calcium, magnesium and sulfur were measured on the resultant solutions using inductively coupled plasma atomic emission spectrometry. Chloride and carbon dioxide were determined by titrimetric and gravimetric methods respectively.

Analyses conducted by the Chemistry Centre (W.A.), DME, Perth.

Appendix 2. X-ray diffraction determinations on gypsum samples

Deposit	*GSWA No.*	*Sample form*	*Minerals detected (%)* Gypsum	Quartz	Halite	Calcite	Aragonite	K-feldspar	Plagioclase	Kaolin	Illite	Smectite	Others
Lake Hillman	103930	kopi	75–100	<5	5–25	n	–	<5	–	n	n	n	–
	103931	seed	75–100	<5	<5	n	–	n	–	n	n	<5	–
	103932	salt	<5	n	95–100	n	–	–	–	n	n	n	n
	103933	clay	n	<10	<10	n	–	–	–	50–75	10–25	n	n*
	103934	seed	75–100	n	n	n	–	n	–	n	n	<5	–
	103935	kopi	75–100	n	n	n	–	n	–	n	n	n	–
	103936	re–xl gyp	75–100	<5	<5	n	–	<5	–	n	n	n	–
	103937	seed	75–100	<5	n	n	–	n	–	n	n	<5	–
	103944	salt	<1	<1	95–100	n	–	–	–	<1	n	n	<1m
	103950	seed	75–100	<5	n	n	–	n	–	n	n	n	–
	103951	seed	75–100	<5	<5	n	–	n	–	n	n	n	–
Lake De Courcy	103952	seed/kopi	50–75	<5	n	5–25	–	<5	–	5–25	n	n	–
	103953	seed/kopi	25–50	<5	<5	5–25	–	<5	–	25–50	n	n	–
	103954	kopi/seed	25–50	5–25	<5	<5	–	n	–	25–50	n	n	–
	103955	sand/seed	25–50	5–25	<5	<5	–	<5	–	25–50	n	n	–
Lake Wallambin	103956	seed	75–100	<5	n	n	–	n	–	n	n	n	–
	103957	clay/calct	n	<10	n	50–75	–	–	–	25–50	<10	n	n*
Lake Moore	103958	kopi/silt	25–50	5–25	n	<5	–	<5	–	5–25	n	n	–
	103959	seed	25–50	25–50	n	<5	–	<5	–	5–25	n	<5	–
	103960	seed/xls	25–50	5–25	n	<5	–	<5	–	5–25	n	n	–
	103961	seed/soil	25–50	25–50	n	<5	–	<5	–	<5	n	n	–
	103962	kopi	75–100	<5	<5	<5	–	n	–	n	n	n	–
	103963	kopi	75–100	<5	n	n	–	n	–	n	n	n	–
	103964	seed	75–100	<5	n	n	–	<5	–	n	n	<5	–
	103965	seed	75–100	<5	n	n	–	n	–	<5	n	<5	–
	103966	seed	75–100	5–25	n	n	–	<5	–	<5	n	<5	–
Lake Austin	103967	seed	75–100	5–25	<5	n	–	<5	–	<5	n	n	–
	103968	seed/xls	50–75	5–25	<5	n	–	<5	–	n	n	n	–
	103969	seed	75–100	5–25	<5	n	–	n	–	n	n	n	–
Parker Range	103973	kopi/seed	75–100	<5	n	n	n	n	n	5–25	5–25	n	<1 Go

Appendix 2. (*continued*)

Deposit	*GSWA No.*	*Sample form*	*Minerals detected (%)* Gypsum	Quartz	Halite	Calcite	Aragonite	K-feldspar	Plagioclase	Kaolin	Illite	Smectite	Others
Lake Rebecca	103974	kopi	75–100	<5	n	<5	n	n	n	<5	n	5–25p	<1 Int
	103975	seed	75–100	<5	n	n	n	<5	n	5–25	5–25a	n	<1 Go
Beete	103976	seed	75–100	5–25	n	<1	n	n	n	<5	<5	n	n
	103977	kopi/seed	75–100	<5	n	n	n	<1	n	<5	<5	n	<<1 Chl, <1 Int
	103978	seed/silt	75–100	<5	<5	n	n	<1	n	<5	<5	<5	<1 Al, <<1 Chl, <1 Int
Scadden	103979	seed	75–100	<5	n	n	n	<1	<1	<5	<5	n	<1 Go, <<1 Chl
Lake King	103980	kopi	75–100	<1	<5	<1	n	n	<1	<1	<1a	<5p	<1 Int
	103981	seed	75–100	<5	<1	n	<1	n	<1	<1	<1	n	n
Lake Magenta	103982	seed/sand	25–50	5–25	n	5–25	n	n	n	5–25	5–25	n	n
	103983	seed/kopi	50–75	<5	n	5–25	n	n	n	5–25	5–25	n	n
	103984	kopi	50–75	<5	<1	5–25	n	n	n	<5	<5	<1p	n
Lake Cobham	103985	seed	75–100	<5	n	<1	<<1	<1	<1	<5	<1	<1p	n
Lake Camm	103986	seed	75–100	<5	<1	n	n	<1	n	<5	n	n	n
Lake Gulson	103987	seed	75–100	<1	<1	<1	n	<1	n	<5	<5	<1p	n
Mt Walker	103988	seed	50–75	5–25	n	n	n	n	n	5–25	<1	n	<5 Al, <1 Go
Cliff Head	103989	inter xls	75–100	<1	n	<5	<5	n	n	<1	n	n	<5 Int

X–RD = X–Ray Diffraction; n = not detected; re–xl = recrystallized; calct = calcite; xls= crystals; inter = intergrown; a = altered illite (shift in X–RD spacing consistent with minor alteration to smectite); p = probable smectite (not confirmed by glycerol or heat treatment); Go = goethite; Chl = chlorite; Al = Alunite Series (majority of lines consistent with natroalunite); Int = interlayered clay; * = the wide percentage ranges reported for these samples reflect a lack of chemical analyses to refine the results; m = the 'other' mineral is poorly crystalline with X–RD peaks in the vicinity of the major peaks for natroalunite. Also minors detected in residue after dissolving halite.

Samples 103973–103989:

- Kaolin percentage may include halloysite;
- Confirmation of smectite and smectite clays not attempted;
- Amorphous iron compounds may be present. A number of samples contain iron-rich particles or iron-stained clays but do not have a detectable X–RD goethite peak.

Analyses conducted by the Chemistry Centre (W.A.), DME, Perth

Appendix 3. Location of gypsum deposits by region (Locality numbers are shown on Plate 1)

Deposits in palaeodrainage systems

Southwest and Murchison regions

1 Baandee
2 Boodarockin
3 Bodallin
4 Boondi
5 Burran Rock
6 Carnamah
7 Chandler
8 Cookernup Siding
9 Coorow Siding
10 Cowcowing Lakes
11 Cunderdin
12 Damboring Lake
13 Elphin Siding
14 Eva Lake
15 Gunyidi
16 Hamersley Lakes
17 Hines Hill
18 Jilakin Lake
19 Kellerberrin
20 Lake Burkett
21 Kondinin
22 Koorda
23 Koorda Southwest
24 Koorda Northwest
25 Lake Annean
26 Lake Austin
27 Lake Baladjie
28 Lake Biddy
29 Lake Brown
30 Lake Buchan
31 Lake Camm
32 Lake Campion
33 Lake Chidnup
34 Lake Cobham
35 Lake De Courcy
36 Lake Goorly
37 Lake Grace
38 Lake Gulson
39 Lake Harvey
40 Lake Hillman
41 Lake Julia
42 Lake Kathleen
43 Lake King
44 Lake Kurrenkutten
45 Lake McDermott
46 Lake Magenta
47 Lake Moore
48 Lake Seabrook
49 Lake Wallambin
50 Lime Lake
51 Mollerin Lake
52 Mongers Lake
53 Moorine Rock
54 Mount Palmer
55 Mount Walker
56 Mukinbudin
57 Nalkain
58 Narembeen
59 Parker Range
60 Pinjarrega Lake
61 Pootenup
62 Southern Cross
63 Stennetts Lake
64 Woolundra
65 Wyola
66 Yarra Yarra Lakes
67 Yellowdine
68 Youngs Siding
174 Lake Chinocup

Eucla region

110 Beete
111 Blue Lagoon Claypan
112 Boomerang Lake
113 Carlisle Lake
114 Davyhurst
115 Emu Road
116 Forrest Lakes
117 Geordie Rock
118 Gidgi Lake
119 Grass Patch
120 Hannan Lake
121 Hope Campbell Lake
122 Jubilee Lake
123 Kopai Lake
124 Lake Ballard
125 Lake Barlee
126 Lake Carey
127 Lake Cowan
128 Lake Darlot
129 Lake Douglas
130 Lake Dundas
131 Lake Gidgi
132 Lake Gillen
133 Lake Gilmore
134 Lake Goongarrie
135 Lake Gwynne
136 Lake Ilma
137 Lake Lefroy
138 Lake Marmion
139 Lake Mason
140 Lake Mends
141 Lake McInnes
142 Lake Minigwal
143 Lake Miranda
144 Lake Noondie
145 Lake Perkolilli
146 Lake Raeside
147 Lake Rason
148 Lake Rebecca
149 Lake Roe
150 Lake Tay
151 Lake Tay East
152 Lake Throssell
153 Lake Way
154 Lake Yeo
155 Lake Yindana
156 Lake Yindarlgooda
157 Lakewood
158 Lightfoot Lake
159 Neale Junction
160 Plumridge Lake
161 Pyramid Lake
162 Red Lake
163 Salt Creek
164 Scaddan
165 Shay Cart Range
166 Shell Lakes
167 Three Star Lake
168 Wangine Lake
169 Wanna Lakes
170 Woodhouse Lagoon
171 Yeelirrie
172 Lake Kirk
173 Norseman

Canning region

80 Gregory Salt Lake
81 Gwenneth Lakes
82 Lake Bremner
83 Lake Buchanan
84 Lake Burnside
85 Lake Carnegie
86 Lake Disappointment
87 Lake Keene
88 Lake Nabberu
89 Lake Waukarlycarly
90 Lake Wells
91 Lake Wilderness
92 Linke Lakes
93 Percival Lakes
94 Prescott Lakes
95 Ten Mile Lake
96 Terminal Lake
97 Watrara Creek
98 Weelarrana Hill

Kimberley region

99 Nicholson Swamp
100 Nicholson Swamp West

Eastern Desert region

101 Lake Dennis
102 Lake Lucas
103 Lake MacDonald
104 Christopher Lake
105 Lake Cobb
106 Lake Farnham
107 Lake Farnham North
108 Lake Newell
109 Van Der Linden Lakes

Deposits in barred basins and birridas

69 Bibby Giddy
70 Brown Inlet
71 Cape Peron
72 Cliff Head
73 Dooka
74 Jurien Bay North
75 Lake MacLeod East
76 Lake MacLeod North
77 Lake MacLeod West
78 Lake MacLeod
79 Useless Loop

Appendix 4. Summary of information on Lake Chinocup
(by M. J. Freeman)

Coordinates: 33°30'S, 118°25'E.

Location: About 45 km south of Lake Grace and 7 km west of Pingrup.

Nature of occurrence: Series of dunes up to 4 m high, over an area of about 3 km by 0.5 km, of seed gypsum.

Production and usage: Nil, but proposed for agricultural application.

Estimated resources: Mining Lease applicant suggests resources of the order of 1 Mt, in Consultative Environmental Review (Masters, 1993) submitted to the Environmental Protection Authority now Department of Environmental Protection.

Remarks: Quality, stated publicly by tenement applicant, is greater than 95% gypsum.

Relevant tenement: Mining Lease application 70/835.

Reference:

MASTERS, B. K., 1993, Mining of agricultural gypsum from Lake Chinocup A Class Nature Reserve, No. A28395. Report for P. and W. Patterson, and P. and D. Shiner: Capel, B. K. Masters and Associates, Consultative Environmental Review for Department of Environmental Protection, Perth.

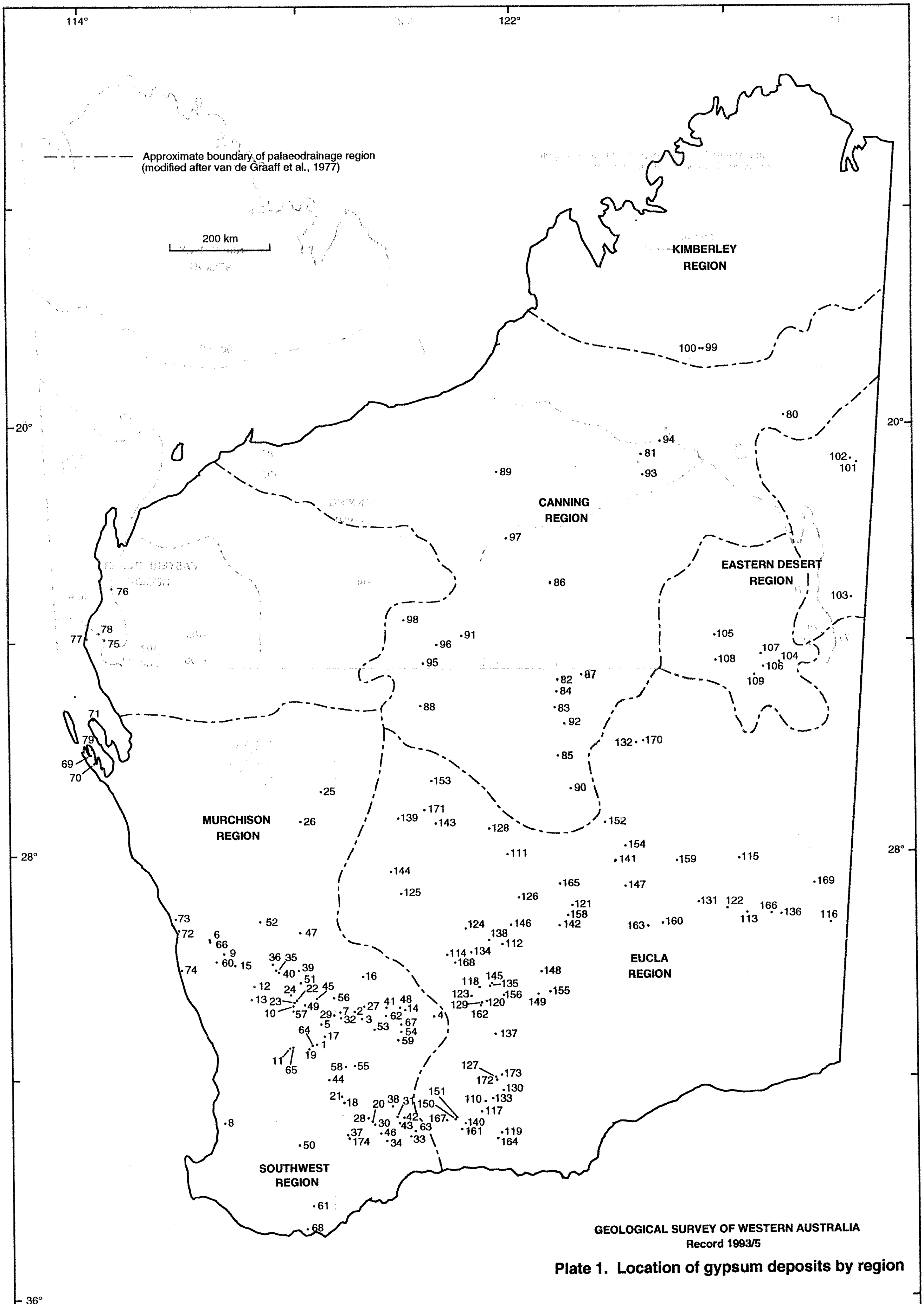

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Plate 1. Location of gypsum deposits by region