GOVERNMENT OF
WESTERN AUSTRALIA

BARITE AND FLUORITE IN WESTERN AUSTRALIA

by P. B. Abeysinghe and J. M. Fetherston

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

MINERAL RESOURCES BULLETIN 17

BARITE AND FLUORITE
IN WESTERN AUSTRALIA

by

P. B. Abeysinghe and J. M. Fetherston

Perth 1997

Contents

Chapter 1: Introduction

Part One — Barite

Chapter 2: Barite mineralogy, mode of occurrence and uses

Chapter 3: Barite production and market trends

Chapter 4: Barite in Western Australia

Part Two — Fluorite

Chapter 5: Mineralogy, mode of occurrence and uses of fluorite

Chapter 6:   Fluorite production and market trends

Chapter 7:   Fluorite in Western Australia

Figures

Tables

Barite and fluorite in Western Australia

by

P. B. Abeysinghe and J. M. Fetherston

Abstract

Barite

From 1946 to 1990, Western Australia produced 138 697 t of barite valued at $6 million. No production has been recorded since 1990. Although Western Australia's published resource figures total only 1.3 Mt, the total inferred barite resource is estimated to be several million tonnes

Production has been from seven centres, the largest of which, North Pole, producing 129 505 t from 1946–1990. North Pole is a bedded barite deposit associated with a sequence of Archaean basic and acidic volcanics, quartzites and minor dolomite, pyroxenite calc-schists and carbonate rocks, intruded by granite and dolerite. The grade of barite varies from 65.5% to 97.4% $BaSO_4$, with a specific gravity range from 3.86 to 4.27. An inferred resource of several million tonnes has been calculated although published reserves are less than 1 Mt. The Cooke Bluff Hill deposits, located 25 km north of North Pole, have a pre-resource estimate of 0.5 Mt to a depth of 10 m. At Chesterfield, barite of moderate to good quality occurs in gabbro and basaltic tuff of an Archaean mafic sequence, but a resource estimate has not been calculated. The barite deposits at Cranbrook occur in veins, with some samples indicating around 98% $BaSO_4$. The total inferred resource of the Cranbrook deposit in 1955 was 2500 t, though 2487 t had already been mined out.

Fluorite

Western Australia has no recorded production of fluorspar, but contains two large deposits at Speewah and Meentheena.

The Speewah deposit has been explored and commercial development is planned. Fluorite mineralization at Speewah is found in fault zones associated with an Early Proterozoic dolerite and a granophyre. The deposit contains a measured resource of 1.87 Mt at 25.8% CaF_2, an indicated resource of 0.41 Mt at 24.2% CaF_2 and an inferred resource of 1.59 Mt at a cut-off grade of 13% CaF_2. Fluorite mineralization at Meentheena is mainly in the form of veins in faulted volcanic rocks. An inferred resource of 132 450 t fluorite at 80% CaF_2 from all the veins mined to a depth of 17 m has been calculated for the deposit.

KEYWORDS: Industrial minerals, industrial mineral resources, mineral occurrence, barite, fluorite, economic geology, mineral exploration, mineral processing, mineral industry, Archaean, Proterozoic

Chapter 1

Introduction

The demand for barite and fluorite is expected to remain stable at the current weak levels, although it is possible that demand may increase in line with global economic trends until the turn of the century. After South Australia, Western Australia has been the largest barite producer in Australia, although production has been only 138 697 t from 1946 to 1995.

Fluorite has never been produced in large amounts in Australia, and Western Australia has no recorded production although two large deposits are known.

There is no single source of information on Western Australian barite and fluorite deposits, although a significant amount of information is available in both published and unpublished reports. The main objective of this Bulletin is therefore to compile all such information in one publication. It is not intended to be an exhaustive study of all known barite and fluorite occurrences because details of many occurrences are lacking. However, adequate geological descriptions are given for the few relatively large deposits.

Sources of information

Information contained in this study has been culled from published and unpublished sources such as records, annual reports, and technical files held by the Western Australian Geological Survey Division of the Department of Minerals and Energy (DME). Also, open-file data from the reports submitted to DME by many exploration companies have been widely used. Some of the major deposits, and others thought to be significant, were visited by the first author during May 1994. Samples collected from the North Pole barite deposit, the Meentheena fluorite deposit and a few other deposits were submitted to the Chemistry Centre of W.A. for chemical analyses and mineralogical studies.

Back-issues of industrial minerals journals and magazines can be perused at the Geological Survey Library in Mineral House, 100 Plain Street, Perth.

Absolute accuracy of mineral occurrence locations

Many locations given by Simpson (1948, 1951) and a few other sites given by other authors are listed as minor occurrences. Many of these sites are not precisely located and little geological information is available on them. Accuracy of site location is indicated by the letters A (within 200 m) and B (greater than 200 m) after the latitude and longitude of individual sites). Many of Simpson's sites belong to category B.

Arrangement of the bulletin

This Bulletin is divided into two parts; Part 1 deals with barite, and Part 2, with fluorite. Each part consists of three chapters: mineralogy, mode of occurrence and uses; global production and market trends; and Western Australian occurrences.

In the chapters on Western Australian barite and fluorite mineralization, occurrences are assigned to tectonic provinces. Major deposits in each tectonic province are discussed first, followed by a section on minor occurrences.

Prices

Unless stated otherwise, prices are quoted according to the Australian dollar value of the day.

Abbreviations

CIF	Cost, insurance, and freight
CIS	Commonwealth of Independent States
E	Exploration licence
EDXRA	Energy dispersive X-ray analysis
FOB	Free on board
GSWA	Geological Survey of Western Australia
GML	Gold mining lease
LOI	Loss on ignition
MC	Mineral claim
ML	Mineral lease
OCMA	Oil Companies Materials Association
P	Prospecting licence
PA	Prospecting area
SEM	Scanning electron microscope (or microscopy)
SG	Specific gravity
USA or US	United States of America
XRPD	X-ray powder diffractometry

Part One

Barite

Barite mineralogy, mode of occurrence and uses

Mineralogy

The name 'barite', also known as barytes, heavy spar, and tiff, was derived from the Greek word *barus*, meaning heavy. Pure barite has a specific gravity of 4.5 and is relatively soft with a hardness of 2.5–3.5. However, impurities can sharply reduce the specific gravity. A relatively inert mineral, insoluble in acids and water, barite contains 58.8% barium (Ba) and 41.2% sulfate (SO_4) (or 65.7% BaO and 34.3% SO_3). The colour of barite is white to grey, but can vary depending on the nature of the impurities. Other physical characteristics include a vitreous to pearly lustre, perfect cleavage, and uneven and brittle fracture. Industrial qualities include its high brightness, low oil absorption, and the fact that it is easily wetted by oils.

The term 'primary barite' refers to the first marketable product and includes crude barite, flotation concentrate, and other beneficiated material such as washer, jig, heavy-media, table, or magnetic-separation concentrate.

Uses

Approximately 90% of barite produced in the world is used as a weighting agent in drilling mud in oil and gas well drilling. Historically, the first use of barite was as a filler in white paints (Ampian, 1985). With the advent in 1842 of lithopone, a white pigment composed of a mixture of barium sulfate and zinc sulfide, a second important market was opened up in the USA. In 1908 another use emerged when the Chicago Copper Refining Co. began manufacturing barium chemicals using barite. The use of barite as a weighting agent in rotary-drilling mud began in 1916.

High specific gravity (4.5), low abrasiveness, chemical inertness, and opacity to X-rays make barite useful for many diverse applications. The main uses of barite for non-drilling applications are in fillers and extenders, chemicals, and ceramics. Specifications for different uses are given in Table 1.

Weighting agent in drilling mud

Drilling mud is a mixture of various minerals and chemicals in a fluid medium, usually water or oil. The main function of barite, which constitutes up to 40% of drilling mud, is to prevent blowouts during the drilling of oil and gas wells. In addition, mud is pumped down the drill pipe in order to achieve the following:

- Removal of cuttings from the bottom of the hole and to transport them to the surface without interfering with downhole testing or logging
- Release of sand and cuttings from suspension at the surface
- Holding of cuttings, other materials, and even equipment in suspension even if circulation ceases
- Cooling and lubrication of the drill bit and pipe
- To achieve sufficient density to control subsurface pressures
- To wall the hole with an impermeable filter cake to prevent loss of circulation
- To be capable of transmitting hydraulic power to the bit when mud-driven bits are employed (Griffiths, 1986).

The general specifications for drilling-mud barite are given in Table 1. The specifications given by the American Petroleum Institute (API) are that wet screen analysis residue on US sieve no. 200 should not be more than 3.0% and the residue on sieve no. 325 should be less than 5.0%. Also required are a specific gravity of 4.2 and a maximum of 250 ppm of soluble alkaline earth content, as calcium (Harben and Bates, 1990a). A small percentage of iron oxide is acceptable.

Barite used for drilling mud may be a crushed ore, or a processed mineral obtained by various beneficiation methods such as washing, tabling, jigging, or flotation. Common accessory minerals in commercial-grade barite ore include quartz, chert, other silicates, carbonates, and concomitant metallic oxide and sulfide compounds. Because of these impurities, the commercial product may vary in colour from off-white to grey to red-brown.

Filler and extender applications

One of the most important non-drilling applications for barite is as a filler and extender. General specifications for filler applications are given in Table 1. The highest quality barite fillers are achieved by acid leaching and treatment with reducing or oxidizing agents. It is possible to prepare an acid-washed barite with a grade comparable to precipitated synthetic barium sulfate (blanc fixe). Although synthetic barium sulfate is higher in price, it is not necessarily a superior product compared to natural

Table 1. Specifications for different uses of barite (*after* Andrews and Collings, 1990)

General specifications for drilling-mud barite

Specific gravity	4.2 min.
$BaSO_4$	92% min.
Soluble alkaline earth content, as calcium	250 ppm max.
Particle size	95% — 45 μm (325 mesh)

Source: American Petroleum Specification 13A for Oil — Well Drilling Fluid Materials, 1981

General specification for pharmaceutical-grade barite

$BaSO_4$	97.5% min.
LOI	<2% (600°C)
Heavy metals (as Pb)	0.001% max.
Sulfides	<0.1 ppm
Arsenic	<0.1 ppm
Particle size	90% — 20 μm
Colour	white or near-white
Odour	odourless

General specifications for filler applications

$BaSO_4$	95% min.
Particle size	95% — 45 μm
Colour	colour specifications vary depending on application, usually a near-white product is required

General specifications for glass-grade barite

$BaSO_4$	95% min.
SiO_2	1.5% max.
Iron (as Fe_2O_3)	0.15% max.
Al_2O_3	0.15% max.
Particle size	100% — 850 μm with less than 5% — 150 μm fines

General specifications for barite as heavy aggregate

$BaSO_4$	95% min.
Particle size	gravel size

Specifications for barium chemicals manufacture

$BaSO_4$ (lump material)	92 to 96% min.
$BaSO_4$ (flotation concentrate)	96 to 98% min.
Fe_2O_3	1.0% max.
$SrSO_4$	1.0% max.
CaF_2	0.5% max.
Particle size	-5.0 to +0.5 mm

General specifications for paint-grade barite

Particle size	99.98% passing 37 μm (400 mesh)
Hegman number	6.5
Brightness (green filter)	81%
Oil absorption	5 kg/45 kg
$BaSO_4$	95% min.
Iron content	0.05% max.
Water-soluble compounds	0.2% max.
Foreign matter	2.0% max.
Moisture	0.50%
pH	6.4

Source: American Society for Testing and Materials, ASTM D — 1366 (size), D — 281 (oil absorption), D — 280 (moisture), D — 1208 (water insoluble), D — 1208 (pH)

barite since each has advantages in specific applications due to variation in particle size distribution, which can affect settling properties, oil absorbency, and other physical characteristics. The specifications for high-quality fillers marketed in Europe are given in Table 2.

Paint

The paint industry is the largest consumer of filler-grade barite. Since the introduction of paint sales on a volume basis, the use of barite fillers has dropped considerably to give way to less dense and cheaper fillers such as calcium carbonate and dolomite (Griffiths, 1984). Although it does not possess any pigmentary properties, high-grade barite that has been acid washed to remove impurities is suitable for use in the paint industry to optimize the optical properties of various pigments. Barite has an extremely low binder requirement due to its low oil absorption characteristics, which results in dense packing within the coat. These characteristics prevent agglomeration, thereby enhancing the dispersability of the liquid coating and efficient optical configuration of the particles (Industrial Minerals, 1978).

As a filler in varnishes, water-based paints and anti-rust primers, barite imparts a high degree of imper-meability and durability through its close packing density. It is particularly useful in undercoats for preventing the absorption of top coats, for filling scratches, and increasing resistance to sanding marks. Barite filler, unlike calcium carbonate, is not prone to blistering in the presence of moisture since it does not contain water-soluble materials.

Brake linings

Barite is used as a filler in friction materials, including brake linings and clutch facings. Depending on the end-use of the product, such as in industrial machinery, trucks or saloon cars, the amount of barite present in friction materials can vary from 10% to 40%. Typically, brake linings require barite which is 99% less than 40 μm, has a minimum specific gravity of 4.3, and has consistent chemistry (Griffiths, 1992a).

Other filler applications

Barite is used in backings for floor coverings, such as linoleum and carpets, primarily because of its high density. Other filler applications where barite is added to give weight to the product include playing cards, hardboard materials, and rope finishes.

Construction industry

Radiation shielding

The ability of barium compounds to absorb radiation makes barite suitable for use in concrete structures for radiation shielding. Barite satisfies a number of important factors that must be considered when selecting a material for radiation shielding: density, workability, durability and heat transfer properties. Accordingly, barite is used in concrete aggregate for the construction of nuclear reactor shields. Barite concrete with a density of 3.5–3.6 g/cm^3 is considered to be a suitable shield material. Its use, however, is governed by its availability close to an installation site. The efficiency of barite concrete against a low–medium energy neutron flux can be attributed to the high neutron cross-section capture property of barium. However, at high neutron energies barite concrete has no advantage over ordinary concrete.

Weighting agent

The high density of barite makes it suitable for concrete used to weigh down pipelines in marshy ground.

Glass manufacture

In glass manufacture, barite is added to continuous melting tanks where it imparts a greater brilliance and clarity to the finished glass through homogenization of the melt.

Table 2. Specifications for high-quality fillers marketed in Europe (extracted *from* Industrial Minerals, 1978)

Variable	Rutenia G	Rutenia F	Rutenia FF	Rutenia FFF
$BaSO_4$	Min. 97.0%	Min. 98.0%	Min. 98.0%	Min. 98.5%
SiO_2	Max. 3.0%	Max. 2.0%	Max. 2.0%	Max. 1.5%
Heavy metals	Nil	Nil	Nil	Nil
Soluble salts	Max. 0.1%	Max. 0.1%	Max. 0.1%	Max. 0.1%
pH	6.2–7.8	6.2–7.8	6.2–7.8	6.2–7.8
Specific gravity	4.4	4.4	4.4	4.4
Reflectance (Elrepho)	Min. 95%	Min. 95%	Min. 96%	Min. 96%
Oil absorption	11.50	10.00	11.00	12.00
Retention on 44 microns	Max. 0.2%	Max. 0.1%	Max. 0.01%	Nil
Fineness: min 99% finer than	40μm	30μm	20μm	15μm

Table 3. Additional barium chemicals commonly used in the industry (modified *from* Industrial Minerals, 1978)

Production	Method of production	End uses
Barium chlorate	Reaction of $BaCl_2$ with sodium chlorate	Fireworks (green flame)
Barium chromate	Reaction of potassium chromate with a barium salt	Yellow pigment for artists' colours
Barium fluoride	Reaction of $Ba(OH)_2$ with hydrofluoric acid	Laser crystals, enamels, embalming
Barium hydride	Reduction with hydrogen at 200°C	Source of nascent hydrogen
Barium manganate	Reaction of $BaCO_3$ with manganese dioxide	Green pigment
Barium nitrate	Reaction of BaS with dilute nitric acid	Green flares for pyrotechnics
Barium oxide	Reduction of $BaCO_3$	Desiccant
Barium titanate	Reaction of $BaCO_3$ with titanium dioxide	Electro-ceramics

Chemicals manufacture

A significant amount of barite produced in the world is used in the production of barium chemicals. It is estimated that, of the 1982 world production, approximately 8–9% was used for this purpose (Griffiths, 1984). Barium sulfide (black ash) forms the starting point for most barium chemicals. It is produced by the reduction of barium sulfate (barite) with finely powdered coal in a rotary kiln at a temperature of 1100–1250°C. General specifications of barite required for barium chemicals manufacture are given in Table 1. Some of the more widely used chemicals manufactured using barite are blanc fixe, barium carbonate, barium chloride, and lithopone. A summary of other chemicals manufactured and their end uses is given in Table 3.

Blanc fixe

Blanc fixe is chemically precipitated barium sulfate which is prepared by a number of methods depending on the end use. The main chemical reactions involved in these different methods are:

$$BaCl_2 + Na_2SO_4 \rightarrow BaSO_4 + 2NaCl$$
$$BaCO_3 + H_2SO_4 \rightarrow BaSO_4 + H_2O + CO_2$$
$$BaS + H_2SO_4 \rightarrow BaSO_4 + H_2S$$
$$BaS + Na_2SO_4 \rightarrow BaSO_4 + Na_2S$$
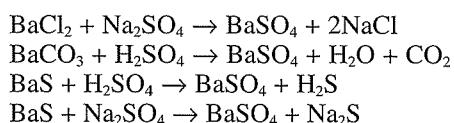
Blanc fixe is used as either a powder or a paste. It is used mostly in paint (70%), paper (including photographic papers) (10%), plastics and battery manufacture (10%), and as a high-purity filler and extender. Approximately 10% is also used in medicine as a barium meal indicator in X-ray photography.

Table 4. Properties of typical blanc fixe paper-coating grade (*after* Griffiths, 1984)

Density	4.0 to 4.2
Brightness	95 to 99
Mean particle size (mm)	0.5 to 4.0
Specific surface (m^2/g)	4.0 to 4.5
Hardness	3 to 4
Binder requirement (g casein/100 g pigment)	9 to 14
Oil index (g oil/100 g pigment)	12 to 22
Water index (g water/100 g pigment)	16 to 23
Zeta potential (mv)	-20 to -35

Specifications for typical blanc fixe paper-coating grade are given in Table 4. In the paint industry, blanc fixe is used in place of barite when a finer particle size is needed to form an extremely tight and dense film. Blanc fixe is also used in coloured enamels with organic compounds to enhance brilliance and has an added advantage of resisting effects of corrosive acids and alkalis.

In the preparation of blanc fixe paste, granulometry and gloss of the product can be varied depending on the end use. Aqueous pastes are unsuitable for use in paints, but are useful in some coated papers such as the base coating of photographic paper upon which the silver halide coating is applied. The extreme insolubility of $BaSO_4$ prevents reaction between the pigment coat and the sensitive emulsion.

Barium carbonate — specialty glass

The largest end use for barium carbonate is in the manufacture of glass for television cathode ray tubes. Picture tube glass contains 0–15% BaO, such that the total of BaO and SrO is 5–20%, while the face plate glass usually contains less than 5% BaO to block X-ray emissions (Griffiths, 1992a).

Barium carbonate — ceramic applications

In ceramic applications barium carbonate is used for two separate purposes. The first is to convert the soluble sulfates in a clay body to insoluble barium sulphate, and the second is to modify the properties of the ceramic body through the incorporation of the active constituent BaO. The free-soluble sulfates, present as a loose layer of white residue on the surface during drying of ceramic bodies, are commonly those of sodium, potassium, magnesium, and to a lesser extent calcium. This layer results in poor adhesion of any further layers such as glazes or engobes (a white clay coating used to cover pottery). The effect of adding barium carbonate is to remove free-soluble sulfates present in the water contained in the pores of the moist clay, by conversion to barium sulfate which has a very low solubility and high thermal stability.

Barium carbonate is also used in the manufacture of heavy clayware such as roof tiles, bricks, clinkers, floor slabs, and wall panels. If free-soluble sulfates are allowed to remain in the clay used in roof tiles and bricks, they can absorb atmospheric water during wet or humid conditions resulting volume expansions, which can contribute to structural collapse. The formation of insoluble sulfates also prevents discolouration of bricks and tiles and inhibits the formation of efflorescence on the fired surface.

Another use of barium carbonate is in the manu-facture of barium titanates and ferrites as electro-ceramics. Magnetic barium ferrite is used for the manufacture of permanent magnets. Since the raw material costs are low compared with that of the newer rare-earth-cobalt, or neodymium-iron-boron permanent magnets, ferrites are able to retain their sector of the magnet market. The market for ferrite is growing and finds use in the automotive industry. Applications of ferrite include motors, reed switches, dynamic speakers, earphones, telephones, and microphones. However, barium ferrites face strong competition from strontium ferrites which have a higher coercive field strength.

Barium carbonate — chemical purification

Barium carbonate is used in the purification of brine for chlor-alkali electrolysis by the removal of sulfate. Barium carbonate reacts with the sulfate impurity to form insoluble sulfate which then precipitates. Another use is in the purification of factory liquid wastes by the removal of sulfuric acid, dissolved sulfates and chromic compounds.

Barium chloride

Barium chloride can be produced either by reaction of barium sulfide with hydrochloric acid (or chlorine gas) or through the reaction of barium carbonate with hydrochloric acid. Two types of chloride commonly used in the industry are anhydrous barium chloride ($BaCl_2$) and barium chloride dihydrate ($BaCl_2.H_2O$). Anhydrous barium chloride is used entirely in the production of heat treatment salts, whereas a major portion of dihydrate production is used for the removal of sulfate impurities from various systems and the remainder in miscellaneous applications including the manufacture of molecular sieves.

Lithopone

Lithopone, which is a precipitate of barium sulfate and zinc sulfide, can be prepared by the reaction of barium sulfide with zinc sulfate. It has been used as a pigment in the paper and paint manufacturing industries but is now mostly replaced by titanium oxide pigments. It is now almost exclusively used in paints, with minor amounts in pastes, putties and artists' colours.

Other uses

Compounds derived from barite have many varied uses in the form of reagents and catalysts in industry. They are used in the sugar refining, metallurgical, and brick industries, and in the manufacture of textiles, drugs, pyrotechnics, synthetic rubber, plastics, chemicals, phosphors, paper, welding fluxes, and oil and grease additives.

Substitute minerals

A number of minerals have been used as a substitute for barite as a weighting medium in drilling mud. For example, celestite ($SrSO_4$) was used before World War II but because of its higher price and lower specific gravity it is no longer used. Iron ores, which are heavier and within the same price range as barite, could be substituted as a weighting agent but they are slightly more abrasive and unpleasant to handle, soiling both equipment and personnel. A weighting agent containing barite and up to 20% by weight of specular hematite has been known to be more effective in oil and gas well drilling than pure barite agents. An iron oxide weighting agent prepared by calcining pyrite ores has also been known to be satisfactory in laboratory and field trials. In addition, ilmenite can replace up to 15% of the barite in drilling mud (Ampian, 1985).

Mode of occurrence

Barite occurs in a variety of geological environments and deposits are commonly classified on the basis of morphology, as bedded, vein and cavity filling, and residual types.

Bedded deposits

Bedded deposits contain vast reserves and have emerged as commercially the most significant style of barite mineralization throughout the world. These can occur as part of a sedimentary sequence, as either a principal constituent or a cementing material, or associated with stratiform massive sulfide deposits. The barite in these deposits is commonly fine grained and dark, occurring in beds up to 16 m thick and extending over several square kilometres. The barite content can be as high as 95%, but may form 50% or less due to the presence of fine-grained quartz, clay, pyrite, chert or silt. Carbonate minerals are rare. In places, hydrocarbons and fatty acids may constitute several percent of the rock (Harben and Bates, 1990a).

Clark et al. (1990) suggested that, in addition to morphology, knowledge of the geological settings of barite occurrences and geological processes that produce barite are factors which need to be considered in the classification of barite deposits. This improves the ability to assess resources and to effectively provide

information for exploration and development to meet world needs. Based on these suggestions, Clark et al. (1990) suggested the following subdivisions for bedded deposits:

A   Sediment-hosted, stratiform, syngenetic-diagenetic deposits
B   Sediment-hosted, stratiform, syndepositional turbiditic and debris flow deposits
C   Sediment-hosted, stratiform, diagenetic occurrences at reduction–oxidation (redox) interfaces
D   Evaporite-associated, stratiform, syngenetic–diagenetic deposits
E   Volcanic-rock-associated, stratiform, syngenetic–diagenetic deposits

Types A, B and C are found in China, USA, CIS, Mexico, India, Ireland, Thailand, etc. Most bedded barite is used in drilling fluids for oil and natural gas exploration drilling as the purity of deposits is commonly insufficient for more refined uses. Bedded deposits provide large tonnages of barite that can be mined by openpit methods.

Type D has been deposited in some areas by direct precipitation from seawater, selective enrichment of barite relative to strontium during diagenesis, or mixing of marine and freshwater in an evaporitic environment (Clark et al., 1990). An example of this type is in Brazil in the State of Bahia.

Type E barite is associated with Kuroko-type massive sulfide deposits. Some examples are the Kuroko-type deposits of the Hokuroku District, and southwestern Hokkaido in Japan, and massive sulfide-barite deposits associated with volcanic rocks which extend from the Lesser Caucasus in the CIS, through Bulgaria, Yugoslavia, Turkey, and Algeria.

Vein and cavity fillings

Barite derived from hydrothermal fluids or deep-seated brines is commonly found as veins in faults, joints, bedding planes, breccia zones, and solution channels. Veins are characterized by sharp contacts, extensive pinching and swelling, and extreme variations in length, depth and attitude. Barite in this type of deposit is typically recovered as a by- or co-product of lead/zinc mining.

Clark et al. (1990) gave the following subdivisions for this type of barite deposit:

A   Epigenetic vein deposits that are not stratabound
B   Carbonate rock-hosted, stratabound, epigenetic deposits
C   Clastic rock-hosted, stratabound, diagenetic–epigenetic deposits

Type A is one of the major sources of high-purity barite used in filler, extender, and chemical processes. Some examples are barite and barite-polymetallic hydrothermal veins of Mesozoic age occurring in the Greater Caucasus of Georgia (CIS), barite veins occupying faults occurring in the same areas as Tertiary mafic dyke swarms in the Midland Valley of Scotland, and barite veins in many areas in Morocco such as in the vicinity of the High Atlas Mountains and surrounding foothills.

Type B host rocks occur as shallow-water carbonate sediments in cratonic platform and continental shelf rock sequences. Mineralization is attributed to transport of barium or barium compounds by basinal brines or mineralized groundwater to favourable depositional sites in the carbonate host rocks. Some examples of these deposits are on Sardinia and near Chaudfontaines and Fleurus in Belgium.

Type C barite forms the cement or replaces the matrix of clastic rocks. Some examples are those in the Dierks district in Arkansas (USA), and barite rosettes of Oklahoma (USA).

Residual deposits

Residual deposits are concentrations of barite fragments in soil and colluvium, and commonly overlie subeconomic carbonate rock-hosted, stratabound epigenetic deposits. Barite fragments can vary from sand size to lumps weighing 90 kg or more. The size and shape of these deposits are extremely variable. For example, the thickness can vary from 3 m to more than 50 m, with elongate or circular geometry reflecting the original vein or sink structure.

Commercial production of residual deposits occurs by development of surficial deposits. These deposits are important sources of high-purity barite required for chemical, filler and extender uses. Deposits are mined by openpit operations or hand picking. Some examples of these are found in Georgia and Missouri in the USA.

Methods of mining

Bedded and vein deposits may be mined by openpit or underground methods, depending on local conditions. For example, bedded barite deposits in Nevada are mined by openpit methods using a combination of ripping and conventional blasting (Ober, 1990). Residual deposits of barite are generally mined by draglines in openpits after removal of overburden by conventional methods using elevating scrapers, bulldozers, front-end loaders, and trucks.

The broken ore is trucked to a processing plant where it is usually washed and screened to remove adhering clay and low-grade fines before reduction by jaw or impact crusher to 25 cm or finer for further processing.

Barite has also been recovered by underwater mining off Castle Island near Petersburg in southeastern Alaska. The ore is blasted, recovered by a crane equipped with a special digging bucket, and loaded into barges.

Processing and beneficiation

Most ore requires beneficiation by jigging or flotation, but in some deposits the ore is of sufficient grade to be either screened and direct shipped or washed, crushed, screened, and shipped to a grinding plant. Grinding is usually done by heated airswept Raymond mills, a type of roller mill. When iron contamination is not important, as in drilling mud, ball mills are used. Barite may be ground wet or dry. For use in well drilling, barite is ground dry, but if it requires upgrading by flotation, it is ground wet. Flotation is used to concentrate the fines that are present in coarse-grained ores. Fines are usually separated by screening before gravity concentration of the coarse fraction. When the liberation size is very fine (about 75 µm), the preferred concentration method is flotation (Andrews and Collings, 1990; Ober, 1990).

Barite is also ground wet when it is to be bleached for filler use. After grinding, impurities are removed by treatment with sulfuric acid and the bleached barite pulp is then settled and separated, washed, dried, sized and bagged.

Gravity methods of concentration including heavy-media drums or cones, wet or dry mineral jigs, wet or dry tabling and spiral classifiers, are used to separate high specific gravity barite from lower specific gravity gangue minerals such as calcite, dolomite, quartz and shale. The choice of technique depends on liberation size. For example, if the size is coarser than 2 mm, heavy-media separation and wet or dry jigging are usually applicable. The upper size is approximately 50 mm for heavy media separators and 12 mm or less for wet or dry jigs. Barite ore that must be reduced to 2 mm or less for liberation is concentrated by wet or dry tables, spirals, rake and cone classifiers. Before further concentration, the removal of very fine, -75 µm material by hydrocyclone is usually essential for grade control. Electrostatic separation, magnetic separation and acid leaching techniques may be considered for separation of certain specific minerals <1 mm in size. Wet or dry high-intensity magnetic separation is useful in removing iron-rich minerals such as siderite.

Chapter 3

Barite production and market trends

World production

Annual world production of barite during recent years has stablized at about 5 Mt. In 1975, global production was 4.9 Mt, but increased to a peak production of 8.2 Mt in 1981. Production declined to 4.9 Mt in 1994 (Table 5, Fig. 1). These changes in production reflect significant changes in demand for barite by the world petroleum drilling industry at various times. A noticeable feature in production trends is that production from China increased from 0.2 Mt in 1975 to 1.9 Mt in 1994. During the same period, USA production declined from 1.2 Mt to 0.3 Mt. In 1994, the contribution from China to world production was 36% compared with 7% from each of CIS, India, and USA (Fig. 2). Other countries with significant production are Morocco and Turkey (each with 6% of world production).
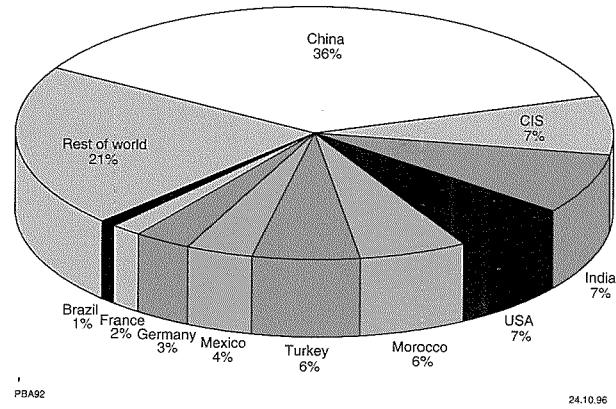
Figure 2. Global barite production by country—1994. (Source of data: US Bureau of Mines, Mineral Commodity Summaries, 1995)
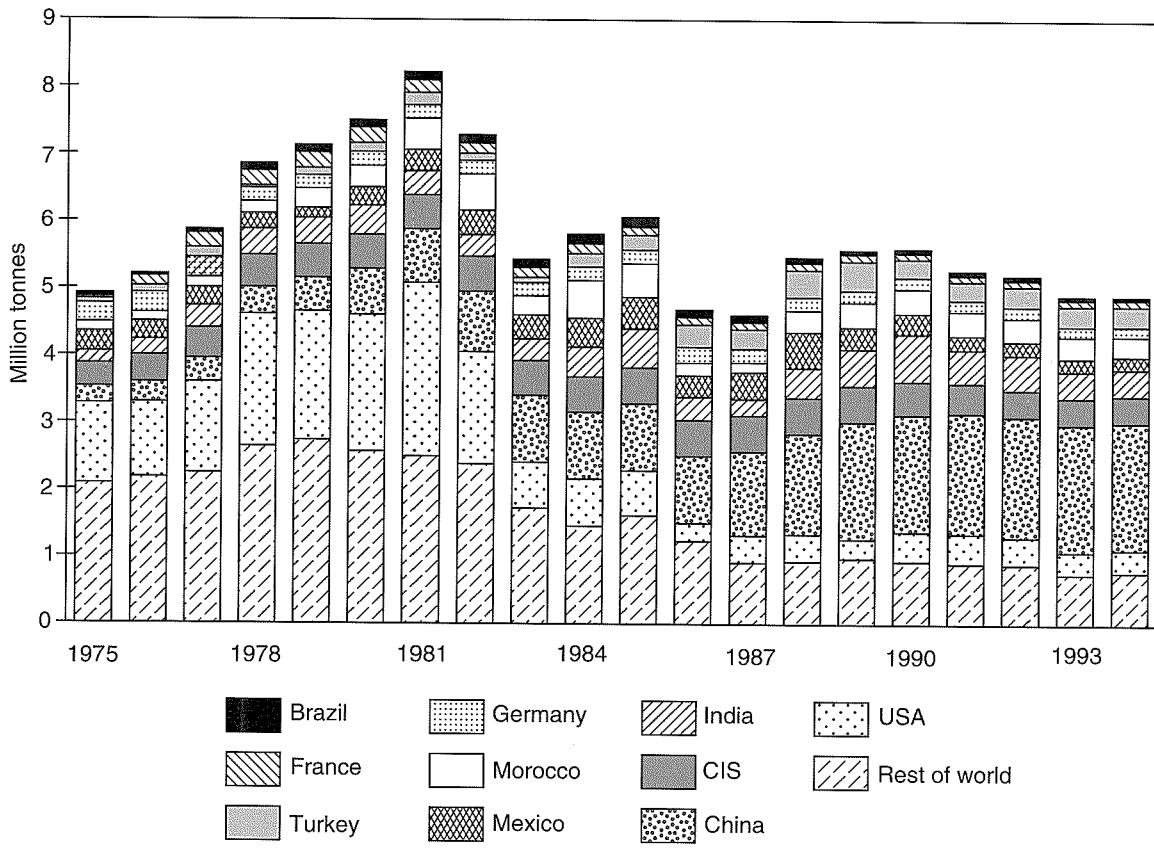
Figure 1. Global barite production 1975–1994. (Source of data: US Bureau of Mines Minerals Year Book, production statistics from 1977 to 1993; US Bureau of Mines, Mineral Commodity Summaries, 1993 and 1995)

Table 5. Global barite production: 1975–1994

Year	USA	China	CIS	India	Mexico	Morocco	Germany	Turkey	France	Brazil	Rest of world	World
						(tonnes)						
1975	1 195 670	249 476	344 730	175 087	300 278	136 985	278 506	66 225	30 844	53 524	2 084 711	**4 916 036**
1976	1 119 466	299 371	399 161	234 961	270 341	128 820	293 021	99 790	149 686	31 751	2 179 058	**5 205 428**
1977	1 355 334	349 266	453 593	331 123	270 341	149 686	296 649	143 335	220 446	49 895	2 245 283	**5 864 951**
1978	1 968 591	399 161	476 272	388 275	231 332	176 901	204 117	31 751	224 982	107 048	2 642 630	**6 851 061**
1979	1 915 975	498 952	498 952	387 368	151 500	286 670	197 766	108 862	234 961	107 955	2 736 977	**7 125 938**
1980	2 036 630	680 389	508 024	433 634	269 434	320 236	210 467	127 913	236 775	104 326	2 567 334	**7 495 162**
1981	2 584 570	798 323	508 024	353 802	317 515	465 386	200 488	185 973	190 509	116 120	2 493 852	**8 214 560**
1982	1 673 756	898 113	517 095	325 679	363 781	537 961	201 395	107 048	156 036	119 748	2 379 546	**7 280 160**
1983	684 017	997 904	517 095	322 958	357 431	282 135	199 581	77 111	149 686	117 934	1 724 559	**5 430 409**
1984	703 068	997 904	526 167	446 335	426 377	561 548	202 302	197 766	147 871	143 335	1 456 939	**5 809 613**
1985	670 410	997 904	539 775	579 691	468 107	499 859	205 024	220 446	120 656	142 428	1 614 789	**6 059 089**
1986	269 000	1 000 000	540 000	344 000	321 186	189 881	235 565	330 758	116 400	105 489	1 235 269	**4 687 548**
1987	406 000	1 250 000	540 000	247 000	401 336	143 503	205 356	291 913	104 050	102 220	916 256	**4 607 634**
1988	404 000	1 500 000	540 000	445 604	534 954	321 562	197 317	405 017	104 400	78 842	934 634	**5 466 330**
1989	290 000	1 750 000	540 000	548 103	324 739	370 000	174 106	434 664	111 800	51 407	979 045	**5 573 864**
1990	439 000	1 750 000	500 000	707 000	304 996	363 580	172 776	271 300	92 500	55 576	937 929	**5 594 657**
1991	448 000	1 800 000	450 000	500 000	210 000	360 000	168 500	275 000	90 000	65 000	904 781	**5 271 281**
1992	410 000	1 800 000	(a) 400 000	525 000	200 000	350 000	170 000	300 000	90 000	65 000	890 000	**5 200 000**
1993	335 000	1 900 000	(a) 400 000	400 000	193 000	325 000	155 000	300 000	96 000	47 000	749 000	**4 900 000**
1994	340 000	1 900 000	400 000	400 000	190 000	300 000	150 000	300 000	95 000	45 000	780 000	**4 900 000**

Source of data: US Bureau of Mines Minerals Year Book, production statistics from 1977 to 1993; US Bureau of Mines, Mineral Commodity Summaries, 1993 and 1995
(a) estimates only

USA

According to United States Bureau of Mines mineral statistics, USA barite production declined significantly from 2.6 Mt in 1981 to 0.3 Mt in 1994 but other sources indicate a recovery in production in 1994. Almost 70% of current production comes from Nevada and much of the remainder from Georgia and Missouri.

Barite in Nevada occurs as bedded and vein deposits in a northeast-trending zone up to 96 km wide stretching for some 480 km across the central part of the State. Individual beds of barite are usually lenticular and conformable with adjacent chert, shale, and argillite of Cambrian to Devonian age.

The main deposits occur in the Devonian Slaven Chert, consisting of tightly folded and deformed, black to grey chert beds separated by thin selvages of clay. Other rock types in the formation include carbonate-rich argillite, limestone, siltstone, and sandstone. Barite units dip less than 30°, are commonly less than 300 m in strike length and rarely exceed 550 m. Associated minerals are quartz, pyrite, and secondary iron oxide. The deposits are believed to be of exhalative sedimentary origin formed by solutions that rose along fissures in the ocean floor and discharged as submarine hot springs. Barium in solution reacted with seawater to precipitate barite.

Vein deposits are contained in a broader zone and appear to be contemporaneous with the bedded deposits. The steeply dipping veins are mostly 1 to 6 m thick with strike lengths of less than 100 m.

In Georgia, the barite production centre is the Cartersville district of Bartow County, located approximately 65 km northwest of Atlanta. Barite, along with iron oxide, occurs in a residual clay derived from a light grey Cambrian dolostone. Barite is more common near faults, which are interpreted to be conduits for barium-rich hydrothermal solutions.

Production of barite from Missouri is from residual deposits in two main localities: Washington County area, 121 km west of St Louis; and the Central District in Cole, Morgan, Miller, and Moniteau counties farther west. Of these, the more important deposit commercially is a 1036 km^2 district in northeastern Washington County, where barite is present in residual beds largely derived from the underlying Cambrian Potosi and Eminence Dolomites (Harben and Bates, 1990a).

China

Production of barite from China substantially increased from the late 1970s to rank as the world's second largest producer behind the USA in 1981. From 1986 to 1994, China was the largest producer of barite in the world with a production in 1994 of 1.9 Mt. Chinese barite is particularly high grade with a specific gravity around 4.35. The main production areas are in Guizhou, Hunan, Guangxi, and Jiangxi Provinces (Watson,1982; O'Driscoll, 1994). China is the dominant supplier of barite to the USA,

and is expected to continue to be a major force in the world market.

India

With annual production of around 0.4 Mt in 1994, India is a major producer of barite. The largest producer is from the Mangampet deposit in the Cuddapah District of Andhra Pradesh (Griffiths, 1992a).

Barite deposits of considerable size and quality, mostly distributed around the villages of Amantharajupet and Mangampet, are contained within a sequence of purple shale with dolomitic bands of the Upper Cuddapah Formation. This sequence is folded locally into a series of doubly plunging anticlines and synclines, and the eastern margin is marked by a thrust fault. Mineralization, which trends north-northwest with an average dip of 20° to the east, occurs in two lens-shaped bodies 1097 m and 274 m in length and with respective thicknesses of 18 m and 6 m. The barite is grey, massive, and fine-grained, with a yellow coating of limonite on weathered surfaces (Harben and Bates, 1990a).

Companies operating in Andhra Pradesh are Indian Barytes & Chemical Ltd (IBC), Gimpex Pvt Ltd, Tiffins Barytes Asbestos & Paints Ltd, Krishnappa Asbestos & Barytes Pvt Ltd, and Trimex International Of Abu Dhabi (operating mines for Andhra Pradesh Minerals Development Corporation).

The only other producing region of some importance is in Rajasthan. Companies operating in this area are Rajasthan Barytes Ltd and Ram Narain & Bros.

Mexico

Production from Mexico decreased from around 0.5 Mt in 1988 to less than 0.2 Mt in 1994. Mexico's barite industry has been affected by declining reserves in several major mines, and also by significant increases in imports of Chinese barite (Kendall, 1995).

Morocco

Morocco is the biggest producer of barite in Africa with an annual production of around 0.3 Mt in 1994.

The largest producer is Cie Marocaine des Barytes (Comabar), which has mines at Jabel Ighoud and Zelmou. Zelmou Mine, located to the southwest of Bouarta, is newer with a capacity of 0.3 Mt per year from an openpit. Ore from this mine has an average specific gravity of 4. The older Ighoud Mine is the only barite mine in Morocco to beneficiate ore and has a capacity of around 25 000 t per annum. Ore from this mine is extracted from near vertical veins up to 6 m thick that have been traced through the mountain range for more than 40 km. Output from both mines is believed to be used entirely for oilwell drilling (Harben and Bates, 1990a; Griffiths, 1992a).

SA Cherifienne d' Etudes Minières (Sacem) has a large barite deposit at Taza with reserves in excess of 1 Mt. Sacem has other deposits at Imini and Khenifra. In the Taza area, a barite (+ galena + copper oxide) bearing vein 1.2 km long and 1.8 m to 3.7 m thick cuts a Cambro-Ordovician schist near the Caledonian Taxxeka granite intrusion. The deposit was at the development stage in 1992 with a view to supplying barite to API specifications for use in drilling muds, and later for the chemical industry.

Sacem has four mines having a combined capacity of over 130 000 t per year. The mines at Tazarine near Ourzazate and Loukaimeden near Marrakech produce higher grade barite than the company's other two mines.

Morocco Minerals Co. produces barite from two established underground mines at Chemaia in Safi, and Beni Tadjite in Errachidia. Annual production from the former is around 8000–10 000 t and that from the latter is about 1000 t. The grade of ore at Chemaia is more than 97% $BaSO_4$ and is low in silica, but is too reddish in colour for inclusion in paint. Beni Tadjite barite is white and is sold for paint manufacture.

Germany

Production of barite from Germany in 1994 was around 0.15 Mt. A major producer in western Germany is Metallgesellschaft AG through a wholly-owned subsidiary Sachtleben Bergbau GmbH & Co. and associate company Deutsche Baryt-Industrie, Rudolf Alberti GmbH & Co. KG (owned by Sachtleben 50% and Solvay Barium Strontium GmbH 50%) (Griffiths, 1992a).

Sachtleben has underground mines at Driesler and Wolfach. The Dreisler Mine is located in Hochsauerland, 70 km northeast of Meggen, and produces around 70 000 t per year averaging 60–70% $BaSO_4$, which is upgraded to a 95% $BaSO_4$ by wet-mill concentration. The Clara Mine at Wolfach, which has been in operation since 1882, produces fluorite and about 80 000 t of barite per year. Mine products consist of a micron-sized filler material and a chemical grade with a minimum $BaSO_4$ content of 98%.

Deutche Baryt, operator of the Bad Lauterberg underground mine in western Germany, produces around 87 000 t of crude barite. The ore is beneficiated at the plant by froth flotation, gravity and heavy-media separation, and bleaching to produce 33 000 t per annum of white filler grades and 10 000 t per annum of flotation concentrate.

In eastern Germany, Fluss und Schwerspatwerke GmbH has three underground barite mines at Brundobra, Trusetal, and Schmalkalden. Output from these mines has been decreasing steadily and estimated annual production in 1990 was about 75 000 t.

In Germany, approximately 75% of domestic barite goes into the production of barium chemicals, about 18% into fillers, particularly for paint, and about 7% into oil-well drilling muds.

Turkey

Turkey produces approximately 0.3 Mt of barite annually and mining operations are found at Sarkikaraagac, Huyuk and Yalvac in Middle Anatolia. Most production is for drilling grade but hand sorting has resulted in the production of some iron-free ore. Filler-grade material is processed by washing and jigging. Deposits in the area bounded by Huyuk town, Konya city, Sarkikaraagac town, and Isparta city are operated by Etibank General Management. The company produces approximately 15 000 t, 35 000 t and 1000 t per annum of washed barite having specific gravities of 4.25, 4.3 and 4.38 respectively.

Another significant company operating in Turkey is Baser Mining Industry & Commerce Inc. which produces non-drilling grades from underground mines at Konya and Isparta and quarries in Antalya, Korkuteli, Gazipasa and Nevsehir. Production is approximately 15 000 t per annum of barite for paint, ceramic and filler applications grading more than 98% $BaSO_4$ and a specific gravity of 4.4.

Emas Industrial Minerals Co., which has surface and underground operations at Mush in Mush province, produces approximately 45 000 t of barite per annum used for drilling as well as for chemical applications.

France

Barite production from France has dropped from around 237 000 t in 1980 to around 95 000 t in 1994. Major production is from a deposit at Chaillac, in Indre Department, on the northwestern edge of the Massif Central. Chaillac is a stratiform deposit consisting of a concretionary and banded baritic iron ore known as 'Barytine des Redoutières' which is interbedded with an iron-rich bed above and a barite/fluorite bed below. The barite generally grades 98% $BaSO_4$ and has a low strontium sulfate to barium sulfate ratio, rendering it suitable for chemical industry uses. Annual production from this deposit is approximately 95 000 t (Harben and Bates, 1990a, Griffiths, 1992a).

A bedded deposit at Pessens near the southern edge of the Massif Central is the next largest barite deposit in France. Further to the south there are a number of residual deposits at Font d' Arques, Auriac, and Montgaillard, contained in Palaeozoic limestone overlain by Mesozoic rocks. Vein deposits, which occur at Porres near Les Arcs, are commonly associated with galena and sphalerite.

Australia

The average annual production of barite in Australia from 1990 to 1994 was around 7500 t, although there was a peak in production of 91 066 t in 1979. Most production has been from South Australia with a significant contribution from Western Australia and New South Wales (Fig. 3). The main producer in Australia at present is Commercial Minerals Ltd which has title over significant barite deposits in the Flinders Ranges of South
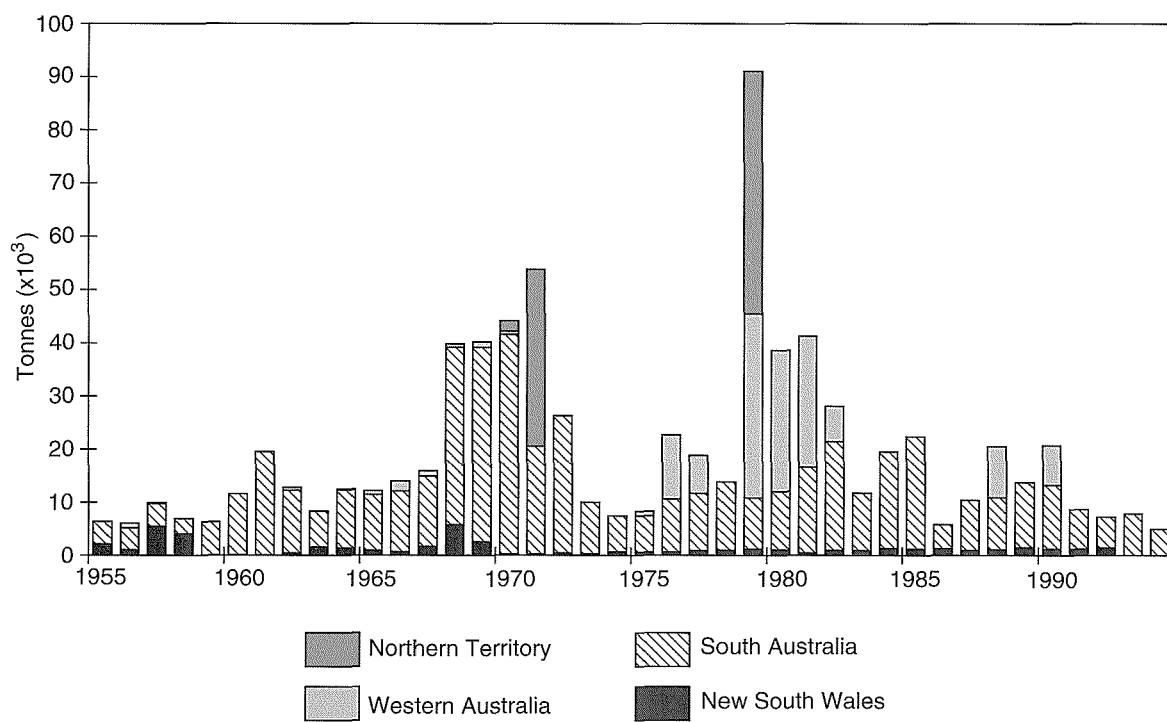
Figure 3.   Australian barite production 1955–1994. (Source of data: Kalix et al., 1966; Australian Bureau of Mineral
             Resources production statistics, 1967 to 1989; Departments of Mineral Resources of South Australia and New
             South Wales)

Australia. The Northern Territory has produced a total of
80 807 t to date, but individual operations did not last
more than three years. There has been no recorded
production from Victoria and Tasmania.

South Australia

Production of barite from South Australia has been
recorded from deposits in Precambrian and Cambrian rocks
in seven districts in the State. Barite also occurs in the upper
portion of Permian glacial beds underlying Tertiary rocks
at Hallet Cove 20 km south of Adelaide, in Jurassic sand
on the southern margin of the Great Artesian Basin, and
in veins associated with the Cretaceous Coorikiana
Sandstone (Hiern, 1976).

Deposits associated with Precambrian rocks are in the
Olary and Corunna districts. In the Olary district, barite
occurs at five localities in large masses up to 30 m wide
associated with an arenaceous calc-silicate unit named the
Ethiudna Group. The barite contains impurities such as
iron oxides, silica and sulfide minerals. The largest
occurrence in the Corunna district is a vein deposit near
Mount Whyalla in the Pandurra Formation.

Barite in Cambrian rocks is mostly hosted in purple
shales of the Wilpena Group, and particularly the Brachina
Formation in the Flinders Ranges and at the old Noarlunga
mines south of Adelaide. Several deposits in the Flinders
Ranges lie adjacent to diapiric piercement structures. These
deposits are of vein type and contain quartz, iron oxides
and small amounts of pyrite and chalcopyrite.

Approximately 40 occurrences of barite have been
recorded in the Flinders Ranges between Hawker and
Blinman. Currently, all production is from a mine at
Oraparinna and an openpit at Dunbar. The Oraparinna
mine is approximately 500 km north of Adelaide, and
the Dunbar deposit is located approximately 70 km north
of Hawker. Production from Oraparinna mine at
present is around 3500–5000 t per year which satisfies
approximately 90–95% of Australian market industrial-
grade requirements. Mining of major veins has been by
opencut as well as underground development of two
lodes. Annual production from the Dunbar deposit has
been highly variable depending on the level of
oil-well drilling activity in Australia. The lode system
in this deposit is up to 35 m wide with individual veins
varying in thickness from a few centimetres to
10–12 m (Griffiths, 1992b).

New South Wales

Most of the known occurrences of barite in New South
Wales are restricted to the eastern portion of the Lachlan
Fold Belt where mineralization is either stratiform or vein
type with considerable variation within each type
(Stevens, 1976).

Stratiform deposits are larger in size than vein deposits
but fewer in number. The deposits at Kempfield, south
of Blayney, and Gurrunda, west of Goulburn, are relatively
large stratiform deposits.

The Kempfield deposits comprise small lenticular
bedded units, consisting of fine-grained greyish barite

with lenses of chert and minor sulfides. Host rocks are Silurian siltstones, slaty siltstones, and various acid volcanic and volcanically derived rocks, including sandstone and minor quartz porphyry. Barite in the Gurrunda deposit is very fine grained and greyish, and contains pyrite. The deposit occurs as two lens-shaped bodies within a steeply west-dipping sequence of tuffaceous sandstones, chloritic shales, black shales, and altered rhyodacitic volcanics typical of Middle to Upper Silurian sequences in the region. Stratiform deposits are also known at Clarevale, south of Goulburn, and at Bombay and Little Bombay, west of Braidwood.

Vein-hosted barite deposits occur in a variety of rocks, but granitic rocks are the most common. Some veins containing white barite occupy joints in the Ordovician Walli Andesite at Walli and Cliefden Springs and black barite occurs in the Ordovician Cargo Andesite. Veins containing barite and minor base metal and iron sulfides occur in acid volcanics at the following localities: Tarago, Bredbo, Lue, Mitta Mitta, Jooriland, Black Rock and Chakola near Cooma; Reedy Creek and Annies deposit south of Boorowa; and Dripstone.

Northern Territory

Recorded production of barite from Northern Territory has been from two deposits. One is situated approx-

imately 25 km north-northwest of Inverway Station in the southwestern part of the Victoria River district and the other is at Dorisvale, approximately 100 km west of Katherine. The former deposit consists of two main high-grade veins in basaltic flows of the Antrim Plateau Volcanics. The veins have an aggregate strike length of about 4 km and average 2 to 4 m in width. Production from this deposit lasted only two years, in 1970–1971, and amounted to 35 226 t. Operations at the Dorisvale deposit had to be suspended after one year due to mining problems, but recorded production of 45 581 t in 1979 (Gourlay, 1971; Northern Territory Geological Survey, 1976; Driessen, 1979).

Western Australia

Total production from Western Australia from 1946 to 1990 was 138 697 t, valued at $6 million. No recorded production has occurred since 1990. Production has been from seven centres (Tables 6 and 7), the most significant of which were North Pole, Chesterfield, and Cranbrook. Production from Chesterfield and Cranbrook ceased in 1970 and 1975 respectively, while production from North Pole occurred from 1970 to 1990. Other centres were only minor producers.

The geology of these deposits and other known occurrences of barite in Western Australia are discussed below.

Table 6. Western Australian barite production (tonnes)

Year	North Pole	Chesterfield	Cranbrook	Coonana	Paraburdoo	Mount Gould	Gnows Nest	Total
1946	–	–	–	10	–	–	–	10
1950	–	–	16	–	–	–	–	16
1951	–	–	5	–	–	–	–	5
1952	–	9	–	–	–	–	–	9
1953	–	–	172	43	–	–	–	215
1954	–	114	947	–	–	–	–	1 060
1955	–	–	10	–	–	–	–	10
1956	–	433	509	–	–	–	–	942
1957	–	–	142	–	–	–	–	142
1962	–	502	–	–	–	–	–	502
1964	–	174	–	–	–	–	–	174
1965	–	763	–	–	–	–	–	763
1966	–	1176	662	–	–	–	–	1 839
1967	–	927	–	–	–	–	51	978
1968	–	666	–	–	–	–	–	666
1969	–	1034	–	–	–	–	–	1 034
1970	528	46	–	–	–	–	–	574
1975	–	–	22	–	475	281	–	778
1976	12099	–	–	–	–	–	–	12 099
1977	7117	–	–	–	–	–	–	7 117
1979	34658	–	–	–	–	–	–	34 658
1980	26602	–	–	–	–	–	–	26 602
1981	24668	–	–	–	–	–	–	24 668
1982	6643	–	–	–	–	–	–	6 643
1988	9669	–	–	–	–	–	–	9 669
1990	7521	–	–	–	–	–	–	7 521
Total	**129 505**	**5 845**	**2 487**	**53**	**475**	**281**	**51**	**138 697**

Source: Department of Minerals and Energy, Western Australia
Production from: Northpole: MC45/1522 and MC1102 (528 t in 1970 only), Chesterfield: MC20N, PA3626M, MC11N, PA3615N and MC2N Cranbrook: 511H and PA 907H (21 t in 1950 and 1951 only), Coonana: MC2K & ML1K, Paraburdoo: MC8/1350 and 1351; Mount Gould: MC52/937, Gnows Nest: MC64.

Table 7. Total value of barite from Western Australian deposits

Year	North Pole	Chesterfield	Cranbrook	Coonana	Paraburdoo	Mount Gould	Gnows Nest	Total (Aus $ value of day)
1946	–	–	–	100	–	–	–	100
1950	–	–	112	–	–	–	–	112
1951	–	–	35	–	–	–	–	35
1952	–	99	–	–	–	–	–	99
1953	–	–	2820	760	–	–	–	3 580
1954	–	1230	14032	–	–	–	–	15 261
1955	–	–	140	–	–	–	–	140
1956	–	4062	6312	–	–	–	–	10 374
1957	–	–	1820	–	–	–	–	1 820
1962	–	6232	–	–	–	–	–	6 232
1964	–	1366	–	–	–	–	–	1 366
1965	–	6006	–	–	–	–	–	6 006
1966	–	13620	13040	–	–	–	–	26 660
1967	–	20613	–	–	–	–	1000	21 613
1968	–	9968	–	–	–	–	–	9 968
1969	–	15271	–	–	–	–	–	15 271
1970	6240	676	–	–	–	–	–	6 916
1975	–	–	415	–	9018	5255	–	14 688
1976	1330890	–	–	–	–	–	–	1 330 890
1977	87450	–	–	–	–	–	–	87 450
1979	482235	–	–	–	–	–	–	482 235
1980	650042	–	–	–	–	–	–	650 042
1981	1109904	–	–	–	–	–	–	1 109 904
1982	281749	–	–	–	–	–	–	281 749
1988	1160280	–	–	–	–	–	–	1 160 280
1990	1006603	–	–	–	–	–	–	1 006 603
Total	**6 115 393**	**79 143**	**38 726**	**860**	**9 018**	**5 255**	**1 000**	**6 249 394**

Source: Department of Minerals and Energy, Western Australia

Market trends

Market activity

An estimated 3.5 Mt of crude barite was traded world-wide in 1983, the bulk of which was used in oil and gas well drilling activities. During the same period, barium chemicals also entered into world trade in a significant way. However, average prices of primary barite have not changed significantly over the last two decades, except for a sharp increase in the value of ground barite in 1980, which had subsided by 1983. Markets for drilling grade as well as non-drilling grade barite were hit by the recession in the late 1980s. For example, a drop in the number of oil wells drilled and a decline in the building construction and automobile manufacturing sectors had negative effects on marketing barite of all grades. However, O'Driscoll (1991) observed that the early 1990s have witnessed a mini-boom in European drilling activity resulting in a recovery from the slump of the mid-1980s. This is shown by the fact that the UK imported 177 000 t of barite in 1990, up by 64 000 t over the previous year.

According to Griffiths (1984), the total world filler market has been variously estimated at between 0.3 and 0.5 Mt. In 1983, approximately 59 000 t and 19 000 t of barite were used in this field by the USA and UK respectively. By 1989, consumption in the USA had dropped to 47 000 t, although some sign of recovery had occurred by 1990 when consumption rose to 57 000 t.

Griffiths (1992a) stated that markets for non-drilling grades such as paints and primers, fillers in plastics and rubber, and brake lining manufacture were depressed by worldwide recession in the late 1980s. Economic recovery currently being experienced by many countries may lead to a positive trend in consumption.

On the supply side, it appears that since around 1994, exports from China have been affected by internal problems such as inability to supply high-grade material, and increases in local prices, taxes and freight costs. Supplies from India have also been affected by cessation of mining of the Mangampet deposit. These factors have resulted in a resurgence of USA barite production. Spain is also re-emerging as a drilling-mud producer, and production in 1995 is expected to be around 50 000 t. Production from Turkey has declined since the early 1990s due to the disappearance of its major markets in Iraq and the former USSR (Griffiths, 1995).

Prices

Prices of ground white paint grade barite of 96–98% $BaSO_4$ quoted in the journal *Industrial Minerals* show an increase from around $160 to $442 per tonne over the
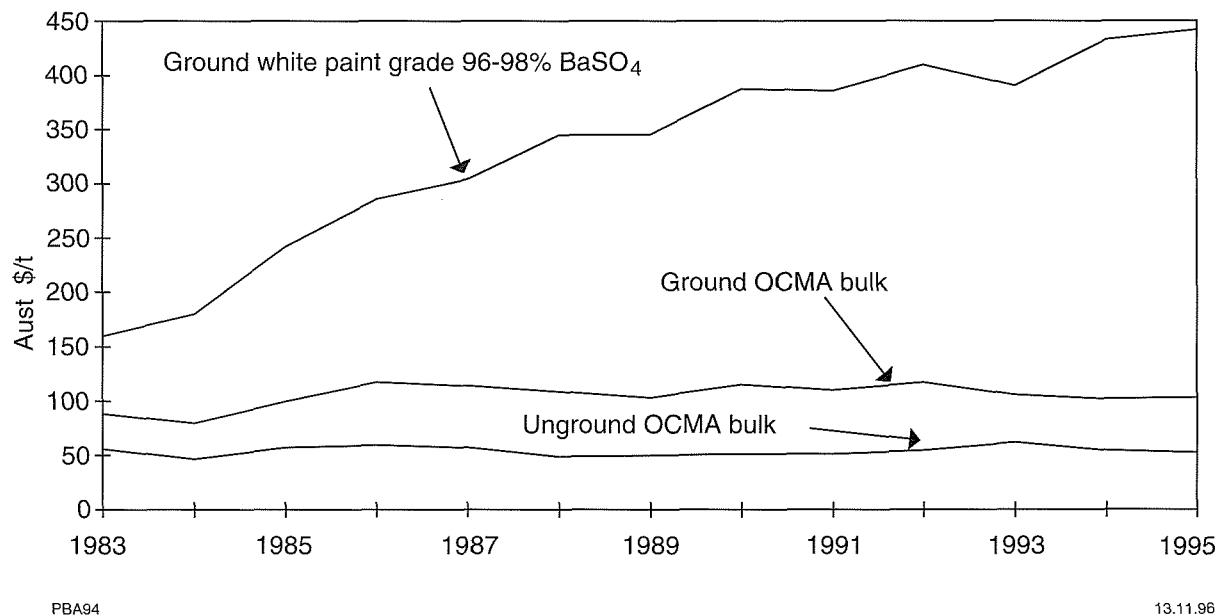
Figure 4. Barite prices 1983–1995 ($ value of the day). (Source of data: Industrial Minerals Journal, 1983 to 1995)

period 1983 to 1995 (Fig. 4). The price of ground OCMA bulk (delivered to Aberdeen, UK) shows only a slight increase from 1983 to 1995 of $88 to $103 per tonne.

Prices for various grades of unground barite have remained virtually flat or marginally depressed from 1983 to 1995. For example, the price per tonne for unground OCMA bulk from Morocco decreased from $56 in 1983 to $52 in 1995 (prices based on the value of the Australian dollar at the end of 1995).

Outlook

Demand for barite in the oil well drilling market is likely to remain at around 4 Mt per year in the foreseeable future. The majority of barite producers worldwide are currently operating at somewhat less than full capacity, and several leading companies have been forced to merge or to rationalize their operations.

Hodge (1994) suggested that even if demand increased to levels as high as that in 1981 (approximately 8.2 Mt), supply would increase, since demand for drilling mud tends to be balanced by variations in the degree of drilling activity from one area to another. There are some optimistic signs for improvement in future demand, particularly for drilling mud. An example is a forecast of a 25% increase in drilling activity on the UK continental shelf in 1995 (Hodge, 1995).

Another interesting development in the industry is the enhancement of product quality now achievable. For instance, a handful of companies are currently engaged in developing natural white, micronized barite products of high brightness which can compete in certain markets with blanc fixe (chemically precipitated barium sulfate) (Griffiths, 1995).

In the near future there is the possibility of an upward movement in CIF prices for barite because of an anticipated rise in freight rates. Furthermore, the current economic recovery shown by major economies may have some positive impact on long term demand.

Barite in Western Australia

Barite occurs in a number of localities of Western Australia (Fig.5). The earliest recorded production was 10 t in 1946 from a deposit at Coonana. The total recorded production from the State from 1946 to 1990 was 138 697 t with a total value of over $6.2 million. More than 90% of this production was from a deposit at North Pole, in the Pilbara Craton, where a total of 129 505 t was produced from 1970 to 1990. The only other significant producing centres were Chesterfield and Cranbrook which had productions of 5845 t and 2487 t respectively prior to 1975 (Tables 6 and 7).

Bedded and/or vein type deposits have been exploited commercially in the past with production coming from the following tectonic units:

Pilbara Craton
Albany–Fraser Orogen
West Yilgarn (Murchison area) – Yilgarn Craton
Carnarvon Basin
Gascoyne Complex
Kimberley Basin
Bangemall Basin
Ashburton Basin
Northampton Complex
Canning Basin – Lennard Shelf

Minor occurrences are found in other tectonic units:

West Yilgarn (southwestern area) – Yilgarn Craton
Eastern Goldfields Province – Yilgarn Craton
Southern Cross Province – Yilgarn Craton
Narryer Complex – Yilgarn Craton
Badgeradda Group
Savory Basin
Paterson Orogen
Halls Creek Orogen
North Perth Basin

Pilbara Craton

Regional geology

The Pilbara Craton can be divided geologically into the older Archaean Pilbara granite–greenstone terrane, and the younger, latest Archaean to earliest Proterozoic volcano-sedimentary sequence of the Hamersley Basin.

The Pilbara granite–greenstone terrane (3.6–2.8 Ga) is exposed over an area of some 60 000 km² in the northern Pilbara Craton. The greenstone consists of metamorphosed basalt, sandstone, shale, siltstone, chert, banded iron-formation (BIF), and felsic volcanics, as well as mafic and ultramafic sills, amphibolite, and psammitic–pelitic and ultramafic schist.

Granitic rocks occupy 60% of the granite–greenstone terrane and generally occur as domes in anticlinal culminations, up to 100 km across and separated by greenstones in synclinal structures.

All the Archaean greenstones of the Pilbara are now grouped as the Pilbara Supergroup (Table 8), which is subdivided further into the Warrawoona, Gorge Creek, and Whim Creek Groups, and the Louden and Mt Negri Volcanics. The lowermost Warrawoona Group consists of the Salgash and the underlying Talga Talga Subgroups. The Salgash Subgroup consists of basalt, felsic volcanics and chert lithologies, while the Talga Talga Subgroup consists of basalt, carbonate, schist and chert.

Hickman (1981, 1983) and Griffin (1990a) have described the granite–greenstone rocks of the Pilbara Craton.

The latest Archaean to earliest Proterozoic Hamersley Basin is the depositional basin of the Mount Bruce Supergroup, a sequence of supracrustal rocks exposed over an area of about 100 000 km² in the northwestern part of the State (Trendall, 1990). The Mount Bruce Supergroup forms a relatively undisturbed cover over the granite–greenstone terrane. Along its northern boundary the supergroup rests unconformably on the granite–greenstone terrane, while the southern boundary is a complex arcuate zone of tectonic disturbance.

The supergroup consists of three constituent groups, the Fortescue, Hamersley and Turee Creek Groups. The Fortescue Group consists of mainly mafic volcanic and volcaniclastic rocks, with subordinate acid volcanics, sandstone, conglomerate, and carbonate. Banded iron-formations, mafic–felsic volcanics, shale and carbonate dominate the Hamersley Group which conformably overlies the Fortescue Group. The Turee Group conformably overlies the Hamersley Group and consists of mainly fine-grained greywacke, sandstone and siltstone, with local carbonate and quartzite.

With the exception of the barite deposits at Eastern Creek and Roy Hill (Table 10) within the Hamersley Basin, all other barite occurrences in the Pilbara Craton are within the granite–greenstone terrane, and particularly in the Warrawoona Group. These occurrences are discussed below.

Figure 5. Barite occurrences in Western Australia

Legend:

- Phanerozoic basins
- Late Proterozoic basins
- Early-Middle Proterozoic basins
- Archaean rocks

Barite occurrences in Western Australia

- ♦ Locality of past productions
- ■ Significiant deposit
- ▲ Significant occurrence
- ● Minor occurrence

PBA129

07.05.97

Table 8. Stratigraphy of the Pilbara Supergroup (*after* Hickman et al., 1990)

Formation	Main rock types	Thickness (km)
Mount Negri Volcanics	Basalt and andesite	0.2
Louden Volcanics	Basalt and ultramafics	1.0
~ Unconformity ~		
Whim Creek Group		
Rushall Slate	Slate, minor tuff	0.2
Mons Cupri Volcanics	Felsic volcanics	0.5
Warambie Basalt	Vesicular basalt	0.2
~ Tectonic contact ~		
De Grey Group		
Mosquito Creek Formation	Psammitic–pelitic schist	5.0
Lalla Rookh Sandstone	Sandstone and conglomerate	3.0
~ Unconformity ~		
Gorge Creek Group		
Honeyeater Basalt	Basalt (pillowed)	1.0
Cleaverville Formation	Banded iron-formation	1.0
Charteris Basalt	Basalt and dolerite (locally developed)	1.0
Corboy Formation	Metasedimentary rocks	1.5
~ Local unconformity ~		
Wyman Formation	Rhyolite	1.0
~ Unconformity ~		
Warrawoona Group		
Salgash Subgroup		
Euro Basalt	Basalt (and komatiite)	2.0
Panorama Formation	Felsic volcanics and sandstone	1.0
Apex Basalt	Basalt (and high-Mg basalt and komatiite)	2.0
Towers Formation	Chert and basalt	0.5
Duffer Formation	Felsic volcanics	5.0
~ Local unconformity ~		
Talga Talga Subgroup		
Mount Ada Basalt	Basalt	2.0
McPhee Formation	Carbonate, schist, and chert	0.1
North Star Basalt	Basalt	2.0

North Pole

Location: Lat. 21°09'14"S, Long. 119°26'05"E (A)

Historical background

The North Pole prospects are situated 120 km southeast of Port Hedland and 40 km west of Marble Bar. The presence of a large deposit of barite southeast of North Pole Mining Centre was first reported by Blatchford (1912), and at the time he suggested that exploitation of the deposit was uneconomic due to limited demand and accessibility. In 1959, Stan Hilditch pegged several claims at North Pole. These tenements along with more ground were acquired by Associated Minerals in 1966. In 1970 this company produced 528 t of barite valued at $6240 from Mineral Claim 45/1102. In 1972, Dresser Australia Pty Ltd optioned barite claims totalling 914 ha

from Associated Minerals and carried out exploration work leading to identification of substantial reserves (Dresser Minerals, 1973).

During the period 1976 to 1990, Dresser produced 128 977 t of barite valued at $6.1 million from Mineral Claim 45/1522 (Tables 6 and 7).

A number of prospects situated approximately 6 km west of the northern Dresser claims originally held by Metals Investments Pty Ltd in 1967 were transferred to Leopold Minerals NL in 1970. After preliminary exploratory work, Leopold Minerals entered into a joint venture agreement in 1974 with Carpentaria Exploration Company to carry out more exploratory work involving mapping, soil sampling and percussion drilling. Although Carpentaria's main aim was to explore for base metals, they did some assessment of a roughly circular barite deposit adjacent to a biotite–adamellite batholith occupying the core of a dome (Carpentaria Exploration Company, 1975).

Locality map

Quaternary deposit

Tuffs and interbedded chert

S-chert (sedimentary)

Mafic volcanic rocks

Granite (including eluvium)

Gabbro

Pyroxenite

Large barite deposit

q Quartz vein

Geological boundary

⟋40 Strike and dip of bedding

⟋30 Strike and dip of foliation

Fault

Pillow facing

Mine

Barite mine, open cut, not worked

Gravel road

Track

Building or hut

Watercourse

1 km
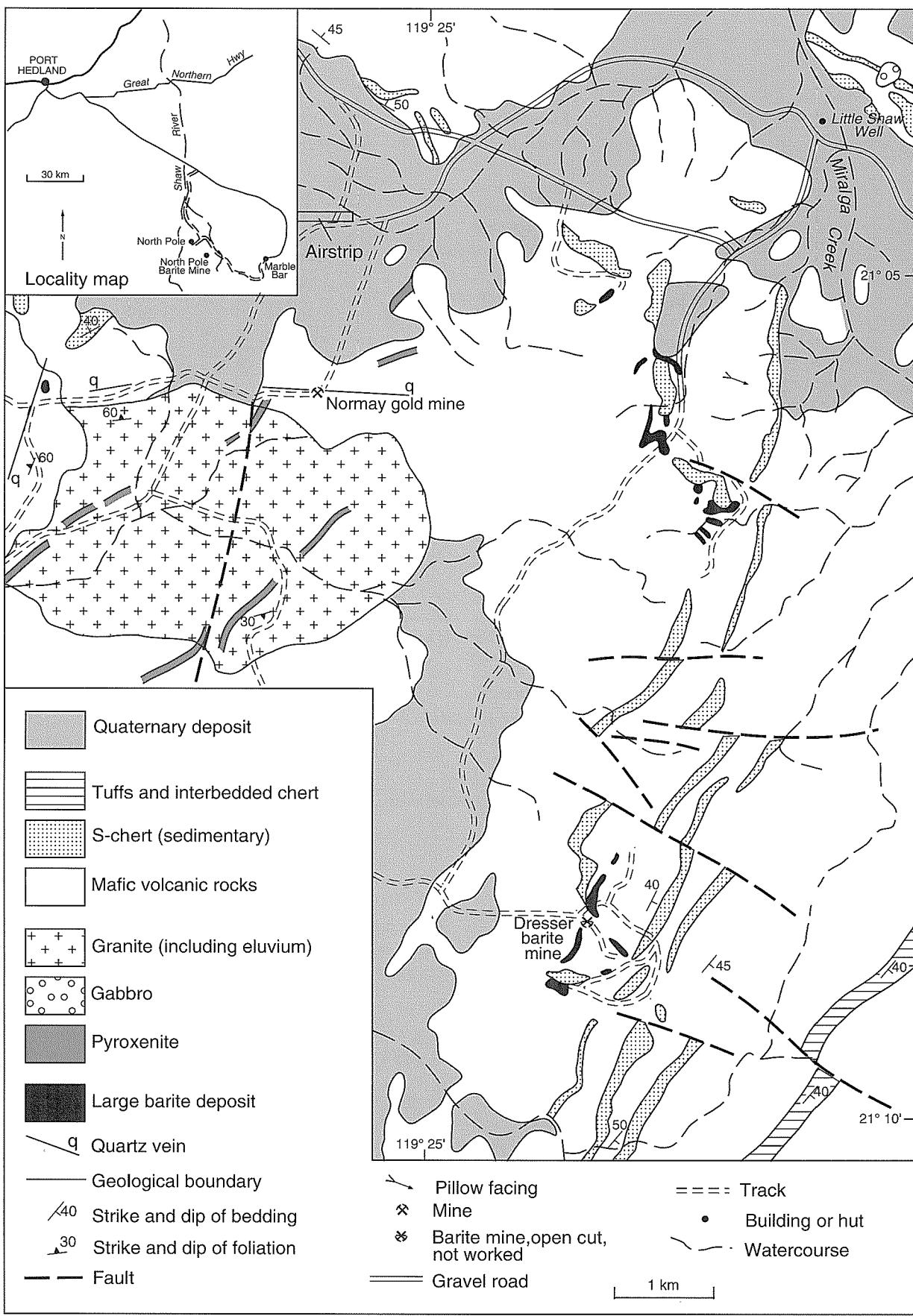
13.11.96

Figure 6. Geology of the area surrounding the Dresser barite mine (*after* Hickman 1973)

Geology

The regional geology of the area around North Pole is given on Figure 6. The main lithologic units in the area are Archaean basaltic and ultramafic rocks, and granitic rocks composed of mainly fine to coarse, even-grained biotite adamellite and biotite granodiorite. Hickman (1973) suggested that the regional Archaean succession enveloping the granite is over 15 km in true thickness.

Erosion of the major, 35 km wide structural unit, the North Pole Dome, has exposed the granite rocks. The prospect area is within the eastern flank of this dome.

The barite prospects consist of a sequence of lower greenschist-facies Archaean basic and acidic volcanics, quartzite (meta-chert) and minor dolomite, pyroxenite calc-schist and carbonate rock of the Warrawoona Group, intruded by granite and dolerite. Stratigraphically, the area occurs close to the base of the Warrawoona Group and apparently straddles the contact between the Talga Talga and Salgash Subgroups (Hickman and Lipple, 1978). Stratigraphic correlations indicate the barite host forms part of the Duffer Formation which has been dated at 3.5 Ga (Sargeant, 1979).

The stratigraphic succession in the barite-mineralized area (Getty Oil Development Company Limited, 1977; Hickman, 1973), is summarized below:

- Basalt, partly pillowed, which has been intruded by ultramafic sills and the North Pole Adamellite (youngest).

- Basic to intermediate volcanics that are extensively altered and commonly pillowed, especially towards the top of the unit.

- Chert and barite (5–50 m thick) and interbedded cherty conglomerate and tuffaceous sandstone.

- Basalt, often pillowed and variolitic, forming the base of the Salgash Subgroup. (oldest)

The widespread occurrence of undeformed pillow structures in mafic lava suggests deposition in a sub-aqueous environment, and that its present thickness closely approximates its original thickness (Hickman, 1973). Hickman also suggested that bedded chert within the succession may have been formed by chemical precipitation. According to Turner and Verhoogen (1960), thick beds of chert commonly found within this type of sequence are derived from late magmatic silica-rich emanations. Alternatively, Hickman (1973) suggested that chert may have originated from the weathering of volcanic ash or by the replacement of pre-existing sedimentary units.

Dunlop and Buick (1981) later interpreted the chert–barite unit to represent sediments containing large amounts of volcanic epiclastic material with a mafic provenance. They suggested that chert and barite were deposited in a shallow water environment with periodic exposure to the atmosphere as evidenced by the presence of littoral structures, stromatolites, evaporitic gypsum casts, and desiccation phenomena.

Structure

The North Pole area is structurally a dome, measuring about 35 km in diameter, and surrounded by deep synclinal greenstone belts. The axis of the dome is slightly elongate about a north-northeast to south-southwest direction with an anticlinal extension towards the southwest where there are chert boxworks. Rocks in the area have been extensively disrupted by normal faulting which, in the area of the barite mineralization, generally dips 10° to 60° easterly. Faults tend to be steeper in the southern parts of the prospect.

The regional distribution of the barite deposits is stratigraphically controlled, but structural features govern their size, shape and lateral distribution along strike. Individual barite prospects are contained within a box-work pattern of ramifying cherts which form a rugged range of hills more than 100 m above the surrounding countryside. Many of the barite deposits occupy veins within the dome fracture system. Hickman (1973) suggested that the fracture system related to the dome was formed by tensional stress either during or shortly after uplift.

Interlayered barite and chert beds contain tight to isoclinal folds with local mesoscopic thrusting. Cleavage planes within barite are commonly slightly crenulated, revealing the presence of deformation subsequent to recrystallization. Hickman (1973) considered that structural features such as the weakly developed bedding plane schistosity in some of the mafic lavas, and a subvertical strain-slip cleavage disposed radially about the eastern and southern domal flanks, could have been formed by circumferential compression associated with upwards movements in the centre of the fold.

Mineralization

Hickman (1973) considered that all North Pole barite deposits are situated close to and generally underneath the lowest thick-bedded chert unit of the succession. Getty Oil Development Company Limited (1977) suggested that chert and barite veins were extensive in the basic to intermediate unit and in a zone of basalt immediately below it. Chloritization and silicification of host rocks is associated with the vein system while widespread carbonate alteration is thought to be unrelated to the veining.

Barite deposits are largest at fracture intersections and in regions of minor flexure, with widths of 20 to 50 m or more. Depending on local structural control, deposits are lenticular, tabular, wedge shaped or sigmoidal. In contrast, barite deposits within 'S-chert' (sedimentary chert) occur in tabular masses and are stratigraphically controlled by, and closely interbedded with, sedimentary chert. In general, these constitute thinner bodies, but are more predictable at depth.

Mineralization within the Dresser leases extends for over 8 km in a belt up to 0.5 km wide. The Dresser mine is situated it the southern end of the belt, while smaller, undeveloped prospects are in the north. Within the belt, barite is interlayered with chert, either in subvertical vein-like structures or in beds which appear to be a part of the succession (Hickman, 1973). Pale blue-grey, coarsely crystalline barite occurs in discrete layers about 10–20 cm thick. Sargeant and Sampson (1980) divided the barite–chert host into three zones (+50%, 10–50% and no barite) depending on the amount of barite.

Barite mineralization within Carpentaria Exploration Company leases also occurs underneath the lowest thick-bedded chert unit of the succession. Detailed mapping in these prospects indicates that barite was emplaced as a discordant vein (Carpentaria Exploration Company, 1975), with a maximum true thickness of 3 to 12 m. At the surface, the barite is colourless to white, coarsely crystalline, and with minor iron oxide staining and secondary silicification along fracture planes. Small pods of ferruginous gossan, common within the barite, are marked by the occurrence of malachite, anomalous Zn and Ag values, and conspicuously low Pb values.

Origin

Hickman (1973) suggested an Archaean age for the barite deposits because they are strongly folded and injected by tectonically controlled Archaean 'T-chert'. After discussing the following three possible origins, Hickman concluded that the deposits were probably sedimentary in origin.

1. Formation by the replacement of pre-existing sediments
2. Precipitation from hydrothermal solutions
3. Deposition as bedded sedimentary barite

The replacement origin was discarded because of the absence of relics of the protolith. The following arguments were given to rule out a hydrothermal origin:

1. The occurrence of barite as concordant layers with chert and surrounding lavas in less deformed areas.
2. The occurrence of barite deposits in a single stratigraphic level for 8 km along strike.
3. The bedded form of the barite layers and the absence of wedging out or crosscutting of these layers.
4. Monomineralic nature of the barite deposits.
5. Absence of accompanying sulfide mineralization.
6. Absence of wallrock alteration.
7. The emission of a strong fetid odour on breaking and crushing barite, which is a characteristic of certain bedded barite deposits.
8. The common association of barite–chert in sedimentary barite deposits.

In addition, Hickman (1973) noted that the joints and fracture system formed during uplift of the North Pole dome were locally invaded by diapiric folds in bedded barite.

According to Sargeant (1979), there is convincing textural evidence that the barite deposits formed by diagenetic replacement of an original evaporative calcium sulfate–carbonate sequence. Sargeant and Sampson (1980) endorsed the views of Hickman (1973) on the origin of the barite–chert horizons after detailed mapping in the area and inferred that the mode of deposition of the barite together with gypsum was due to normal exhalative chemical deposition. Furthermore they suggested that the T-cherts would represent a favourable in-basinal environment for the deposition of a sulfate facies. They also raised the possibility that the finely disseminated galena and sphalerite in the system might indicate the occurrence of a massive sulfide deposit down dip from thick barite horizons. Lead isotope data on galena associated with barite gave ages of around 3.4 Ga, comparable to the known age of the host Duffer Formation (Richards et al., 1981).

Grade, reserves and resources

Analyses of five barite samples from workings in the Dresser leases indicate that BaO% ranges from 52.48 (79.86% BaSO$_4$) to 64.76 (98.55% BaSO$_4$) (Table 9), and SiO$_2$ content from 0.83 to 15.30%. High silica in some samples is due to contamination with chert. Trace element data indicate high concentrations of Sr, V and Ce.

Although a resource of several million tonnes has been estimated for the North Pole deposit, the published total inferred resource for all Dresser leases is 500 000 t (Australian Mining, 1983; Hickman, 1983).

Barite samples from costeans in the Carpentaria Exploration Company leases assay 95.4% to 97.4% BaSO$_4$, with specific gravity varying from 4.35 to 4.42 (van Toll, 1981). Drill core samples had generally lower grades of between 65.5% and 88.2% BaSO$_4$ with some associated witherite, calcite and silica. The specific gravity of these samples was lower, varying from 3.86 to 4.27. Carpentaria Exploration Company (1975) concluded that material of this nature would require beneficiation before shipment, although none of the impurities was deleterious. The inferred reserves, assuming a maximum mining depth of 30 m, was 150 000 t with a possible extension of mineralization to the north with an additional 50 000 t to 100 000 t. Tests have proved that the ore from this deposit can be beneficiated to drilling mud grade specifications.

The North Pole deposit is considered to be the largest yet discovered in Australia and is strategically situated to supply the needs for oil exploration activities on the North West Shelf and also for export markets in southeast Asia.

Cooke Bluff Hill

Location: Lat. 20°57'00"S, Long. 119°23'00"E (B)

Introduction

Geological mapping by the Geological Survey of Western Australia revealed the presence of large barite deposits near Cooke Bluff Hill (Hickman, 1977, 1983), situated

Table 9. Chemical analyses of North Pole barite

GSWA no.	117390	117391	117392	117393	117394
			%		
SiO_2	15.30	8.37	3.36	3.98	0.83
TiO_2	0.13	0.13	0.14	0.14	0.14
Al_2O_3	<0.10	0.13	<0.10	<0.10	<0.10
Fe_2O_3	<0.05	<0.05	<0.05	<0.05	<0.05
FeO	<0.05	<0.05	<0.05	<0.05	<0.05
MgO	<0.05	<0.05	<0.05	<0.05	<0.05
CaO	<0.01	<0.01	<0.01	<0.01	<0.01
Na_2O	0.80	0.82	0.88	0.90	0.91
K_2O	<0.01	<0.01	<0.01	<0.01	<0.01
MnO	<0.01	<0.01	<0.01	<0.01	<0.01
BaO	52.48	59.40	63.53	64.76	63.19
P_2O_5	<0.01	<0.01	<0.01	<0.01	<0.01
SO_3 (a)	27.4	31.01	33.12	33.81	32.99
CO_2	<0.10	<0.10	<0.10	<0.10	<0.10
F	<0.01	<0.01	<0.01	<0.01	<0.01
$H2O^+$	0.12	0.14	0.08	0.11	1.06
$H2O^-$	0.11	0.22	0.14	0.13	0.21
		Trace elements (ppm)			
Ag	<2	<2	<2	<2	<2
As	<4	<4	<4	<4	<4
Bi	16	19	14	13	12
Cd	<5	<5	<5	<5	<5
Ce	175	201	234	211	222
Co	60	4	<4	6	<4
Cr	11	59	16	25	6
Cu	144	184	179	196	176
Ga	<3	<3	<3	<3	<3
Ge	<3	<3	<3	<3	<3
La	<3	<3	<3	<3	<3
Mo	<2	<2	<2	<2	<2
Nb	<7	<7	<7	<7	<7
Ni	15	41	22	37	29
Pb	<4	15	<4	40	<4
Rb	<2	<2	<2	<2	2
Sb	6	<4	<4	8	<4
Sn	<4	<4	<4	<4	<4
Sr	4100	7750	6310	7590	8200
Ta	<6	<6	<6	<6	<6
Te	<6	<6	<6	<6	<6
Th	<2	<2	<2	<2	<2
U	<2	2	<2	<2	<2
V	762	831	867	894	881
W	120	5	<4	<4	7
Y	2	<2	3	<2	<2
Zn	46	294	80	386	158
Zr	<5	<5	<5	<5	<5

Analyses: Chemistry Centre (W.A.)
(a) SO_3 calculated stoichiometrically from BaO (assuming $BaSO_4$)
Sample locations — 117390 and 117391 — Lat. 21°08'54"S, Long. 119°25'36"E; 117392 — Lat. 21°09'03"S, Long. 119°25'48"E; 117393 and 117394 — Lat. 21°09'14"S, Long. 119°26'07"E

100 km southeast of Port Hedland and 25 km north of North Pole, at the western end of the Gorge Range. Barite occurs in veins as well as barite sandstone, within Archaean sandstone, conglomerate, banded chert and felsic volcanogenic rocks.

Geology

The geology of the Cooke Bluff Hill area is shown in Figure 7. All the major barite deposits are associated with chert overlain by a succession of Archaean sedimentary rocks and underlain by a succession of dominantly Archaean volcanic rocks. Both volcanic and sedimentary rocks are exposed as low hills flanked to the west by a large plain which is probably underlain by granitic rocks (Hickman, 1977). A faulted contact, indicated by quartz veining and local shear zones, occurs between the granitic rocks and the layered sequence. According to Hickman and Lipple (1978), the barite deposits are concentrated at the contact between the Warrawoona Group and the Gorge Creek Group.

The volcanic and sedimentary rocks have been tightly to isoclinally folded about axial planes striking northeast and dipping steeply northwest. Older faults strike northeast and form tectonic slides displacing fold limbs, while a younger fault set consists of northerly striking sinistral wrenches.

Barite deposits

Nineteen barite mineral occurrences were noted (Fig. 7), with barite occurring in two forms:

1. coarsely crystalline blue-grey barite veins within chert, sandstone, and less commonly in felsic tuff and lava;
2. barite cement in sandstone beds (barite sandstone).

Larger veins of the first type occur within or adjacent to grey-white banded chert units in which the proportion of barite to chert gangue varies from 2:1 to 1:4. The veins are generally steeply inclined and less than 2 m in width, although some range up to 10 m in width. Euhedral pyrite crystals, up to 5 mm across, are disseminated in chert at the contact zones with barite.

In the second type barite typically makes up about 50% of thinly bedded barite-cemented sandstone which is about 1 to 2 m wide and alternates with thin-bedded, grey-white banded chert units. There is only a minor change in appearance between the unmineralized sandstone and barite-rich sandstone but they can be distinguished on the basis of barite sandstone being softer and more resinous in lustre compared to the unmineralized sandstone.

Where barite sandstone and veins occur together, the veins invariably intrude the sandstone.

Origin

Hickman (1977, 1983) suggested that barite sandstone may have originated as a replacement deposit and barium was precipitated from surface water or hypogene solutions associated with volcanic activity. He also suggested that vein deposits were derived from the bedded deposits during deformation or nearby granitic intrusion. The Sr abundance discrepancy between vein barite (7100–9800 ppm) and sandstone-hosted barite (1200–1300 ppm) is considered to be due to mobility of strontium during metamorphism, which favours concentration in displaced material.

LOCALITY MAP

Legend:

- Archaean greenstones
- Archaean granite

50 km

Legend:

Q	Quaternary alluvium
Qa	Quaternary colluvium
	Barite deposit (known extent)
	Limestone
	Sandstone
	Ferruginous sediments

| | Banded iron-formation | | Felsic lava |
	Chert		Mafic lava
	Ferruginous conglomerate		Granite rock
T	T-chert	|60	Strike and dip of bedding
– – –	Track		Anticline, plunge
—x—	Fence		Syncline, plunge
	Creek		Fault
		—o	Facing (cross bedding)

PBA31

11.11.96

Figure 7. Regional geology and barite deposits in the Cooke Bluff Hill area (*after* Hickman, 1977)

30

Grade and reserves

Barite in the Cooke Bluff Hill deposits is of lower grade than that at North Pole. Of the nineteen localities identified, only seven contain large deposits, and these were thought to be of doubtful economic potential without beneficiation, since all contain chert and quartz impurities. Hickman (1977) calculated a total pre-resource estimate of 0.5 Mt of barite to a depth of 10 m in the Cooke Bluff deposits. However, Blackburn (1978) stated that the presence of an economically viable deposit is unlikely because barite occurrences in the area were thin and discontinuous and also were always intimately intergrown with silica.

Marble Bar (Big Stubby deposits)

Location: Lat. 21°13'20"S, Long. 119°45'35"E (A)

The Big Stubby deposits, located 6.4 km southeast of Marble Bar, contain several sulfide bodies, at least two of which carry massive sphalerite and barite (Brook, 1974). Barite occurs as gangue to the massive sulfide mineralization which occurs in Archaean rhyolite tuff overlain by chert. In the mineralized area, the succession strikes northwesterly, with dips steeply west. Underlying the barite lenses are rhyolite or dacite domes and breccias. Hickman (1983) has pointed out that the deposits are at approximately the same stratigraphic level as the North Pole deposits, but suggested that they are almost certainly volcanogenic. The lowermost unit, the Big Stubby Tuff–Breccia, consists of acid fragments in an intermediate to basic tuffaceous matrix. This unit is intruded by at least three rhyolite/dacite domes with massive pyrite at the top. Above some domes, onlapping sediments host zinc- and barite-rich sulfide zones.

Stratiform sulfide bodies, which contain up to 60% barite (Lipple, 1976; Hickman, 1983), are 15–130 cm wide and 60 m long and appear to widen at depth to 1.5 to 6 m containing an average of 40% barite. A resource of 100 000 t to 150 000 t of barite and base metal sulfides could exist above 150 m depth (Brook, 1974; Lipple, 1976; Hickman, 1983).

Jimblebar

Location: Lat. 23°28'35"S, Long. 120°08'25"E (A)

Barite occurs as a 5 m-wide vein associated with an amphibolite at a location 1.6 km west of the former gold mining camp of Jimblebar. The barite is highly translucent and devoid of colour except for minor surficial iron staining. However, while the occurrence contains a significant volume of high-grade barite, its remote location makes commercial development unlikely (Simpson, 1948).

More barite veins in sheared granite were reported from Jimblebar by Finucane (1939). Barite veins occur in a creek bed by the road, approximately 3 km from Jimblebar towards West End.

Murramunda (Coobina)

Location: Lat. 23°29'40"S, Long. 120°21'10"E (A)

Barite associated with galena occurs in veins within a fault zone forming the northern margin of the Coobina ultramafic intrusion, 2 km west of Murramunda (Williams and Tyler, 1991). Talbot and Simpson (1926) stated that near the gold workings, at the east end of the Ophthalmia Range, detrital pebbles of barite are plentiful.

Minor occurrences

Minor occurrences of barite in the Pilbara Craton are listed in Table 10.

Albany–Fraser Orogen

Regional geology

The Albany–Fraser Orogen borders the southeastern margin of the Yilgarn Craton and is characterized by high-grade gneiss and granitoid intrusions (Myers, 1990a). The orogen can be divided into two parts:

1. A complex of high-grade quartzofeldspathic gneiss and layered intrusions named the Biranup Complex (1.2–1.1 Ga).
2. A complex of less intensely deformed high-grade orthogneiss and paragneiss, intruded by sheets of granite at about 1.1 Ga, and collectively named the Nornalup Complex.

Metasedimentary rocks of middle Proterozoic age are situated in a fault-bounded block which abuts the Biranup Complex. The Stirling Range Formation, which originally formed part of the northern foreland of the Albany–Fraser Orogen (Myers 1990a), appears to have been thrust northwards over the Yilgarn Craton (Clarke et al., 1954).

The only known barite deposit in the orogen is situated 6 km east of Cranbrook within the Stirling Range Formation, and has yielded around 2500 t of ore. The simplified geology of this area is given in Figure 8. Muhling and Brakel (1985a) subdivided the formation, which is more than 1.6 km thick, into lower and upper units of quartzite, and a middle unit of quartzite, slate, and phyllite.

## Cranbrook

Location: Lat. 34°17'48"S, Long. 117°36'48"E (A)

Historical background

The Cranbrook barite deposits, located approximately 6 km east of Cranbrook township and approximately 2.5 km east-northeast of Sukey Hill, were discovered in

Table 10. Minor occurrences of barite in the Pilbara Craton

Locality	Lat. (S) Long. (E) (approximate)	Remarks	References
Pilbara granite–greenstone terrane			
Cookes Creek	21°37'10", 120°25'45" (A)	Veins of barite and fluorite in granitic and mafic volcanic rocks	Hickman (1978)
Cossack	Approx. 3 km from the port of Cossack (direction unknown) (B)	Milky white, feebly translucent barite associated with greenstones. Barite is considerably stained with iron and manganese oxides	Simpson (1948)
Eginbah (30 km southwest)	21°04'35", 119°36'00" (B)	A 50 cm wide cross-cutting barite vein	Hickman and Gibson (1982)
Mount Edgar (Lennons Find) 16 km south-southeast of Mount Edgar	21°21'24", 120°14'00" (B)	Barite occurs as a gangue mineral in a number of lead- and copper-bearing lodes. Percentage of barite in the ore was variable	Simpson (1948)
Nullagine	21°54'00", 120°06'00" (Nullagine town) (B)	A sample of several tonnes of Nullagine conglomerate contained barite along with a number of other minerals such as quartz, feldspar, kaolin, zircon etc	Simpson (1948)
Panorama deposits Kangaroo Caves	21°12'40", 119°14'07" (A)	In the Archaean Strelley Succession barite occurs in both prospects as a gangue mineral together with quartz, chlorite, sericite and dolomite,	Morant (1995)
Breakers	21°16'40", 119°13'44" (A)	in VMS-style Zn–Cu deposits associated with dacite sills intruding andesitic–basaltic volcanics beneath a chert carapace	
Hamersley Basin			
Eastern Creek (24 km northeast)	21°31'05", 120°50'30" (B)	Coarsely crystalline barite with pinkish and brownish tinge	Simpson (1948)
Roy Hill (16 km northeast)	22°29'30", 120°02'05" (B)	A fibrous, hard, compact, greyish yellow to neutral grey specimen of detrital barite of SG 4.37 was found at this location	Simpson (1948)
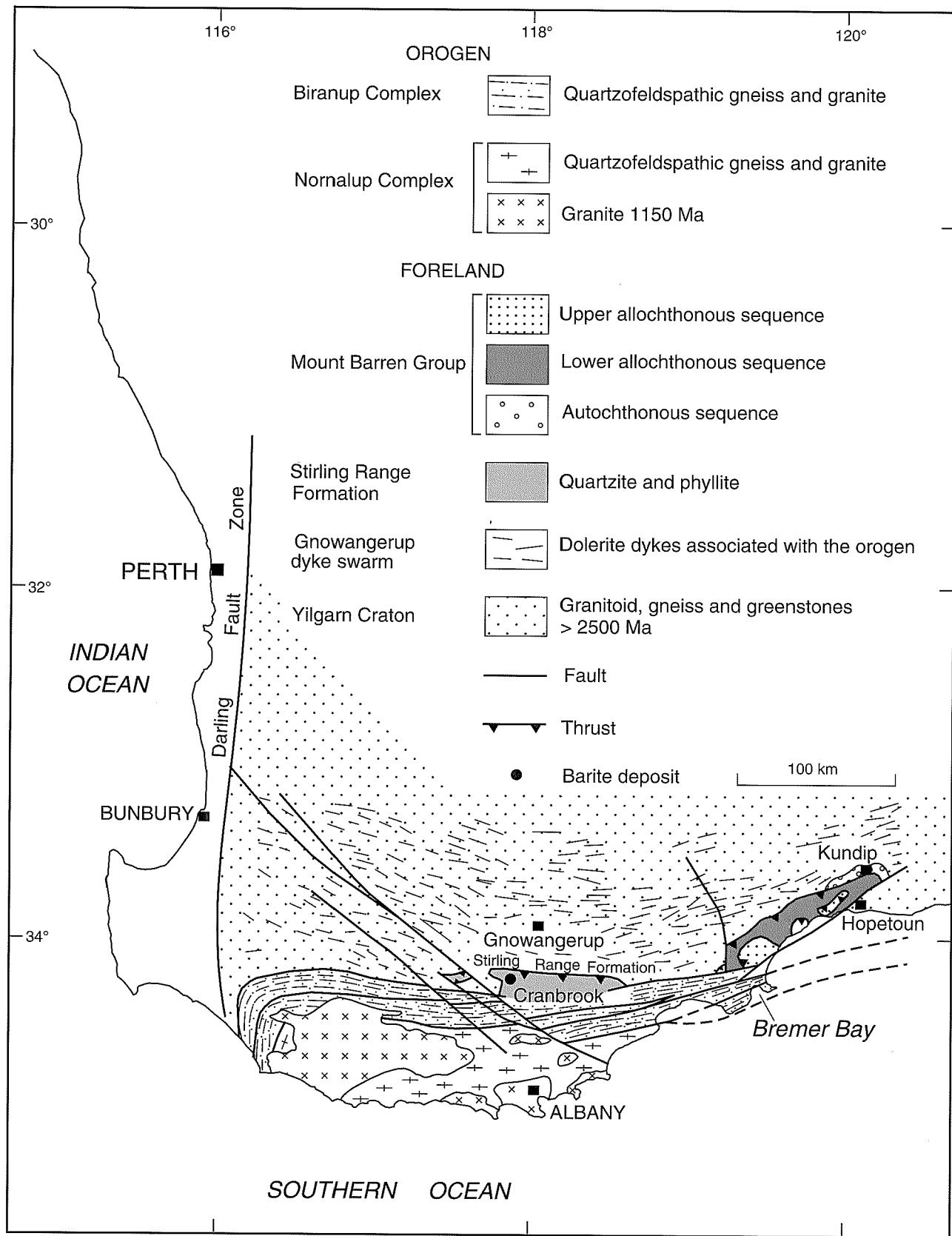
Figure 8. Simplified geological map of the western part of the Albany–Fraser Orogen (*after* Myers, 1990a)

Table 11. Chemical analyses of barite from Cranbrook (*after* Simpson, 1948)

Sample no.	3093D	5510E	609/40
		%	
BaSO₄	96.38	98.69	nd
BaO	nd	nd	63.61
CaSO₄	0.34	0.00	nd
Fe₂O₃	0.39	0.02	0.05
SiO₂	2.89	1.55	3.32
Pb	nd	nd	0.00
CO₂	nd	nd	0.00
SO₃	nd	nd	32.31
Total	100.00	100.26	99.29

nd = not determined

1897 by Mr J. H. Cox, a local farmer. Simpson (1948) recommended an investigation of the deposit because three analysed samples were of very high quality (Table 11) but, due to lack of satisfactory markets at the time, no attempt was made to exploit the deposit commercially. In May 1920, Mr Cox pegged a mineral lease and a prospecting area. The deposits were inspected by a government geologist, F. R. Feldtmann, who reported the occurrence of three veins (Noldart, 1955), the two largest of which were located in the mineral lease and the smallest in the prospecting area. Later in the same year, the prospecting area was acquired by Mr L. M. Healy and pegged as a mineral lease.

From 1920 to 1953, very little work was done on these leases except for a production of 21 t during 1950 and 1951. In February 1953 several prospecting areas were pegged by Mr A. Ferrari and were later repegged as a mineral claim in July 1953. The area of this claim was subsequently reinstated under the ownership of Mr J. Ilich. Production from these claims was continuous from 1953 to 1957, totalling 1781 t (Tables 6 and 7). After 1957, the only recorded production was 662 t in 1966 and another 22 t in 1975. Total production from the deposit from 1946 to date is 2487 t valued at $38 726.

Geology

Barite workings are within a fine-grained, reddish, silicified sandstone that closely approaches quartzite in texture and hardness. Muhling and Brakel (1985a) stated that at this location, a zone of steeply dipping barite pods and quartz veins occurs in a medium-grained quartz arenite of the Stirling Range Formation. The width of the main barite zone ranged from 0.25–0.75 m. The flat country north, south and west of the deposits is covered by superficial deposits and salt lakes.

Mineralization

Barite mineralization is confined mainly to Veins 1, 2, and 3.

Vein 1

This, the largest and most southerly of the three veins, has an arcuate-shaped outcrop pattern. It has a surface width of about 15–120 cm, trends at 083°, and is traceable for a distance of at least 120 m (Simpson, 1948; Noldart, 1955). Surface width pinched to about 15 cm at each end of the vein. The vein also narrowed slightly with depth with an average width of 0.8 m, and the maximum width observed was approximately 2 m at a depth of 10 m, approximately 7 m west of the main shaft. The vein, hosted in pinkish quartzite, had a nearly vertical dip and contained finely granular, feebly translucent, white barite, surrounding a coarse granular more translucent variety. According to Simpson (1948), the only impurities present were localized patches of limonite and quartz. Noldart (1955) also observed that pure fine-grained, opaque white barite, interbanded with a coarsely crystalline variety, is found from a depth of 3 m below the surface and the ore above this was considerably iron stained. This vein had been mined to a depth of 12 m by a main shaft of 18 m depth located 17 m east of the old shaft. Slickensides were commonly developed on both hanging and footwalls.

Vein 2

The second-largest vein is located 183 m northwest of the first and is nearly parallel, having a trend of 080°. It has been traced for a distance of about 55 m (Noldart, 1955), with a width of 0.3 to 1.2 m, but narrows at each end. Barite from this vein is very similar to the No. 1 vein, although nothing is known of the vein at depth.

Vein 3

The third vein in PA 341H had a maximum width of only about 45 cm and a length of 15 m, but contained very dense, microcrystalline, almost colourless to partly milky white, feebly translucent barite of better quality than the other veins (Simpson, 1948). Noldart (1955) noted that the vein trended 290° and dipped 80° north. Mining was to a depth of 12 m where the vein pinched out.

Noldart (1955) observed that during his visit to the workings in 1953, mining was confined to the No. 1 vein. He noted that the surface indications of all three veins were identical, and the scarcity of barite float even in the immediate vicinity of the veins.

Grade and reserves

Analyses of three samples given by Simpson (1948) (Table 11) indicate that BaSO₄ content varies from 96.38% to 98.69% and SiO₂ content from 1.55% to 3.32%. Noldart (1955) noted that the No. 1 Vein barite in the main workings below 3 m level was high in quality and, except for two different varieties of barite, the grade has been consistent. He also suggested that at depth, the grade of the other two veins should remain high.

Noldart (1955) suggested an inferred resource of 1500 t in the No. 1 vein with the assumption that it should extend to a depth 80–90 m. On similar reasoning he suggested an inferred resource of 1000 t in No. 2 vein. Total production to date of 2487 t seems to indicate that the deposit is almost exhausted, but no recent work has been done to estimate current reserves.

Origin

Noldart (1955) suggested that the barite veins were mesothermal deposits derived from a deep-seated magmatic intrusive body, the presence of which is suggested by the occurrence of aplite dykes. However, Sofoulis (1958) postulated that the barite veins were of sedimentary origin on the basis of the veins occurring in a metasedimentary sequence lacking evidence of hydrothermal or igneous activity.

West Yilgarn (Murchison area) – Yilgarn Craton

Regional geology

The Murchison area, the northwestern portion of the Yilgarn Craton, consists of two greenstone sequences (Murchison Supergroup) and four suites of granitic rocks.

The Murchison Supergroup (Watkins, 1990) is subdivided into the Luke Creek Group and the overlying Mount Farmer Group. Both greenstone units consist of mafic volcanics, intrusive rocks, minor ultramafics, and minor felsic volcanics and sedimentary rocks. Outcrops of greenstone are separated by large areas of granitic rocks.

Although there has been production of barite from two deposits located at Chesterfield and Gnows Nest in the West Yilgarn (Fig.5), exploration activities are inadequate to assess their real potential. Another occurrence at Quartzite Hill may be significant on the basis of preliminary geological observations. All the above occurrences are of vein type. A minor occurrence is also recorded in the Mullewa area.

Gnows Nest

Location: Lat. 28°32'25"S, Long. 116°42'50"E (A)
(16 km west-northwest of Gnows Nest)

Background

Muhling and Low (1977) noted that barite has been produced from a granitic pegmatite that intruded fine- to medium-grained, foliated trondhjemite located 22.5 km south-southeast of Yalgoo. The barite forms patches within a weathered quartz–feldspar–muscovite pegmatite. Recorded production from this occurrence (MC 64) was 51 t in 1967. Weeks (1989) stated that 90 t (not reported to the Department of Minerals and Energy) of clear barite had been extracted from a pegmatite located on Badja Station, 22 km south of Yalgoo. It is possible that this location and the one described by Muhling and Low (1977) are the same.

Geology

The barite prospect is in an area of dominantly Archaean granitic rocks where barite is believed to be associated with a deeply weathered quartz–feldspar pegmatite dyke, trending at approximately 243°. Barite occurs as pure white crystalline masses with accessory mica. Approximately 400 m east of the workings is a vein 3 to 5 m wide containing graphic intergrowth of barite and quartz within folded granite and sediments. This is believed to be a recrystallized mass resulting from remobilization of mineral phases within the original pegmatite. Three shallow trenches, 100 m to 150 m northeast of the workings, have exposed extensions of the pegmatite, and the middle trench has intersected a pod of white barite approximately 0.3 m in diameter.

Mineralization and grade

Muhling and Low (1977) suggested that porphyritic adamellite underlying the trondhjemite was probably the source of barite. Weeks (1989) concluded that there are two types of barite-bearing rocks:

1. A primary quartz–feldspar pegmatite containing pure barite pods.
2. A complex graphic intergrowth of quartz–barite–(feldspar) formed as a result of post-emplacement deformation of the original pegmatite.

The specific gravity of 15 samples varied from 2.61 to 4.47. Chemical analyses of samples from three heaps assay 85.4%, 86.5% and 90.9% $BaSO_4$ with corresponding specific gravities of 4.28, 4.34 and 4.44 respectively. Weeks (1989) recommended more exploratory work to assess its economic viability.

Chesterfield

Location: Lat. 260°27'25"S, Long. 118°00'20"E (A)

Simpson (1948) observed that finely granular, yellowish grey barite occurs in a small area of Archaean greenstone surrounded by granite at Chesterfield, located 48 km west-northwest of Meekatharra.

There was sporadic production from this prospect from 1952 to 1962 and continuous production from 1964 to 1970 (Tables 6 and 7). Since 1970 there has been no recorded production. Total production was 5845 t valued at $79 141, which is the second highest in

Table 12. Chemical analysis of Chesterfield barite

GSWA no.	117388
	%
SiO_2	15.40
TiO_2	0.14
Al_2O_3	0.32
Fe_2O_3	<0.05
FeO	<0.05
MgO	<0.05
CaO	0.01
Na_2O	0.80
K_2O	0.10
MnO	<0.01
BaO	53.82
P_2O_5	<0.01
SO_3 (a)	28.10
CO_2	0.08
F	0.06
H_2O^+	0.17
H_2O^-	1.15

	Trace elements ppm
Ag	<2
As	<4
Bi	12
Cd	<5
Ce	166
Co	4
Cr	80
Cu	170
Ga	<3
Ge	<3
La	<3
Mo	<2
Nb	<7
Ni	18
Pb	914
Rb	8
Sb	<4
Sn	<4
Sr	4720
Ta	<6
Te	<6
Th	<2
U	<2
V	760
W	5
Y	<2
Zn	404
Zr	<5

Analyses: Chemistry Centre (W.A.)
(a) SO_3 calculated stoichiometrically
from BaO (assuming $BaSO_4$)
Sample location — 117388 — Lat.
26°27'25"S, Long. 118°00'21"E

Western Australia after North Pole. Most production was from a mineral claim owned by Universal Milling Company Pty Ltd.

The barite occurs as steeply dipping veins in gabbro and basaltic tuff in an Archaean greenstone sequence. Outcrop vein thickness varies between 30 cm and 1.5 m with an average of about 75 cm. The vein has been worked to a depth of 42 m and over a length of 30 m. The width of veins in the mine varies between a maximum of 3.1 m and a minimum of 1.3 m. Most of the barite is considered to be of good quality although some thin seams and lenses of country rock contaminate the vein (Lipple, 1976; Elias, 1982). Chemical analysis of a sample from a vein in the workings indicates 53.82% BaO (81.9% $BaSO_4$) and 15.40% SiO_2 (Table 12). The sample also contains relatively high Sr and V abundances comparable to those of North Pole barite (Table 9). However, it has elevated Pb levels (914 ppm) when compared to North Pole, which averages about 13 ppm Pb.

Quartzite Hill

Location: Lat. 26°19'40"S, Long. 117°33'35"E (A)

Barite occurs in a quartz vein occupying a shear zone in a granitoid rock at a location 11 km east of Quartzite Hill (Elias, 1982). A number of massive barite veins, approximately 1 m thick, are surrounded by zones of thinner barite veins and quartz–barite breccia. The barite occurs over a width of about 40 m and extends over a length up to a maximum of 200 m. On the basis of extensive quartz-filled shear zones, Elias (1982) suggested the possibility of more pockets of barite between Quartzite Hill and Eanally Bore, a distance of about 25 km.

Minor occurrence

Mullewa

Location: Lat. 28°32'00"S, Long. 115°31'00"E (B)

Simpson (1948) noted that heavily iron-stained barite with a radiated 'crustiform' texture has been observed in this district.

Carnarvon Basin

Regional geology

The Carnarvon Basin extends for a distance of about 1000 km from Geraldton to Karratha, along the western and northwestern coastline of Western Australia. The width of the basin onshore ranges from about 50 to 300 km. Sediments in the Carnarvon Basin range in age from Silurian to Holocene (Fig. 9). Of these, the more important rocks in terms of barite mineralization are sediments of Devonian to Permian age cropping out near the eastern margin of the basin.

The only significant barite mineralization in the Carnarvon Basin is in the Mount Sandiman area, within Devonian and Permian sediments, near the unconformity with the underlying Gascoyne Complex. Barite also occurs, associated with Cretaceous sediments, at Cardabia Creek (Fig. 9).
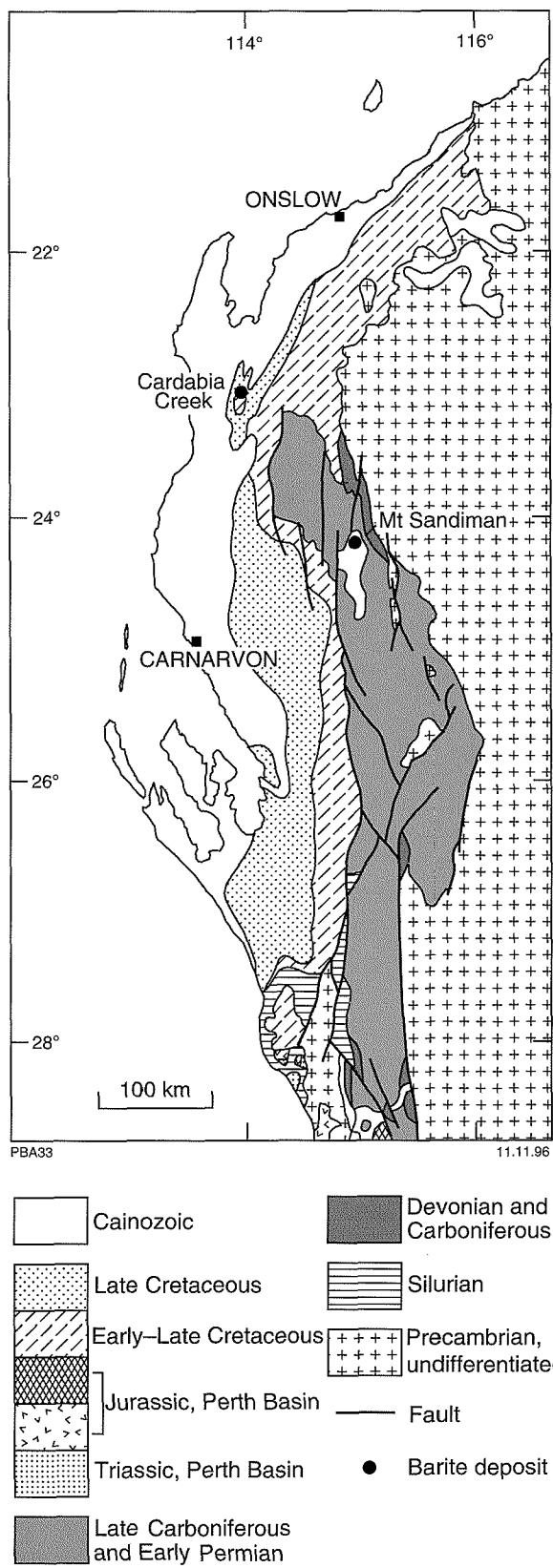
Figure 9. Solid geology of the Carnarvon Basin (*after* Hocking, 1990)

Mount Sandiman

Location: Lat. 24°28'40"S, Long. 115°23'10"E (A)

Mount Sandiman is situated approximately 180 km east-northeast of Carnarvon. The area surrounding Mount Sandiman was explored by Amoco Minerals during 1980 to 1982 (Temporary Reserve 7863H) for possible stratiform Cu, Pb, Zn, Ag and Ba mineralization (Otterman, 1981, 1982). During 1989 to 1990, Arimco carried out exploration work in the Ram Paddock area located 7 km south of Mount Sandiman Homestead (Arimco, 1990).

The earlier exploratory work by Amoco Minerals involved geological mapping, geophysical surveys and geochemical sampling, and work by Arimco involved five RC holes totalling 582 m in Permo-Carboniferous sediments near the contact of the Carnarvon Basin and Proterozoic Gascoyne Complex. The area drilled was in the Ram Paddock area (Fig. 10).

According to Hocking et al. (1985), barite has been mined in the past from a location east of Austin Well in the Mount Sandiman area. However there is no officially reported production from this deposit.

Geology

The rock types outcropping around Mount Sandiman are Devonian, Permo-Carboniferous and Permian sediments, and Proterozoic granitic rocks, gneiss, migmatite and quartzite (Fig. 10).

The Devonian sedimentary rocks consist of Nanyarra Sandstone and Gneudna Formation (Hocking et al., 1980).

Permo-Carboniferous sediments consist of Late Carboniferous Lyons Group and Permian sediments of the Callytharra Formation and Moogooloo Sandstone. The Lyons Group, which hosts significant barite mineralization, is a glacigene sequence consisting of poorly to moderately sorted feldspathic wacke, with minor quartz arenite and quartz wacke, siltstone, tillite and limestone grading into calcareous sandstone. The basal sandstone of the Lyons Group, the Harris Sandstone (formerly the Austin Member), is a discontinuous unit with highly variable thickness. This basal unit rests unconformably on Proterozoic rocks and occurs as intermittent linear outcrops extending southwards from the area around Mount Sandiman Homestead.

A system of faults striking northeast and southeast with southerly and easterly downward displacements has produced abutment contacts between the sediments and metamorphics at several localities (Otterman, 1981).

Mineralization

Barite occurs as vein fillings up to 1.5 m wide along faults at the contact between the Harris Sandstone and
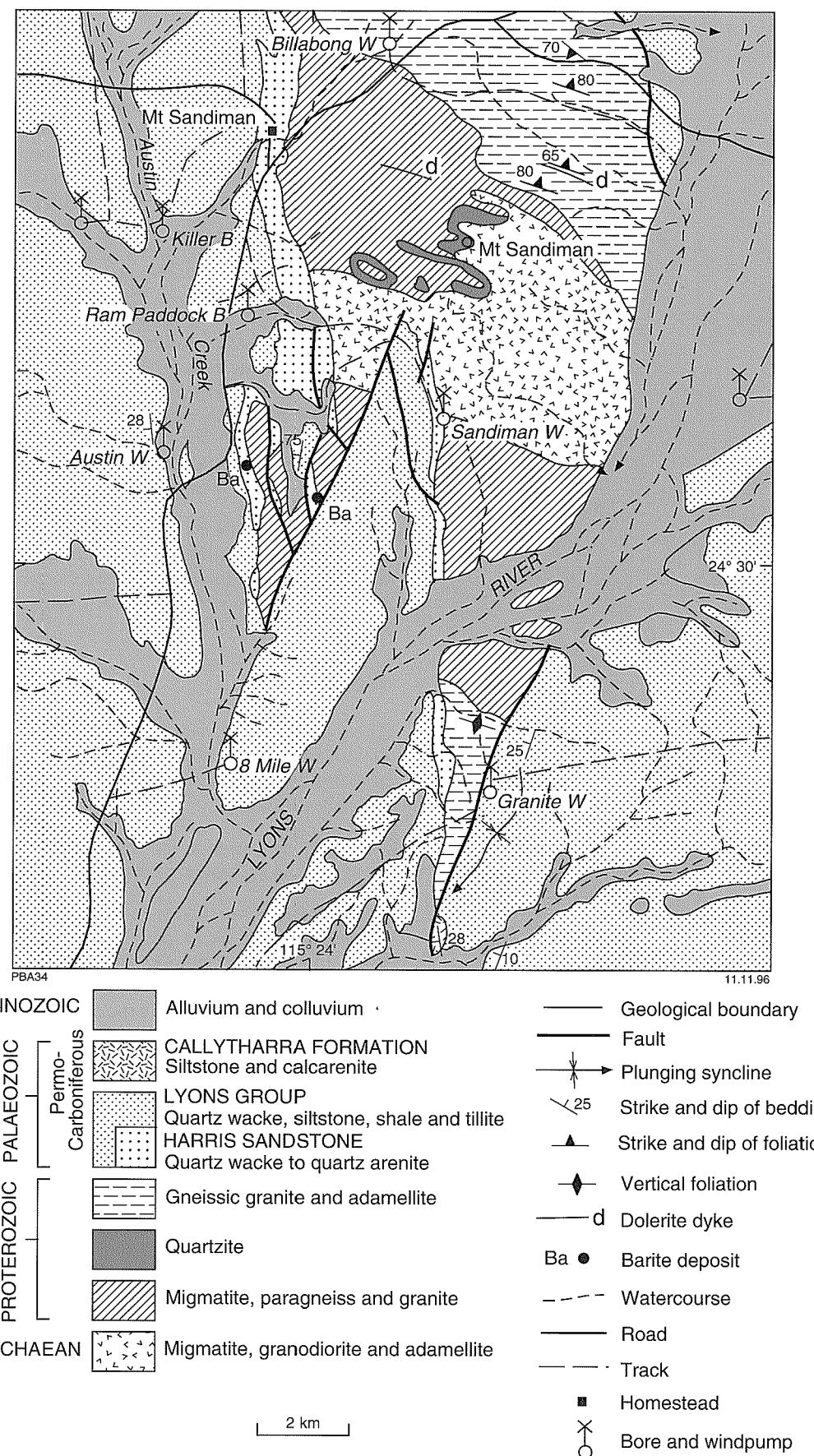
Figure 10. Geology of the area around Mount Sandiman (modified *from* Hocking et al., 1985)

Proterozoic granites and metamorphics (Hocking et al., 1985), and also occurs with minor amounts of galena and traces of sphalerite in and adjacent to a small Proterozoic inlier about 7 km south of Mount Sandiman Homestead. Mineralized veins are present in both Proterozoic gneiss and Harris Sandstone sediments and have lengths of more than 500 m (Otterman, 1981).

Barium values for 51 soil samples analysed by Amoco Minerals varied from 320 ppm to 9400 ppm (Otterman, 1981). Although Arimco recommended detailed examination of the barite resource (Arimco, 1990), the 13 analyses reported by Arimco, presumably of samples from drill chips, indicate that the highest Ba content was 1450 ppm. No analysis of vein barite has been reported.

Cardabia Creek

Location: Lat. 23°10'20"S, Long. 114°09'00"E (B)

Small barite crystals forming a bed about 30 cm thick occur in bentonitic siltstone and shale of the upper part of the Cretaceous Gearle Siltstone outcropping along Cardabia Creek approximately 5.6 km north-northeast of Cardabia Pool (Condon, 1968; Lipple, 1976).

Large spheroidal crystalline nodules of barite occur at a similar stratigraphic horizon east of Remarkable Hill. This appears to have formed by supergene processes from the barite bed. Prospecting of the area has indicated little potential.

Minor occurrences

Further occurrences of barite associated with sedimentary rocks in the Carnarvon Basin are briefly described in Table 13.

Gascoyne Complex

Regional geology

The Gascoyne Complex consists of Proterozoic high-grade metasedimentary rocks, orthogneiss and granitoid rocks which are unconformably overlain by the Bangemall Basin to the east (1.6–1.0 Ga). To the west it underlies or is in faulted contact with Phanerozoic rocks, and to the north, metasedimentary rocks decrease in metamorphic grade and merge with the Ashburton Formation of the Wyloo Group. The Gascoyne Complex is tectonically interleaved with the early Archaean Narryer Gneiss Complex to the south. The geology of the Gascoyne Complex has been described by Williams (1986) and Myers (1990b).

Gascoyne Complex rocks are divided into five major zones based on the distribution of rock types and structures (Fig. 11).

Zone A consists of gneiss (3.7–3.3 Ga) of the Narryer Complex and a minor component of granite intrusions (2.7 Ga), both of which have undergone repeated deformation and high-grade metamorphism prior to the development of the Capricorn Orogen.

Zone B rocks consist of reworked Archaean basement, gneissic granitoid rocks, metasedimentary rocks, and late- to post-tectonic granite plutons.

, Zone C consists of repeatedly deformed metasedimentary rocks of the Morrissey Metamorphic Suite, overlying gneissic granitoid rocks.

Zone D comprises the Minnie Creek Batholith emplaced into gneissic granitoid rocks and the Morrissey Metamorphic suite. The batholith has a Sm–Nd model age of 2060 Ma (Fletcher et al., 1983) and a whole-rock Rb–Sr isochron of about 1600 Ma (Libby et al., 1986).

Zone E consists of repeatedly deformed metasedimentary rocks of the Morrissey Metamorphic Suite intruded by a large number of granite plutons and batholiths of both S-type and I-type granitoid.

Barite occurrences in the Gascoyne Complex are typically vein type. Deposits located at Mangaroon and Mooloo Downs have not proved commercially viable. Minor occurrences are known at Reid Well, Cork Tree Bore and Mount James Station.

Mangaroon

Location: Lat. 23°55'00"S, Long. 115°34'35"E (A)

Table 13. Minor occurrences of barite of sedimentary associations in the Carnarvon Basin

| Locality	Lat. (S) Long. (E) (approximate)	Remarks	References
Manberry Station	24°01'40", 114°08'50" (B)	Low-concentration (2%) barite at a depth of 305 m (in an artesian bore) associated with a phosphatic limestone of Cretaceous age	Simpson (1948)
Thirindine Bluff (approx. 16 km northeast of the mouth of the Murchison River)	27°35'25", 114°15'55" (B)	Concretionary masses of oolitic barite associated with gypsum in Early Cretaceous shale underlying limestone in the Murchison River	Simpson (1948)
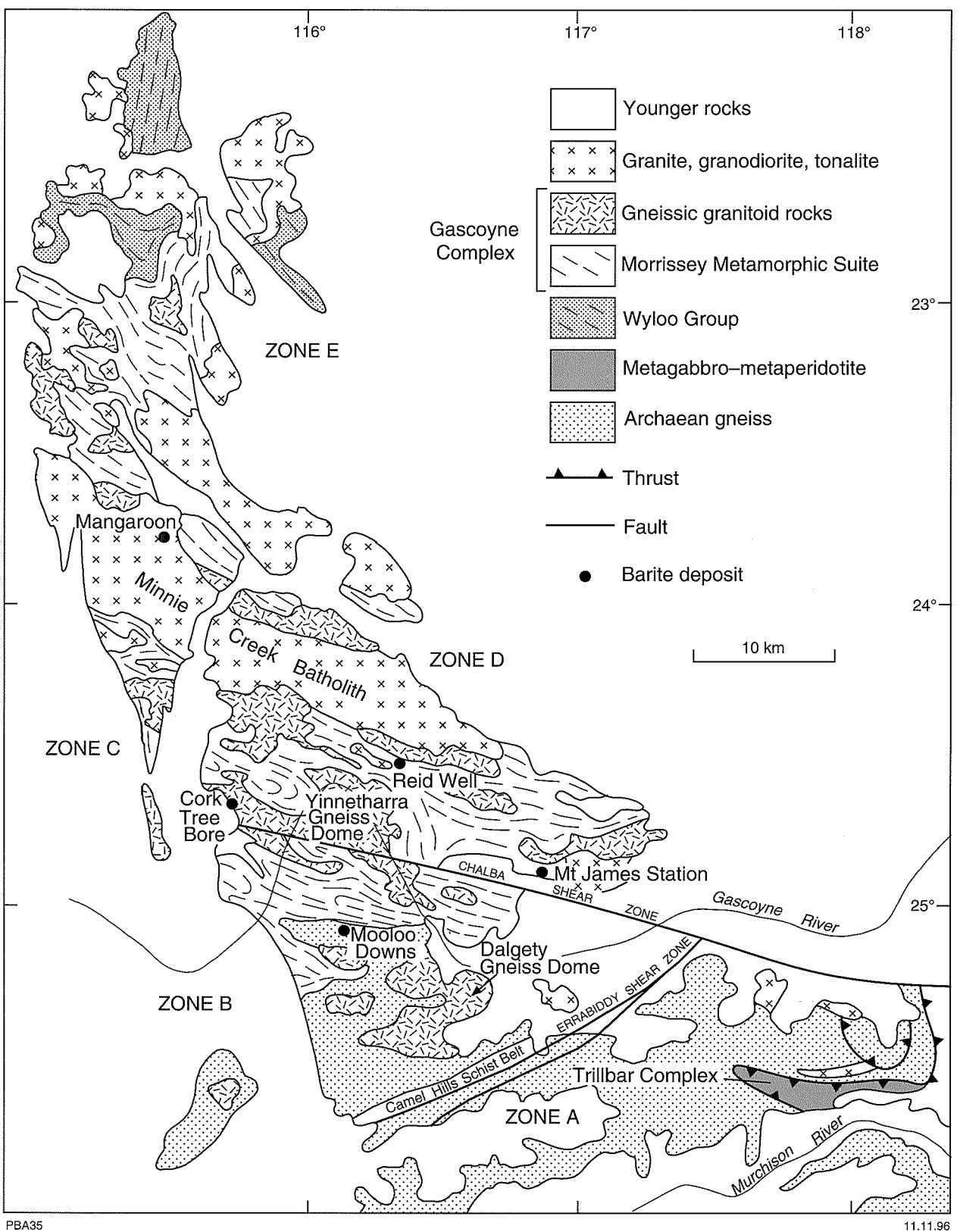
Figure 11. Simplified geological map of the Gascoyne Complex (*after* Myers, 1990b)

The Mangaroon barite prospect is located approximately 5 km west of Mangaroon Homestead. The prospect was held by Mallina Mining (90%) and Mrs R. McDonald (10%) in the early 1970s. Beesley (1971) observed that barite occurs as a lens within Proterozoic granite having a schistose texture in the vicinity of the barite body. Barite outcrop averaging 3.7 m to 4.6 m in width extends for a distance of 90 m striking 160° and dipping 70°–80° west. The barite is fine-grained, euhedral, and translucent white to very faint light brown in colour. Discrete unmineralized granite pods up to 0.9 m wide and 18 m long occur within barite outcrop. Seven percussion holes, totalling 395 m, confirmed the presence of unmineralized granitic pods at depth associated with barite.

Eight samples from drill chips yielded specific gravities ranging from 3.55 to 3.81. Four samples contained 65.0 to 79.8% $BaSO_4$ (average 73.8%). One sample of visually pure barite contained 79.8% $BaSO_4$ and 19.0% SiO_2 indicating quartz as an impurity.

Four other samples of barite from two separate outcrops had specific gravity for three samples ranging from 3.51 to 3.67, and the remaining sample at 4.16. The $BaSO_4$ content of the less dense samples varied from 61.0 to 69.8%, and the other 90.4%. These results also suggest the presence of quartz as an impurity. Thin section studies confirmed the presence of up to 20% interstitial quartz in all barite-rich rock chips.

Beesley (1971) concluded that the deposit was not economically viable mainly due to its remoteness and the quality of the barite. The quantity of barite available for mining may also be limited.

Mooloo Downs (Jones Bore)

Location: Lat. 25°04'55"S, Long. 116°03'55"E (A)

Barite veins in gneissic adamellite have been tested in a prospect known as Pentalls, located 1.5 km south of Jones Bore (Williams et al., 1983b). Traces of malachite and purple fluorite are also present. This is the area very likely explored by Universal Milling Company during 1966–1977. The company report (Universal Milling Pty Ltd, 1977) gives the location of the prospect as approximately 8 km east-southeast of Mooloo Downs Homestead, and approximately 396 km by road from Meekatharra.

Barite veins with lengths in the order of 30 m and varying widths (0.6 m to 1.2 m) are common in gneiss at this locality. A number of costeans in the prospect reveal better quality and wider barite veins developed at the surface, which tend to weather at a depth of about 0.7 m where marked narrowing of veins was observed. Barite mineralization appears to be more intense at vein intersections where horizontal dimensions of barite masses are up to 7.6 × 5.5 m. The barite is commonly off-white to pale pink and coarsely crystalline. One composite vein about 100 m long and averaging 1 m in

width is inferred to contain 3600 t on the assumption that it extends to a depth of 12 m.

Although available information suggests that the prospect does not have great potential, insufficient exploration has been done in the area to draw any positive conclusions.

Minor occurrences

Reid Well

Location: Lat. 24°31'50"S, Long. 116°19'25"E (A)

Discontinuous lenses of low-grade barite containing copper and lead mineralization have been prospected at a location 3 km southeast of Reid Well. The barite occurs in quartz–biotite–muscovite–feldspar–garnet schist of the Morrissey Metamorphic Suite. Chalcopyrite, galena, pyrite, malachite, covellite and chalcocite are visibly associated with the barite (Williams et al., 1978, 1983a).

Cork Tree Bore

Location: Lat. 24° 39' 45', Long. 115° 42' 45" (A)

Barite also occurs with fluorite at a location 1.5 km south-southeast of Cork Tree Bore. The occurrence is in a quartz-filled shear trending north-northeast in augen gneiss.

Mount James Station

Location: Lat. 24°51'00"S, Long. 116°54'00"E (B)

A sample of coarsely crystalline white but partly iron-stained barite has been collected from the above location (Simpson, 1948). The sample is of poor quality for making pigments.

Kimberley Basin

Regional geology

The regional geology of the Kimberley Basin is discussed in Chapter 7. All occurrences of barite in the Kimberley Basin are vein-type and associated mostly with fluorite. Occurrences described below have not been adequately assessed for economic potential.

Speewah

Location: Lat. 16°26'00"S, Long. 127°58'00"E (B)

Background

A number of exploration tenements in the Speewah area, located 110 km south of Wyndham in the Kimberley Mineral Field, have been explored for fluorite and barite by a number of companies. Fluorite is the more commercially viable mineral at this locality, and therefore to avoid repetition, description of the history of exploration and geology at Speewah is given in Chapter 7. The area is currently held by Elmina NL under a number of exploration and mining licences mainly for its fluorite potential.

Geology

Blockley (1972) stated that fluorite and barite mineralization occurs along northerly striking faults within the core of the large Speewah dome. A dolerite sill (Hart Dolerite) 32 km long, 13 km wide and trending 010° occupies the core of the dome. The dolerite is overlain by feldspathic arenite, chloritic lutite and minor acid volcanics. Erosion of the dolerite has led to the formation of the Speewah Valley.

The main area of barite mineralization is located approximately 10 km north-northeast of the Main Zone of fluorite mineralization, described in Chapter 7. In this area, the Landsowne Arkose is considered to be a potential host for barite mineralization. A discontinuous barite vein, varying in thickness from 1 to 10 m, outcrops over 470 m in a northerly trending shear zone, which is a splay from a major northeast trending shear related to the major Greenvale Fault.

The barite is medium to coarse grained and cream coloured. Assay values up to 97% BaSO$_4$ are reported. Another smaller barite unit, parallel to the above vein and 50 m to the east, outcrops discontinuously over 300 m. This unit contains small veins of barite, breccia and barite-cemented, fractured sandstone, and appears to separate sandstone on the west from siltstone on the east.

Barite is also associated with fluorite veins in the Northwest and West Zones, and to a lesser extent in the Main Zone. In the Northwest Zone, three parallel veins outcrop intermittently over 500 m and are reported to contain approximately equal proportions of barite and fluorite. A sample from one vein in the West Zone assayed 63% BaSO$_4$ and 14% Ca F$_2$.

The zones of barite mineralization are shown on Figure 25.

Resources

The potential of barite in the Speewah deposit is unknown although a resource of at least 40 000 t to a depth of 20 m is estimated (Hickman, 1976a).

Minor occurrence

Shangrilla

Location: Lat. 15°49'30"S, Long. 128°29'30"E (A)

Massive barite with some copper mineralization occurs 9.6 km west of the Shangrilla Mineral Claim (approximately 21 km west of Kununurra). The occurrence is located in a quartz–breccia fault zone in Antrim Plateau Volcanics about 300 m east of the Wyndham–Kununurra Road (Sofoulis, 1968).

Bangemall Basin

Regional geology

The Bangemall Group in the Bangemall Basin has been subdivided into six subgroups (Muhling and Brakel, 1985b; Williams, 1990) as shown in Figure 12.

The western part of the basin is dominated by the older (1.6–1.2 Ga) Edmund Subgroup, and consists mainly of shale, mudstone, siltstone, dolomite, limestone, conglomerate and chert.

In the east, older basin rocks are represented by the Scorpion Subgroup that consists of dolomite, siltstone, shale and sandstone.

The Mucalana Subgroup (1.2–1.0 Ga), occupies the core of the regional syncline which lies along the main axis of the Bangemall Basin, and consists of a sequence of shale, mudstone, sandstone and chert.

The younger rocks in the east (1.2–1.0 Ga), comprise the Collier, Manganese, and Kahrban Subgroups that are dominated by siltstone, shale, sandstone, conglomerate, dolomite, and chert (Williams, 1990). The Cornelia Sandstone is an inlier of Bangemall Group rocks surrounded by sediments of the Neoproterozoic Savory Basin.

Exploration for base metals in the Bangemall Basin has resulted in discoveries of significant barite mineralization in localities around the Abra deposit. However, since the main emphasis there is on base-metal mineralization, the commercial viability of barite has not been investigated adequately. Other occurrences are known at Billinnooka, Prairie Downs and Wootha Wootha Creek. A minor occurrence is located on Woodlands Station.

Abra

Location: Lat. 240°37'00"S, Long. 118°36'00"E (B)

Abra is situated approximately 25 km north-northeast of Mulgul Station in the Peak Hill Mineral Field. Initial exploration activity in the area was aimed at investigating
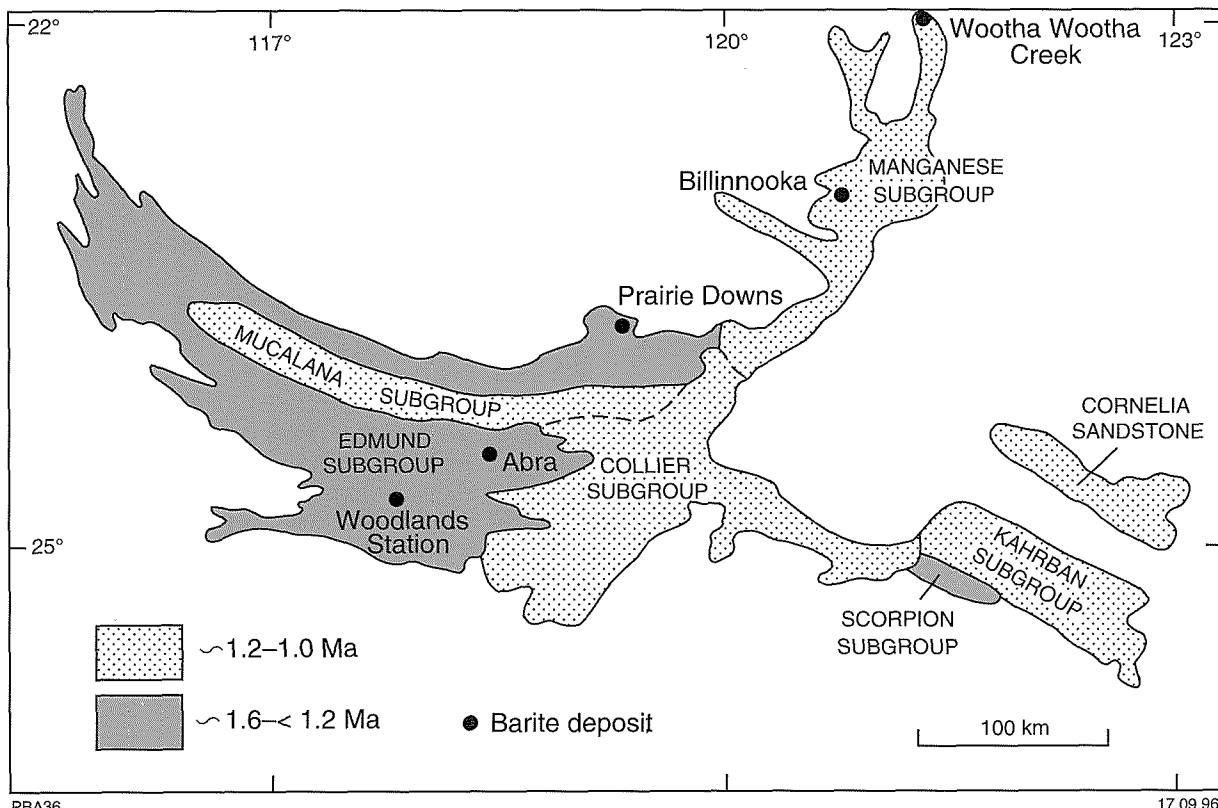
Figure 12. Distribution of subgroups in the Bangemall Basin (modified *after* Williams, 1990)

a circular airborne magnetic anomaly. The area has been explored for base metals, silver, gold, and associated barite mineralization.

Geology and mineralization

The area is covered by Edmund Subgroup rocks consisting of Kiangi Creek Formation overlain by Jillawarra Formation sediments located along the axis of a regional anticlinorium. The Abra anomaly is located to the south of this structure in an area of outcropping sandstones and siltstones of the Kiangi Creek Formation dipping to the south at 30°. The Kiangi Creek Formation is underlain by the Abra Beds which in turn overlie the Irregully Formation.

A few holes drilled to a depth of around 700 m in the area indicate that barite mineralization is associated with the Abra Beds (Murphy, 1989). The Abra Beds consist of an upper layer of pebble conglomerate of quartz and jaspilite in a siliceous and dolomitic matrix followed by a middle layer of 'red beds' consisting of jaspilite-enriched quartz–barite–dolomite vein systems and breccia (Vogt, 1995). A layer of 'black beds' underlie the 'red beds' and consist primarily of veins of magnetite–hematite, and galena–barite–dolomite with abundant chloritic siltstone at the base. A stringer zone at lower levels contains chloritic siltstone with thin quartz–

chalcopyrite veins and thicker galena–barite veins, with a decrease in intensity of veining towards the base.

'Red' and 'black beds' contain more than 30% Ba. The other anomalous metals present are Au, Ag, Cu, Zn, Pb, Mn and W. Further drilling in the area has revealed barite veins containing quartz, carbonate, galena, pyrite, hematite, magnetite and chalcopyrite, within 'black beds' and stringer zones at a depth of 370 m to 806 m. Drilling also indicated that Pb, Zn and Ba concentrations are elevated at a depth of around 256 m with Ba continuing to the end of hole.

Billinnooka

Location: Lat. 23°00'00"S, Long. 120°51'25"E (A)

Several barite veins occur on the Billinnooka–Balfour Downs track 7 km north-northwest of the Billinooka Homestead. The veins strike at 050° and are roughly parallel to regional faulting of the area. Host rocks are dolomite and interbedded shale of the Enacheddong Dolomite (Williams and Tyler, 1991).

The veins are spread over a distance of 500 m and individual veins are up to 5 m wide and 100 m long. The barite is crystalline, white, grey, and pink in colour, and contains traces of copper mineralization.

Prairie Downs

Location: Lat. 23°42'35"S, Long. 119°16'30"E (B)

Blockley (1971) noted that lead and copper minerals in a gangue of ferruginous quartz and barite occur 22.5 km southeast of Prairie Downs Homestead. Mineralization is found intermittently over a distance of 2.4 km along the Prairie Downs Fault, between Archaean basalts on the north side, and Middle Proterozoic sediments of the Bangemall Group to the south. Throw on the fault is estimated to be at least 9100 m.

Two of the three main deposits at this locality are 150 m apart and contain barite veining. One of these, located about 1.6 km west of the third deposit, has a 60 cm-wide barite vein and a 1.8 m-wide zone of gossanous quartz with barite, copper stains and cerussite. The other deposit is characterized by a 3.0 to 3.6 m-wide and 15 m-long lens of barite containing about 75% barite.

Wootha Wootha Creek

Location: Lat. 21°59'34"S, Long. 121°18'52"E (A)

Sediment-hosted stratiform barite was recently discovered in the headwaters of Wootha Wootha Creek, 7.5 km east of Brownrigg Hill (Williams and Trendall, in prep.). Bedded barite occurs in the gently folded Woblegun Formation of the Manganese Subgroup in the northeast part of the Bangemall Basin.

Barite occupies a single bed, 3–9 cm thick, consisting of well-crystallized tabular or prismatic barite roughly disposed at right angles to bedding, which can be traced intermittently over a distance of 350 m (Fig. 15). Crystalline barite is mixed with interlocking half-rosettes of barite growing upwards from the base of the bed. It is grey to bluish grey when freshly broken and has a pearly, pale reddish brown weathered surface. Faint colour bands, parallel to the bedding surface, can be traced across the tabular crystals. Barite is interbedded with silicified dolomite (now largely chert breccia), brown to purple, fine-grained dolomite, silicified shale and mudstone. The barite crystals are capped by a thin (1–2 cm) limonite–goethite ironstone.

The clastic–carbonate, marine-shelf succession which contains the bedded barite also carries minor evaporite minerals such as gypsum.

Preliminary analyses of the barite indicates low base-metal (Pb, Zn, Cu) content and that silica sand (quartz) is the only notable impurity.

Minor occurrence

Woodlands Station

Location: Lat. 24°49'00"S, Long. 118°06'00"E (B)

Finely granular, colourless to milk-white, high-quality barite, suitable for commercial applications, has been found near the upper Lyons River on this Station. However, no information is available on the quantity (Simpson, 1948).

Ashburton Basin

Regional geology

The Ashburton Basin consists of an arcuate belt of Proterozoic sedimentary and volcanic rocks forming the northern margin of the Capricorn Orogen. The latter is a major orogenic zone between the Pilbara and Yilgarn Cratons (Fig. 13). The rocks in the Ashburton Basin belong to the 2000 Ma Wyloo Group which is subdivided into the following formations:

> Ashburton Formation (uppermost formation)
> June Hill Volcanics
> Duck Creek Dolomite
> Mount McGrath Formation
> Wooly Dolomite
> Cheela Springs Basalt
> Beasley River Quartzite (lowermost formation)

The lithology, stratigraphy and structural aspects of the above formations are discussed in detail by Thorne and Seymour (1991).

At Kooline and the Silent Sisters mine in the Ashburton Basin, barite occurs in the Ashburton Formation associated with lead, silver and copper mineralization.

Other barite deposits are not related to deposits of base metals. The Paraburdoo deposit barite is associated with the Mount McGrath Formation, and a minor occurrence has been recorded at Ashburton Downs Station.

Kooline

Location: Lat. 23°06'40"S, Long. 116°27'05"E (A)

Barite is a common mineral associated with lead and silver mineralization in the Kooline lead workings.

Most lead deposits at Kooline are situated in an area of 7.2 km × 2.4 km, centred 25.7 km southeast of Kooline Station Homestead. Miners have worked galena-bearing quartz veins within interbedded shale and greywacke of the Ashburton Formation. The galena-bearing veins have a thickness varying from a few centimetres to 1.2 m and a length up to 60 m, and contain quartz, cerussite, malachite, calcite and barite in addition to galena. Lead is thought to be derived from quartz veins and shears in the Ashburton Formation and to a much lesser extent from the unconformably overlying Capricorn Formation (Thorne and Seymour, 1991).

Following are brief summaries of several individual workings constituting the Kooline lead and silver mines.
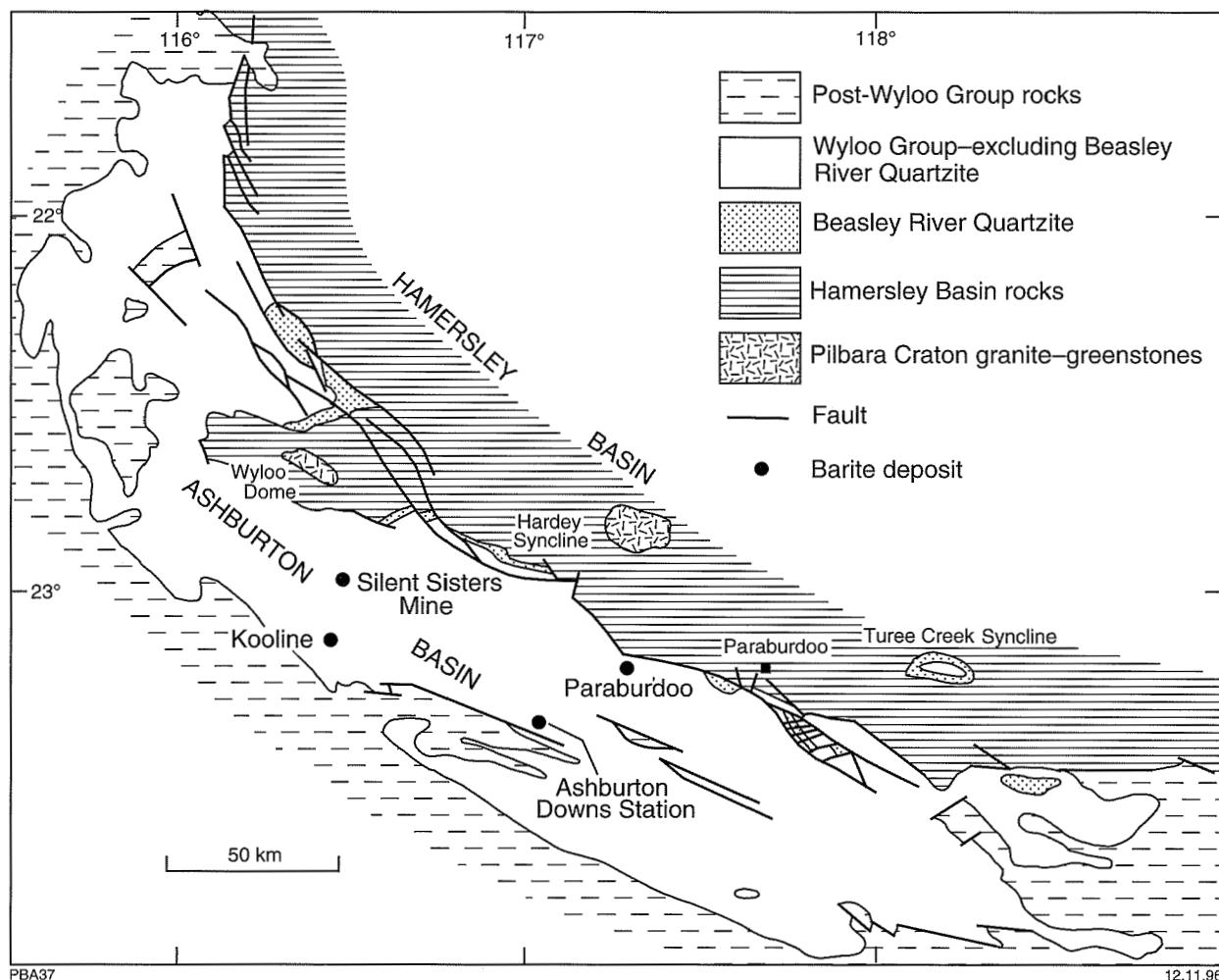
Figure 13. Geological setting of the Ashburton Basin (*after* Thorne and Seymour, 1991)

June Audrey mine (also called Redcraze)

This mine is located approximately 1.6 km west of the Gift mine, which is centrally situated in the main group of workings at Kooline. The two main ore shoots, western and eastern, contain galena, cerussite, barite and traces of copper. Bedding of the host greywacke dips at 15° south. Workings extend for 140 m in the western shoot, which strikes 280° and dips steeply south. The main shaft at the eastern end of the vein is 40 m deep and stopes were cut for about 37 m east and 30 m west of the shaft to a depth of at least 15 m. In stopes, the reef ranged from 45 cm to 1.2 m in width. The eastern shoot has a strike of 105° and dips steeply north (Blockley, 1971).

The mine has produced 512 t of lead and 166 587 g of silver.

Ridge mine

This mine is at the western end of the main group of mines and 4.5 km northwest of the Gift mine. The dumps

of this mine contain galena, cerussite, barite and a little cuprite. The lead and silver produced from the mine was from an ore shoot at the intersection of two quartz veins. The vein exploited by the main shaft (40 m deep) is 75 cm to 90 cm wide and has a strike of 145° with 80° northerly dips. The second vein, with a strike of 190° and steep easterly dips, is accessed by a shaft about 38 m deep (Blockley, 1971). The mine has a recorded production of 208 t of lead and 60 153 g of silver.

Beadon mine

This mine, on the crest of an easterly trending ridge halfway between the Gift and Ridge mines, was the first lead vein pegged in the Kooline field and has produced 90 t of lead and 24 260 g of silver. The vein contains a considerable amount of barite along with quartz, galena and cerussite. It has a strike of 105°, a 75° southerly dip and a width varying from 25 cm to 75 cm.

South Kooline mine

This mine, located 0.6 km north of the Gift mine, is developed on a reef striking at 315° and dipping steeply south. Ore containing galena in a gangue of quartz and barite (Blockley, 1971) occurs in a quartz vein 60 m long. Total production has been 61 t of lead and 18 537 g of silver.

Roebuck mine

This mine is 610 m north of the Gift mine and 210 m north-northeast of the South Kooline mine. The steeply dipping, 100° striking, mineralized shoot, which consists of schistose sediments and narrow quartz veins carrying galena, cerussite, barite and calcite, has been mined to a depth of about 15 m over a distance of 45 m. Total production has been 56 t of lead and 17 355 g of silver.

Silent Sisters mine

Location: Lat. 22° 52' 40" S, Long. 116° 27' 35" E (A)

The Silent Sisters mine is located 24.1 km southeast of Wyloo Homestead. Five lead-bearing quartz veins, striking between northwest and northeast, have been worked at this mine. The steeply dipping veins fill tension gashes that cut a dolomite ridge 37 m high, and terminate in irregular stringers of quartz (Blockley, 1971). The ore contains galena and sphalerite in a gangue of quartz, silicified dolomite, barite, and calcite. Production totals 116 t of lead and 13 779 g of silver.

Paraburdoo

Location: Lat. 23°12'11"S, Long. 117°17'27"E (A)

Universal Milling Pty Ltd (1972) investigated a barite prospect located approximately 39 km west of Paraburdoo in which barite occurs in shale of the Mount McGrath Formation close to, or at the contact with, the conformably overlying Duck Creek Dolomite. Lipple (1976) also observed veins and secondary infillings of barite in the lower part of the Duck Creek Dolomite.

Three barite occurrences are adjacent to, and north of, a prominent breccia composed of limestone (dominant), shale, jaspilite, quartz and chert in a matrix of calcite or dolomite or occasionally barite. Although outcrops are scarce, there are elongated zones of barite rubble, at times mixed with limestone, chert and shale. Barite appears to be in a fault zone between shale to the north and dolomite to the south and seems to be always associated with the brecciated, and not the bedded limestone. The largest of the three occurrences, with a strike length of 300 m and a width of 7.5 to 30 m, has scattered rubble along its length. The second largest occurrence is about 210 m long and the other is smaller. All three occurrences are associated with dolomite breccia and thus appear to be geologically similar.

Percussion drilling totalling 251 m indicated that the two smaller occurrences had little significant economic potential, but that the largest occurrence contained an indicated resource of 1500 t with an average grade of 96.8% $BaSO_4$. Two samples assayed 95 and 99% $BaSO_4$ (Lipple, 1976).

Barite production of 475 t valued at $ 9018 was won from this location in 1975 (Tables 6 and 7).

Minor occurrence

Ashburton Downs Station

Location: Lat. 23°23'20"S, Long. 117°02'00"E (B)

Simpson (1948) noted that colourless or slightly milky, coarsely crystalline barite occurs in the Ashburton Valley on Ashburton Downs Station. Loose pebbles of barite on the outcrop weigh up to 500 g.

Northampton Complex

Barite is a common mineral associated with widespread lead mineralization in the Northampton–Ajana area (Simpson, 1948; Blockley, 1971; Lipple, 1976). However, since the emphasis was on lead mining, very little is known about the economic viability of the barite mineralization.

Northampton–Ajana area

Following are brief descriptions of some Northampton Complex lead mines, which contain barite as an associated mineral.

Surprise mine

Location: Lat. 27°50'00"S, Long. 114°41'00"E (B)

The Surprise mine, located at Galena, 19 km north-northeast of Ajana, is situated on a 70° west-dipping, 340° trending, left-lateral tear fault with a horizontal movement of about 900 m. The orebody occupies an intensely crushed and fractured zone at an en echelon offset of the fault (Blockley, 1971). The ore shoot consists of a massive body of brecciated granulite traversed by branching and looping shears and tension gashes. Mineralization in the mine follows a shear in granulite and dolerite. Various authors (Blockley, 1971; Lipple, 1976) have noted that the mineralization post-dates the metamorphic rocks and a suite of Upper Proterozoic dolerite dykes.

Primary minerals present in the lodes include galena, sphalerite, marcasite, chalcopyrite, barite and quartz. Veins of milk-white barite associated with lead mineralization are conspicuous in the ore shoot (Simpson, 1948). Some crystals of barite found in a vug in this mine were about 1 cm in length and varied in colour from almost white to pale honey yellow. The second grade concentrates produced at the mine during 1923 to 1926 consisted almost wholly of galena and barite, with a barite content of about 70%.

Gurkha mine

Location: 9.6 km north of Northampton.

Barite associated with quartz occurs along the footwall of a mineralized shear containing galena (Blockley, 1971).

Iga mine

Location: 5.6 km north of Northampton and approximately 180 m east of the highway.

An ore shoot 210 m in length and trending 045° contains galena and abundant barite. Barite, galena and siliceous breccia are also found in the dumps of workings on an ore shoot trending 025° (Blockley, 1971).

Rhyhope mine

Location: 3 km west of Northampton and south of the Northampton–Port Gregory Road.

A mineralized shear in gneiss trending 025° with easterly dips contains barite along with quartz, pyrite, galena and sphalerite (Blockley, 1971).

Dingo mine

Location: 2.4 km northwest of Galena.

The mine exploits a lead-mineralized lode striking 050° and dipping 80° westerly located on a slight curve on the eastern edge of a dolerite dyke. Mine dumps contain brecciated dolerite with galena, cerussite, and barite (Blockley, 1971).

Ethel Maud mine

Location: 2.4 km west-southwest of Galena.

The ore body at the mine strikes 060° and dips northwesterly within slightly altered garnet granulite. The ore appears to occur as veins of sulfide minerals in fractured and jointed granulite. Samples of galena and sphalerite with barite gangue are present on mine dumps.

Canning Basin – Lennard Shelf

Regional geology

The Lennard Shelf is notable for extensive Middle to Late Devonian reef complexes exhibiting basin, marginal-slope and platform facies. The principal stratigraphic units are the Windjana, Nullara, Bugle Gap, Pillara and Sadler limestones and the Gogo, Virgin Hills, Napier and Piker Hills formations. These units collectively vary from shale and mudstone, through arenite, to rudite and megabreccia, commonly with a substantial calcareous component. A number of conglomerate units are also present. Relationships of the Lennard Shelf sedimentary sequence are shown in Figure 14.

Minnie Pool

Location: Lat. 18°22'22"S, Long. 126°01'59" (A)

Minnie Pool is located 40 km north-northeast of the Cadjebut–Kapok mining area. In this and other deposits in the region, barite mineralization occurs at or near the contact between the Sadler Limestone and the overlying Virgin Hills Formation. At this stratigraphic level, barite occurs as stratabound, epigenetic, carbonate-hosted cavity fillings (Fig. 16). Barite and calcite appear to have been chemically precipitated in cavities by the action of stromatolite cyanobacteria, probably during the Late Devonian or Early Carboniferous (the age of mineralization at Cadjebut and other Mississippi Valley-type (MVT) deposits in the Lennard Shelf).

The structure of deposits appears to reflect MVT mineralization and as such may have important ramifications for the genesis of MVT base-metal deposits, although no lead–zinc mineralization has yet been found in association with the barite (P. E. Playford, pers. comm.).

Other occurrences

Barite mineralization similar to the style described at Minnie Pool has also been recorded from a number of other localities in the region:

- Sadler Ridge, Emanuel Range — 12 km north northeast of Cadjebut–Kapok mining area
- Southeastern end of Pillara Range — 28 km north of Cadjebut–Kapok mining area
- Pillara Spring, northwest Pillara Range — 45 km north-northwest of Cadjebut–Kapok mining area

Minor occurrences in other tectonic units

A number of small barite occurrences are known in the following tectonic units:

West Yilgarn (southwestern area) – Yilgarn Craton
Eastern Goldfields Province – Yilgarn Craton
Southern Cross Province – Yilgarn Craton
Narryer Complex
Badgeradda Group
Savory Basin
Paterson Orogen
North Perth Basin
Halls Creek Orogen

Available information on these occurrences is summarized in Table 14.
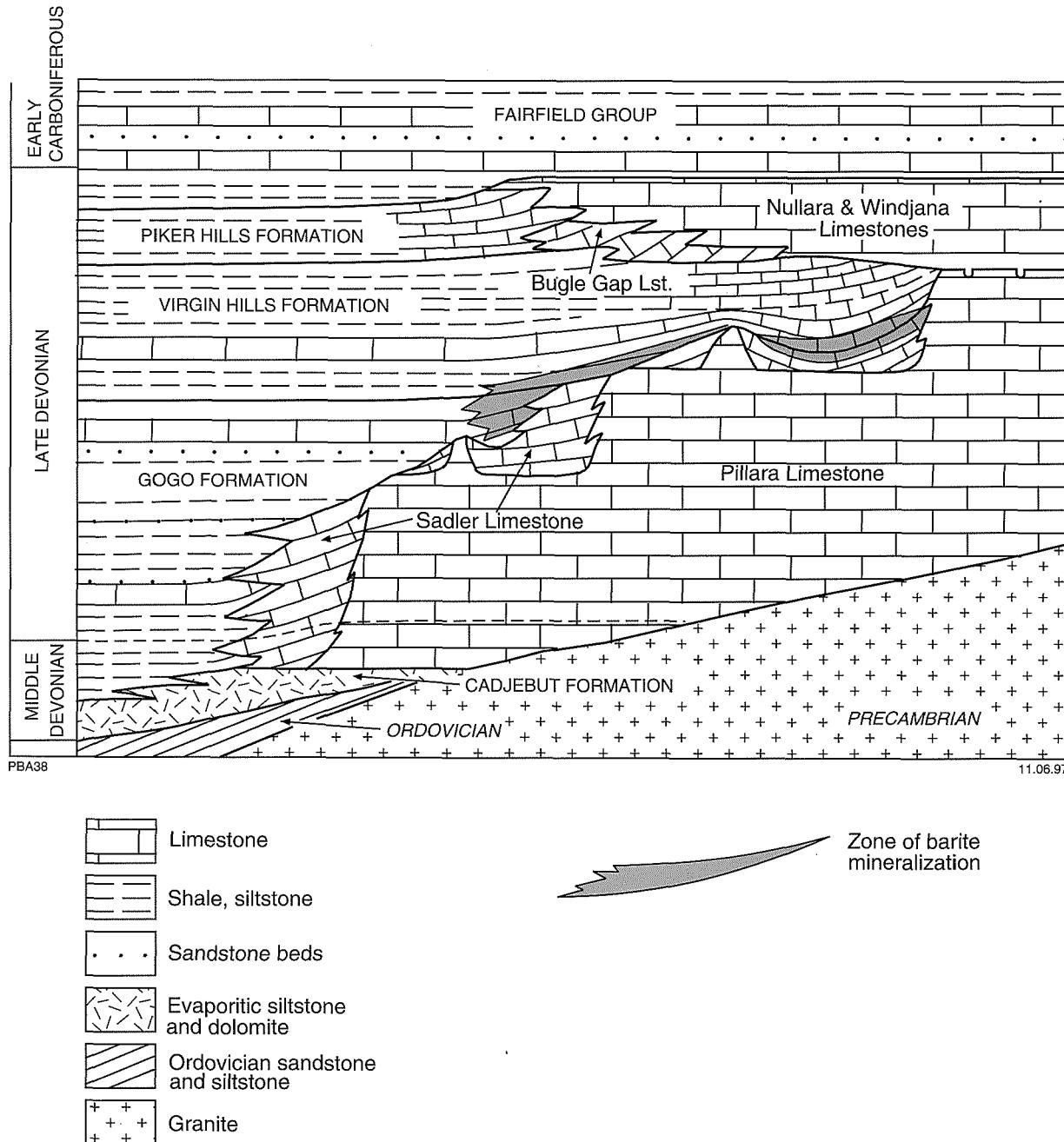
Figure 14. Relationship of units on the Lennard Shelf (*after* Hocking et al., 1996)

Summary

Barite is an insoluble mineral ideally containing 58.8% Ba and 41.2% SO_4. It has a hardness of 2.5–3.5 and a specific gravity of 4.5, but generally contains impurities that can sharply lower this value. Depending on the nature of impurities, its colour varies from white to grey.

Approximately 90% of barite produced in the world is used as a weighting agent in oil and gas well-drilling mud. Other uses include filler and extender applications, chemicals manufacture, radiation shielding, the glass industry and pharmaceutical formulations. Demand for barite in oil well drilling is likely to remain around 4 Mt per year in the foreseeable future, which is more than 33% less than its 1980 level. The filler market, after

Figure 15. Crystals of prismatic barite from the sediment-hosted, stratiform Wootha Wootha Creek deposit (prisms up to 4 cm in length)
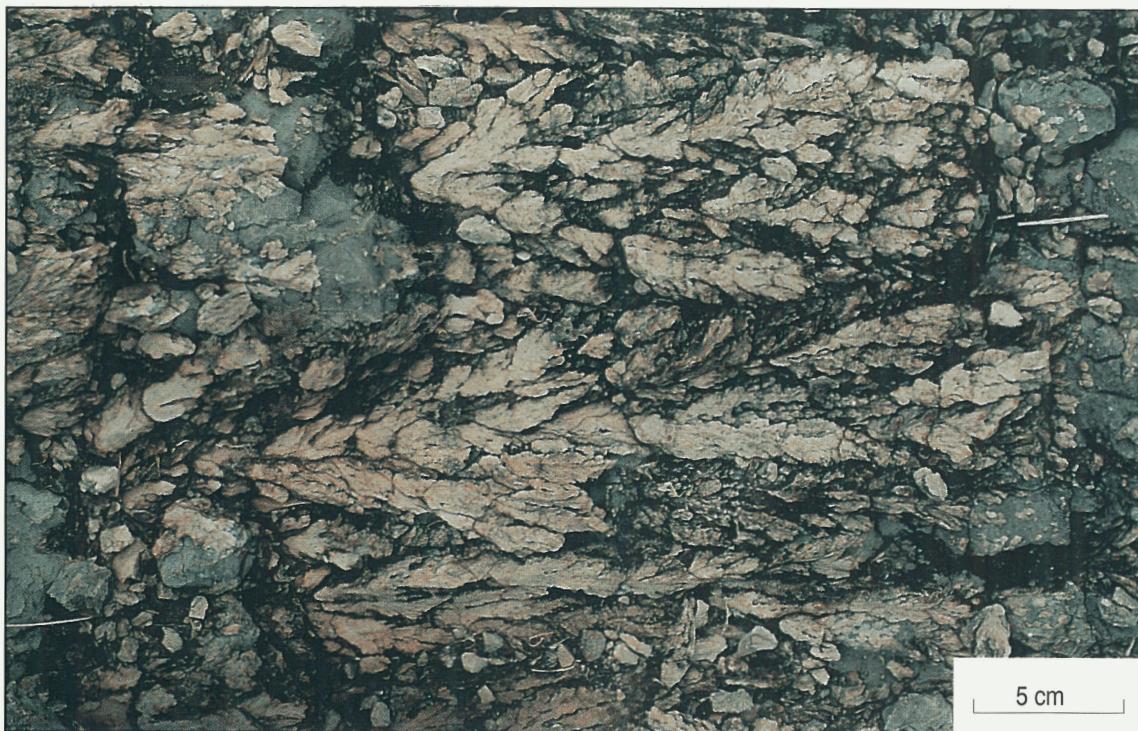
PBA 141   04.06.97

Figure 16.   Radiating barite crystals from the stratabound, carbonate-hosted deposit at Minnie Pool

Table 14. Minor occurrences of barite in other tectonic units

Locality	Lat. (S); Long. (E)	Remarks	References
West Yilgarn (southwestern area) – Yilgarn Craton			
Armadale	32°10'00"; 116°01'00" (B)	Crystalline barite 8 cm to 25 cm long and almost colourless has been found in a slate quarry at Armadale. It occurs in veins and along joint surfaces in Cardup Group rocks. Although some pits were opened up, there has been no recorded production	Simpson (1948) Wilde and Low (1980)
Cardup	32°15'00"; 116°00'00" (B)	Barite veins varying in width from 30 cm to 120 cm, striking due north with 50° to 60° westerly dips occur at Cardup in Precambrian slate, approximately 15 m west of a granite contact. The veins carry mainly barite and quartz in varying proportions with minor limonite, kaolin and fluorite. Pure barite is often coarsely lamellar and highly translucent with a distinct bluish tinge. An analysis of this purer variety assays 99.19% $BaSO_4$, and a typical sample containing barite and quartz had 56% $BaSO_4$ and 37% SiO_2	Lipple (1976) Simpson (1948)
Collie	33°22'00"; 116°09'00" (B)	Small crystals of barite (0.5 to 1 cm) have been found in a Permian coal seam at Collie. Most of these crystals were colourless and transparent	Simpson (1948)
Gosnells	32°03'24"; 116°01'20" (A)	Granular detrital barite, intergrown with quartz, and with tabular crystals projecting into cavities occurs in the foothills northeast of Gosnells Railway Station. The source of this barite is traced to small quartz veins in banded slate and sandstone	Simpson (1948)
Katanning	33°41'20"; 117°30'00" (B)	Coarsely tabular, heavily iron-stained barite has been found in surface boulders approximately 5 km west of the town -	Simpson (1948) Chin and Brakel (1986)
Mundijong	32°18'40"; 116°00'30" (A)	Barite occurs in veins and along joint surfaces in the Cardup Group at Mundijong	Wilde and Low (1980)
Currans Well	25°42'10"; 117°31'12" (A)	Barite occurs at 2 km south-southeast of Currans Well. Barite occurs as a vein in coarse-grained, foliated biotite granite, and the crystals are lamellar, plate-like and often curved	Elias and Williams (1980)
Holdens Find	25°56'00"; 118°33'25" (B)	A vein of barite 45 m long and about 1.3 m wide occurs at Holdens Find, 1.2 km north of old Jillawarra gold mine, and 75 km north of Meekatharra. A specimen consisting of an intimate mixture of barite and quartz has also been collected 2.4 km northeast of the Jillawarra gold mine. This specimen had a specific gravity of 3.8 and contained 62% barite and 38% quartz	Simpson (1948) Lipple (1976)
Mount Gould	25°40'50"; 117°25'00" (A)	Universal Milling Co Pty Ltd produced 281 t of barite in 1975 valued at $5255 (Tables 6 and 7) from mineral claim 52/937, located approximately 15 km north-northeast of Mount Gould and approximately a kilometre north-northwest of Sandy Creek Well	Department of Minerals and Energy, Western Australia, production statistics
Eastern Goldfields Province – Yilgarn Craton			
Coonana	31°03'25"; 123°05'20" (A)	A barite vein containing quartz and accessory galena, chalcopyrite and covellite occurs at a location 8 km southwest of Coonana Siding. From this vein there has been production of 10 t in 1946 and another 43 t in 1953, valued at $860 (Tables 6 and 7)	Simpson (1948) Doepel and Lowry (1970)
Buningonia Rock	(see remarks)	Barite also occurs at a location 16 km east of Buningonia Rock. The locality of Buningonia Rock is uncertain but is probably in the area of Buningonia Spring (31°25'39"S; 123°33'20"E)	Simpson (1948)

Table 14. (continued)

Locality	Lat. (S); Long. (E)	Remarks	References
Southern Cross Province – Yilgarn Craton			
Yellowdine	31°18'00"; 119°39'00" (B)	Barite occurs as vein-filling material near Yellowdine. It is medium-grained, iron stained and occurs with quartz. An analysis of a sample gave 52.3% $BaSO_4$	Simpson (1948)
Richardson	26°35'00"; 119°07'00" (B)	White crystalline barite was collected at a location approximately 18 km east of Richardson near the 373 mile post (600 km) on the old Wiluna railway line. Barite appeared to be free of impurities and could be crushed to a good white powder	Simpson (1948)
Badgeradda Group			
Badgeradda Claypan	26°51'24"; 115°32'18" (A)	A number of thin barite veins occur at a location 2.5 km north-northwest of Badgeradda Claypan. The veins have been prospected over a length of 300 m occur in a fracture cleavage, dipping vertically to 80° west and striking 360°. The veins are in a shallow, easterly dipping (<5°), laminated to thin-bedded, khaki-green micaceous siltstone of the Yarrawolya Formation of the Proterozoic Badgeradda Group. The deposit is very small although a number of veins are present	Williams et al. (1983)
Savory Basin			
Savory Creek	23°38'00"; 121°37'00" (B)	Exploration work for base-metal mineralization in TR 7664, located approximately 200 km east of Newman, and south of Savory Creek, indicated gravity anomalies associated with the Proterozoic McFadden Sandstone. This anomaly was interpreted to be due to high barium content in the sandstone which was found to contain up to 40% barite in the matrix and veins. A single analysis of the rock indicated barium and strontium values well above 10 000 ppm	Oilmin NL (1982)
Paterson Orogen			
Watrara	22°31'20"; 122°02'10" (A)	Barite occurs in veins up to 0.3 m wide in deformed adamellite at a location 4.4 km southeast of Watrara rockhole. Colour banding parallel to the margins of the vein is defined by concentration of hematite grains which pseudomorph pyrite or magnetite. A sample of breccia, containing quartz fragments in a fine-grained, iron-stained matrix, from a fault zone, contained 32 000 ppm Ba	Chin et al. (1980)
North Perth Basin			
Dandaragan	30°41'20"; 115°42'00" (B)	Well-formed colourless prismatic crystals of barite up to 1 cm long and several millimetres wide were found in boulders composed of mainly apatite nodules on Cataby Estate in the Dandaragan area	Simpson (1948)
Halls Creek Orogen			
Mabel Downs	16°55'00"; 128°19'25" (B)	Boulders of coarsely crystalline barite occurs approximately 37 km northeast of Mabel Downs Homestead. Barite is brown and contains veinlets and small lenses of ankerite	Simpson (1948)
Turkey Creek	17°01'55"; 128°12'40" (B)	A vein of coarsely crystalline and heavily iron-stained barite occurs at this location	Simpson (1948)
Boxers Prospect (situated 17.7 km southwest of Argyle Downs Homestead, now submerged beneath Lake Argyle)		Galena, fluorite and barite occur in a quartz vein 25 to 38 cm wide, about 6 m long and striking 230° in a coarse-grained granite. A sample from the location contains 7.7% Pb, 0.3% Zn, 30.8% Ba and 43.54 g/t of Ag	Blockley (1971)

Note: A: absolute accuracy of site <200 m,
         B: absolute accuracy of site >200 m

shrinking in the late 1980s, appears to be picking up in the 1990s. The price of paint-grade barite (96–98% $BaSO_4$) has increased from $160 in 1983 (1983 dollars) to $442 in 1995, whereas prices of ground and unground varieties have remained virtually flat during the same period.

In recent years, annual world production of barite has been stable at approximately 5 Mt. Peak production of 8.2 Mt was in 1981, but decreased to about 5 Mt in 1994. China, the highest producer, had a 1994 output of 1.9 Mt which amounted to 36% of world production. Other countries with significant production during the last few years include the CIS, India, USA, Morocco, Turkey, Mexico, Germany, France, and Brazil.

Australia is not a major producer of barite. Annual production in recent years has been approximately 11 000 t, with South Australia being the highest producer. Peak production of 91 066 t occurred in 1979. Western Australia has been the second largest producer but at present has no production. The last recorded production from Western Australia in 1990 amounted to 7521 t valued at approximately $1 million. Recorded production from Western Australia from 1946 to date is 138 697 t, valued at $6 million. Production has been from seven centres, the most important of which was North Pole which produced a total of 129 505 t.

Barite occurs in a variety of geological environments that are commonly classified on the basis of morphology as bedded, vein and cavity filling, and residual types. The most significant economic deposits are the bedded type which can occur as a part of a sedimentary sequence or associated with stratiform massive sulphide deposits. Barite in these deposits is usually fine-grained and dark, occurring in beds up to 16 m thick and several kilometres long. Although barite content can vary from 50–95%, values can be lower depending on the presence of impurities such as fine-grained quartz, clay, pyrite, chert or silt. Vein and cavity fillings are derived from hydrothermal fluids or deep-seated brines. Barite in both the above deposit types is generally mined as a by- or co-product of lead and zinc mining. Residual deposits are concentrations of barite fragments in soil and colluvium. While their size and shape may be extremely variable, they are important sources of high-purity barite required for chemical, filler and extender uses.

North Pole barite mineralization is associated with a sequence of Archaean basic and acidic volcanics, quartzites and minor dolomite, pyroxenite calc-schists and carbonate rocks of the Archaean Warrawoona Group, intruded by granite and dolerite occurring at the eastern flank of a dome about 35 km in diameter. Barite mineralization is adjacent to and generally immediately below the lowest bedded chert unit of the succession and is considered to be sedimentary in origin. Barite grade in costeans and drill core varied from 95.4% to 97.4% $BaSO_4$ and from 65.5% and 88.2% $BaSO_4$, respectively, with a specific gravity range from 3.86 to 4.27. An inferred resource of several million tonnes occurs within the North Pole deposit although the published figure is less than 1 Mt. Cooke Bluff Hill deposits, located 25 km north of North Pole, is considered to be of lower grade than that of North Pole and has a pre-resource estimate of 0.5 Mt to a depth of 10 m. At Chesterfield, barite occurs in gabbro and basaltic tuff of an Archaean mafic sequence. The barite is of moderate to good quality, but a resource has not been calculated. Cranbrook deposits are vein deposits and are thought to be mesothermal deposits derived from a deep-seated magmatic body. Chemical analyses of a few samples indicate a grade of around 98% $BaSO_4$. Although the total inferred resource at Cranbrook was 2500 t, 2487 t have already been mined. Other occurrences in Western Australia are small and have not been investigated in any detail.

The estimated barite resource in Western Australia is several million tonnes, although published figures amount to a total of only 1.3 Mt.

Part Two

Fluorite

Mineralogy, mode of occurrence and uses of fluorite

Mineralogy

The mineral fluorite, also commercially known as fluorspar, theoretically contains 51.1% calcium and 48.9% fluorine. The mineral is chemically known as calcium fluoride (CaF_2). Fluorite is a glassy, translucent to transparent mineral having, in crystalline form, a wide range of colours from colourless to yellow, blue, purple, green, rose, red, bluish, purplish black, or brown. It has a hardness of 4 and a specific gravity ranging from 3.01 to 3.60. Fluorite can occur as well-formed isometric crystals, forming cubes and octahedrons, or as massive and earthy forms and as crusts or globular aggregates with radial fibrous texture. Crystalline fluorite has a very low index of refraction (1.433–1.435), low dispersion, and the ability to transmit ultraviolet light (Pelham, 1985).

Under ultraviolet light, some varieties fluoresce in shades of yellow, green, blue, and violet. Strong fluorescence may be associated with relatively high contents of rare-earth elements; europium, lanthanum, cerium, and yttrium. The yellow fluorescence of brown fluorite is considered to be due to inclusions of organic matter.

Natural fluorite is commonly associated with other minerals such as quartz, barite, calcite, galena, siderite, celestite, sphalerite, chalcopyrite, other sulfides, and phosphates.

Table 15. Typical specifications for fluorspar grades (after Skillen, 1993)

ACID GRADE (ACIDSPAR)	
CaF_2	97%
SiO_2	<1.5%
S (as sulfur or free sulfur)	0.03–0.1%
As	<10–12 ppm
P	100–550 ppm
Also limitations on Pb, Cd, Be, $CaCO_3$ and moisture	
CERAMIC GRADE	
CaF_2 (no. 1 grade)	95–96%
CaF_2 (no. 2 grade)	80–90+%
SiO_2	<2.5–3.0%
Fe_2O_3	0.12%
Also limitations on calcite, trace lead, and zinc sulfate	
METALLURGICAL GRADE (METSPAR) USA specifications	
CaF_2	min 60% ('effective' CaF_2)
Sulfide	<0.3%
Pb	<0.5%

Note: Outside of the USA, the minimum requirement is 80% CaF_2 with max 15% SiO_2

Grades

Commercial fluorspar is available in three grades; acid, ceramic, and metallurgical grades (Pelham, 1985; Harben and Bates, 1990b; Miller, 1991). A summary of typical specifications for fluorspar grades is given in Table 15.

Acid grade

Acid grade, also known as acidspar, contains a minimum of 97% CaF_2, less than 1.50% SiO_2, and 0.03 to 0.1% sulfur as sulfide and/or free sulfur. This grade is used for the manufacture of hydrofluoric acid. Some manufacturers of hydrofluoric acid in the USA and Europe use 96% CaF_2 or slightly lower if the remaining impurities are acceptable. In addition to silica and sulfides, user specifications may impose limits on calcium carbonate, calcite, beryllium, arsenic, lead, phosphates, and other constituents. Moisture content of the dried material should be preferably 0.1% or less.

Ceramic grade

Ceramic grade is generally marketed as No. 1 (95–96% CaF_2), No. 2 (85–90+% CaF_2), and intermediate grades (about 93–94% CaF_2) depending on the calcium fluoride content. The permissible levels of impurities can vary but may allow a maximum of 2.5–3.0% silica, 1.0–1.5% calcite, 0.12% ferric oxide, and trace quantities of lead and zinc.

Metallurgical grade

Metallurgical grade, also known as metspar, is generally applied to material with a minimum of 80% CaF_2 and a maximum of 15% silica and other contaminants. Metspar is commonly required to pass through a 1 to 1.5 inch (2.54–3.81 cm) screen and contain less than 15% of material passing through a 1/16 inch (0.16 cm) screen.

According to USA specifications, metspar should contain a minimum of 60% *effective CaF₂*, less than 0.3% sulfide, and less than 0.5% lead. The effective CaF_2 percentage is calculated by multiplying the silica percentage in the chemical analysis by 2.5 and subtracting the result from the calcium fluoride percentage.

Uses

Chemical industry

Most acid-grade fluorspar is used in the manufacture of hydrogen fluoride (HF). This is made by reacting acidspar with sulfuric acid in a heated kiln or retort to form HF and calcium sulphate. The HF is purified to yield aqueous 70–90% hydrofluoric acid, a colourless fuming liquid.

Hydrogen fluoride is used to make fluorocarbons and other organic and inorganic chemicals, synthetic cryolite (Na_3AlF_6), and elemental fluorine. The principal fluorocarbons are trichlorofluoromethane (CCl_3F or CFC-11), dichlorodifluoromethane (CCl_2F_2 or CFC-12), and chlorodifluoromethane ($CHClF_2$ or HCFC-22). The main use of fluorocarbons is as refrigerants, though this market will decline. Other uses are in foam-blowing agents, fluoropolymers, sterilant gas, aerosol propellants, food freezants, and bug bombs for agriculture.

As a result of scientific evidence indicating the increasing rate of ozone depletion, CFC-11 and CFC-12 production has recently been phased out. Although HCFC-22 is considered to have a much lower ozone-depletion potential, there is increased pressure to cease production of HCFC compounds by the year 2005. Makers of refrigerators, air conditioners, and foam insulation oppose the accelerated phase out of HCFCs because they claim that there is no commercially viable alternative.

The aluminium industry consumes a significant amount of hydrogen fluoride in the form of aluminium fluoride and synthetic cryolite. For example, the Hall-Heroult process consumes an estimated 20 to 30 kg of fluorine for each metric ton of aluminium produced.

Another use of hydrogen fluoride is in uranium processing where anhydrous hydrogen fluoride is used to manufacture uranium hexafluoride, which in turn is used in the isotopic separation of U_{235} and U_{238} by the gaseous diffusion process or the gas centrifuge process.

Hydrofluoric acid is used in the manufacture of alkylate, which is an ingredient in high-octane fuel for aircraft and automobiles, in steel pickling, enamel stripping, glass etching and polishing, and in electroplating operations. It is also used in refining tantalum and niobium which are usually found associated in minerals such as columbite, tantalite, and pyrochlore. In this application, hydrofluoric acid (70%) is used to digest the mineral and the metals are released by solvent extraction in the form of tantalum pentoxide and potassium tetrafluoride or as niobium oxide plus tantalum compounds (Pelham, 1985; Griffiths, 1990; Miller, 1991).

Metallurgical industry

The ability of fluorspar to form lower melting eutectics with refractory materials has led to its uses in metallurgical industry. The steel-making process requires that various elements contained in iron such as silicon, sulfur, phosphorus, and carbon be removed by oxidation and the formation of a mobile slag. Fluorspar is used as a fluxing agent to reduce the melting point and surface tension of slag and to improve its fluidity. Reducing the melting point of the slag assists in bringing lime and other fluxes into solution to allow for the absorption of impurities. Fluorspar also assists in the effective desulfurization and dephosphorization of the melt. Fluorspar serves a similar function in iron foundries, where it is added to the cupola to facilitate coke combustion, increase carbon pick-up by metal, and prevent bridging (premature slag solidification).

Metallurgical fluorspar is also used in welding fluxes and welding rod coatings. The flux is usually prepared by melting the components to form a homogeneous mixture, which is then cooled and ground. In these applications fluorspar comprises 2–50% of the mixture. Minor quantities of fluorspar are also used as a flux in refining aluminium, antimony, chromium, copper, gold, lead, nickel, silver, tin, zinc, and other metals.

Ceramic industry

Ceramic-grade fluorspar is used in the production of flint glass, white or opal glasses, and enamels covering the steel parts of refrigerators, cooking ware, bathtubs etc. In such uses, fluorspar acts as a flux and as an opacifier. Ceramic-grade fluorspar is also used in the manufacture of fibreglass insulation, and as an abrasive on certain types of sandpapers.

Substitute minerals

A number of minerals and compounds were tested during the early 1970s for their suitability as a substitute for fluorspar in steel making. Some of these are alumina, aluminium dross, bauxite, colemanite, feldspar, ilmenite sand, lime and furnace dust, olivine, topaz, and various combinations of these minerals. The tests had only limited success indicating that satisfactory use of substitutes to fluorite was restricted to the low-carbon and medium-carbon steels produced in open-hearth furnaces. The most successful was colemanite containing about 40% boric oxide, less than 0.08% arsenic, and less than 2% moisture. Limited supplies of low-arsenic colemanite, however, made it difficult to use this mineral as a substitute for fluorspar. Two other minerals which were considered as substitutes for fluorspar in the steel industry are dolomite and massive manganese slag. However, it was found that dolomite had a tendency to build up in the vessels and therefore was not suitable. In addition, massive manganese slag is not available in large volumes, and has more variable chemistry than fluorspar (Pelham, 1985).

Mode of occurrence

Fluorite occurs in a wide variety of geological environments, with significant concentrations often present in regions of gravity lows and zones of high heat flow, igneous activity, and hydrothermal processes (Harben and Bates, 1990b). Pelham (1985) and Miller (1991) listed seven deposit styles as being commercially important modes of occurrences:

- fissure veins
- stratiform-replacement deposits
- replacement deposits in carbonate rocks
- stockworks and fillings in shear and breccia zones
- carbonatite and alkalic-rock complexes
- residual concentrations from weathering of primary deposits
- recoverable gangue minerals in base-metal deposits

Fissure veins

These deposits commonly occur along faults or shear zones and are considered the most readily recognizable form of fluorspar occurrence. Fissure veins occur in igneous, metamorphic or sedimentary rocks. Although vein structures are persistent, fluorite commonly occurs as lenses or ore shoots separated by barren or poorly mineralized portions of vein. The typical associated minerals are silica, calcite or other carbonates, iron, lead, and zinc sulfides, and barite. The CaF_2 content of mineable portions of veins normally ranges from 25–80%, although occasionally grades above 90% are known. An example of this type of deposit is the Rosiclare–Goodhope vein system in southern Illinois.

Stratiform-replacement deposits

These are also known as manto or bedded deposits and occur as replacement deposits in carbonate rocks. They are frequently overlain by a capping of sandstone, shale, or clay, and are commonly associated with calcite, dolomite, quartz, galena, sphalerite, pyrite, marcasite, barite, and celestite. The grade of mineable deposits generally ranges from 15% CaF_2 upwards. Some typical localities for this type of deposit are in the Cave-in Rock district of southern Illinois in the USA, the northern part of the State of Coahuila in Mexico, and in the Ottoshoop district of the Transvaal in the Republic of South Africa.

Replacement deposits in carbonate rocks

Replacement deposits may occur in carbonate rocks along contacts with intrusive rhyolite bodies. These deposits are not necessarily a result of contact metamorphism, but may be introduced later by fluids following the contact zone, which serves as a conduit, and replacing carbonate rocks such as limestone. Typical deposits occur in the Rio Verde, San Luis Potosi, and Aquachile districts in Mexico.

Stockworks and fillings in shear and breccia zones

Many occurrences in the western USA are of the stockwork type. They are generally of low grade although some have significant tonnages. The Buffalo deposit in the Transvaal (Republic of South Africa) consists of a network of fluorite veinlets in sill-like bodies which occur as inclusions in granite of the Bushveld Complex.

Carbonatite and alkalic-rock complexes

Fluorite deposits of this type are generally at the contact zones of these complexes and rarely occur in sufficient quantity to be economic. Some typical deposits are the Okorusu deposit in Namibia and the Ambar–Dongar deposit in northwest India. The Okorusu deposit is made up of a number of bodies of fluorite in limestones, quartzites, and related rocks that have been intruded and metamorphosed by an alkaline igneous rock complex.

Residual concentrations from weathering of primary deposits

These deposits are derived from surficial weathering of primary fluorite deposits and also include detrital deposits blanketing the apex of veins, as well as the upper portions of veins that may have been weathered to depths of 30 m or more. Deposits of this type are known in many countries including USA, UK, Thailand, and Spain.

Gangue minerals in base-metal deposits

Economically recoverable fluorite occurs as a gangue mineral in lead–zinc veins in many parts of the world. Some such veins can carry 10–20% fluorite. One example is acid grade fluorspar produced from lead–zinc mill tailings near Parral in Mexico.

Methods of mining

As with most other minerals, fluorspar deposits throughout the world are mined either by opencut or underground operations depending on the size, shape, depth, and type of deposit. In some opencut operations substantial overburden removal has been required, and in other instances mining may begin with openpit methods but

later go underground when overburden ratios become excessive. Narrow vein mining is often done by shrinkage or open stoping methods where strong walls occur, whereas stratiform or bedded deposits use room and pillar methods. Replacement and fissure vein deposits may be mined by shrinkage stoping, or cut and fill methods if the veins are deep and narrow. Deposits of this type may also be mined by openpit methods when veins occur at shallow depth and the sidewalls are competent. Most USA fluorite production is from underground mines (Pelham, 1985; Miller, 1991).

Processing and beneficiation

Most fluorspar requires processing and beneficiation prior to marketing, with methods of processing and beneficiation dependent on the nature of the ore. Metspar is often produced by hand sorting high-grade lump crude ore, followed by crushing and screening to remove most of the fines. Ores of lower grade and/or ores with relatively coarse interlocking minerals require gravity concentration processes such as heavy-media separation based on the specific gravity of 3.2 for fluorspar and less than 2.8 for most gangue minerals.

According to Pelham (1985), heavy-media cone and drum separators are particularly effective in the size range of 4.8 mm to 38 mm, either for producing metallurgical gravel or for pre-concentrating the crude ore for flotation feed. For the finer sizes, the heavy-media cyclone process is frequently used. Ores as low as 14% CaF_2 can be pre-concentrated to yield a flotation feed of 40% CaF_2. Along with the fluorite, other minerals such as barite and lead or zinc sulfides may be concentrated in this process. In some instances washing plants are used prior to flotation to remove clay or manganese oxides.

Andrews and Collings (1993) did several studies to concentrate coarse, 3 mm to 25 mm fluorite ore samples using heavy-media separation. Although there were limitations in the efficiency, it was possible to successfully separate calcite of specific gravity 2.75 and fluorite of specific gravity 3.05 with barite remaining in the sink fraction. A combination of jigging and tabling was more successful in concentrating coarse-grained fluorite ores. Tabling fluorite ores of −1.7 mm to + 75 µm, was only moderately successful. It was also found that production of acid-grade fluorspar (>97% CaF_2), was not possible by gravity concentration methods. The highest grades achieved (90–93% CaF_2), were suitable for ceramic applications.

Multistage froth flotation is the beneficiation method used to produce ceramic and acid-grades of fluorspar. Ore is first crushed and ground, and any sulfides (if present) are preferentially floated off with xanthate collector. Fluorspar is then removed in a quick pass through a flotation circuit, and sent on to the cleaner circuit. The intermediate-sized material is reground to separate the more finely interlocked grains of fluorite and gangue, and passed through one or more circuits. Andrews and Collings (1993) also state that when the liberation size is <300 µm, flotation is the preferred method of beneficiation for the production of acid-grade fluorite.

Fatty acids are used as collectors for the fluorspar. Quebracho or tannin is used to depress calcite and dolomite; sodium silicate is used to depress iron oxides and silica; and chromates, starch, and dextrin are used to depress barite (Miller, 1991). Any remaining sulfides are depressed using cyanide. Other depressants used in the industry are oxalic acid for celestite and potassium dichromate for calcite. Acidity can be controlled by using lime or soda ash. The temperatures during flotation can range from ambient to 80°C.

The products at the end of this process generally consist of an acid-grade concentrate, and in some cases various lower grade concentrates which are sold as ceramic grade, or pelletized and sold as metallurgical grade.

Fluorite production and market trends

World production

The production of fluorspar from 1975 remained steady at about 4.2 Mt until 1989 when a peak of 5.5 Mt was reached. Since that time production has declined significantly to around 3.9 Mt in 1994 (Table 16, Fig. 17). Although approximately 30 countries produce fluorspar, more than 75% of world production comes from China, Mexico, CIS, South Africa and Mongolia. Production figures for 1994 indicate that China produced about 53% of world output, Mexico 9%, CIS 6%, and South Africa and Mongolia 5% each (Fig. 18). The only country with significant increases in production in recent years is China, where production has increased from 0.3 Mt in 1975 to 2.1 Mt in 1994, and still remains a clear market leader. All other countries report decreasing production trends from the mid to late 1980s. The most notable decline has been in Mexico's production, which has decreased from more than 1 Mt in 1975, 1980 and 1981 respectively, to 0.4 Mt in 1994.

China

According to China Everbright Trading Co., annual production of fluorspar in China is around 2.1 Mt, approximately 550 000 t of which is consumed domestically and 1.15 Mt exported (Griffiths, 1993). At present, China is the leading producer in the world with known fluorite occurrences in 19 provinces. The most significant of these are Zhejiang, Jiangxi, Hubei, Hunan, and Shandong provinces, with Zhejiang Province probably the largest producer of fluorspar (Figs 19 and 20). Hunan Province is the largest acidspar producer (Skornicki, 1989: Harben and Bates, 1990b).

Fluorite deposits in southeastern China are predominantly vein type, and occur in association with two major types of rocks. Type one deposits occur in rocks of Mesozoic, felsic to intermediate volcanic regions, while Type two deposits occur in Yanshanian Granite areas.

Type one occurrences are located mainly within major fault structures in down-faulted Cretaceous sedimentary basins, basin margins, and underlying Jurassic volcanics. In this setting, fluorine-bearing fluids appear to have emanated from major basin margin and intra-basin fault structures. A typical deposit of this type is located in the Wuyi–Dongyang area of Zhejiang (Fig. 21). Type two deposits are found mostly in areas of uplifted Palaeozoic rocks, and in faults at the contact of the Yanshanian

Granite with uplifted Precambrian basement. Other deposits of this type are located at western Zhejiang, southern Anhui, northern Fujian and eastern Guangdong provinces (Li and Jiang, 1992).

Mexico

Mexico was once the leading producer of fluorspar in the world with peak annual productions of over 1 Mt during the years 1975, 1980 and 1981. Although production dramatically declined to around 370 000 t in 1994, Mexico remains the second largest producer in the world. Metspar production has been adversely affected by an improvement in the efficiency of the iron and steel industry, and the use of more economic substitute materials (Skillen, 1993).

The main deposits are located in the states of San Luis Potosi, Guanajuato, Chihuahua, Coahuila, and Durango.

Mexico's largest deposit is located at Salitrera, in Zaragoza–Rio Verde District, approximately 418 km north of Mexico City. The deposit is owned by the country's largest producer, Cia Minera Las Cuevas SA de CV. The fluorspar produced in this district is of high grade. The Las Cuevas deposit at Salitrera consists of a group of massive fluorite bodies lying between the Doctores Formation, a Cretaceous limestone and dolomite with chert and shale, and an overlying Tertiary rhyolite breccia. The limestone shows evidence of replacement by fluorite, and the rhyolite breccia consists of highly altered, subangular to rounded rhyolite clasts in a clay matrix. The fluorite bodies are also brecciated, with fluorite and limestone forming clasts in a cement of fluorite and calcite (Harben and Bates, 1990b).

In Parral district in the State of Chihuahua, fluorite has been produced from tailings of old silver, lead, zinc, and copper mines which contain fluorite as a gangue mineral associated with mineralized veins. Narrow veins of quartz, fluorite, and calcite cut the sulfide veins and fill open fractures.

In Coahuila State, fluorite deposits occur mostly in the Georgetown Limestone and the overlying Del Rio Shale. Mineralization is a combination of replacement and void filling. Fluorite is also produced from some lead/ zinc mine dumps located near the US border.

In the State of Mexico, veins consisting of 60 to 70% fluorite have been worked to a depth of around 180 m in the Zacualpan District. The mineralization is in fault

Table 16. Global fluorspar production (tonnes): 1975–1994

| Year	China	Mexico	Mongolia	CIS	S. Africa	France	Spain	Thailand	Germany	Italy	UK	Rest of world	World
1975	349266	1088815	302093	471736	202583	318422	306818	244994	165361	231253	235003	606489	**4 522 833**
1976	349266	867402	322051	489880	290717	305721	286653	181851	154928	210812	217000	646998	**4 323 279**
1977	399161	727614	334751	500766	350679	283042	310460	248140	183540	185749	194000	707101	**4 425 003**
1978	399161	944234	455407	509838	393276	303907	301294	230531	175532	171098	189000	586195	**4 659 474**
1979	399161	964791	449964	519817	451111	291206	192897	234304	162962	182791	154000	585532	**4 588 537**
1980	478994	1105999	604185	519817	522717	258500	244749	232892	177943	151964	170999	537569	**5 006 327**
1981	478994	1115998	595113	530703	496521	256200	257127	212492	171599	164234	115997	561112	**4 956 090**
1982	478994	734999	670410	539775	330835	243625	194280	257108	178430	166949	98000	497835	**4 391 239**
1983	498952	604999	700347	539775	274061	196356	232335	206648	180497	177634	199581	487319	**4 298 502**
1984	749970	699430	746976	549754	319207	232101	295666	287379	183058	188261	136700	439993	**4 828 494**
1985	850032	728611	786983	559733	349207	224000	305609	298897	182928	152211	167000	491723	**5 096 936**
1986	900000	766822	790000	410500	333885	198000	282460	167909	188834	145436	133420	532444	**4 849 710**
1987	1000000	823892	583000	410500	316606	184000	171616	102398	175201	134400	120400	578428	**4 600 441**
1988	1400000	756000	699000	410500	328421	203000	142575	76321	167710	139857	103797	659195	**5 086 376**
1989	1700000	779000	701000	410000	368340	221000	161292	98375	163770	126279	122057	678071	**5 529 184**
1990	1700000	634000	614000	380000	311032	201000	100000	94757	155300	122503	118498	593536	**5 024 626**
1991	1600000	352000	520000	350000	270000	200000	90000	100000	135000	100000	80000	557036	**4 354 036**
1992	1300000	300000	400000	320000	250000	100000	70000	100000	135000	50000	80000	495000	**3 600 000**
1993	2100000	370000	180000	250000	218000	125000	85000	na	na	75000	65000	532000	**4 000 000**
1994	2100000	370000	180000	250000	190000	100000	80000	na	na	60000	65000	505000	**3 900 000**

na = not available

Source of data: US Bureau of Mines Minerals Year Book, production statistics from 1977 to 1993; US Bureau of Mines, Mineral Commodity Summaries, 1993 and 1995.

United Kingdom   Spain   Mongolia

Italy   France   Mexico

Germany   South Africa   China

Thailand   CIS   Rest of world

PBA95

13.11.96
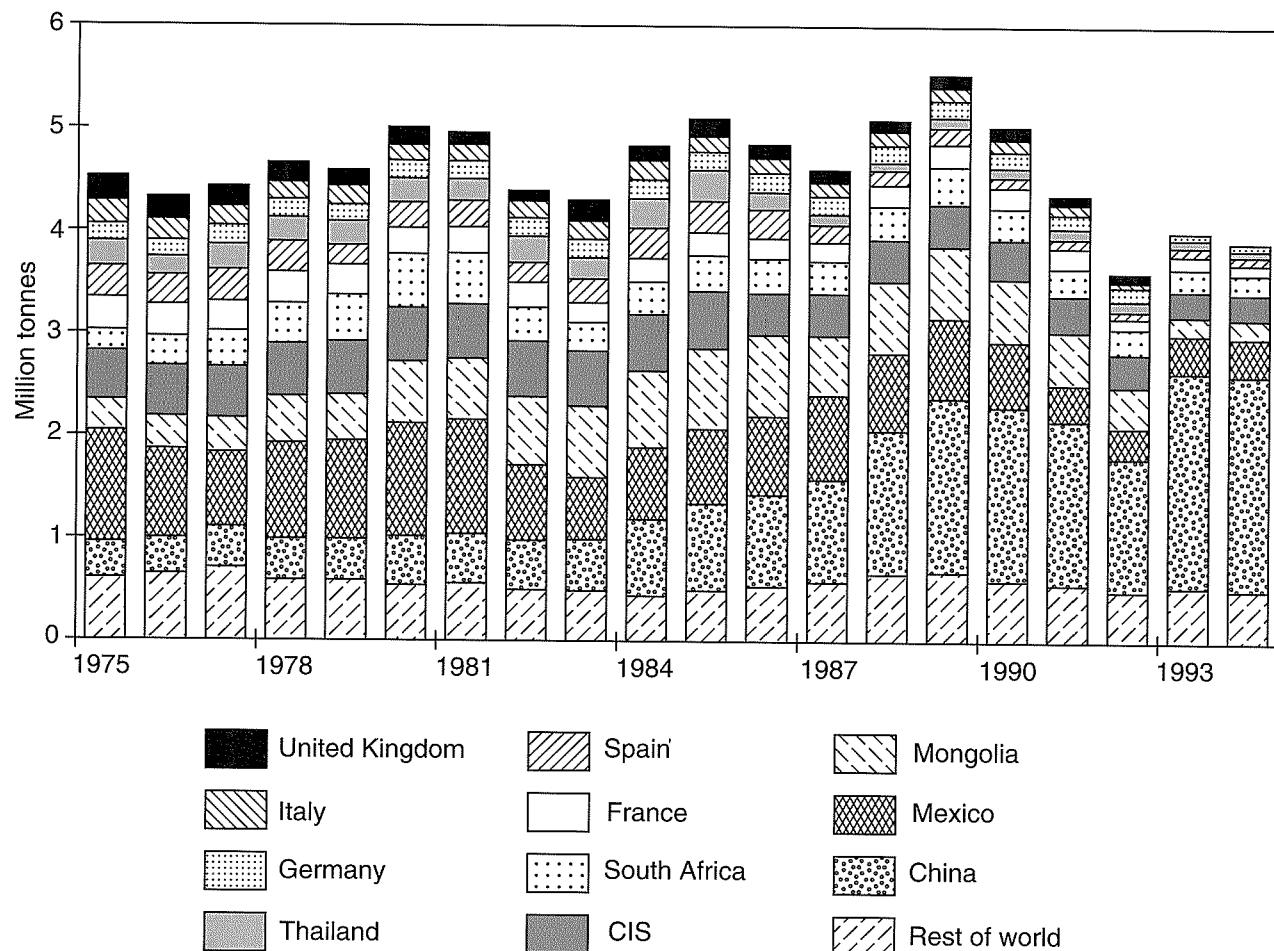
Figure 17. Global trends in fluorspar production 1975–1994. (Source of data: US Bureau of Mines Minerals Year Book, production statistics from 1977 to 1993; US Bureau of Mines, Mineral Commodity Summaries, 1993 and 1995)

China
53%

Mexico
9%

Rest of world
13%

Italy
2%   United
      Kindom Spain   Mongolia   South Africa   CIS
      2%   2%   France   5%   5%   6%
                    3%

PBA96

13.11.96
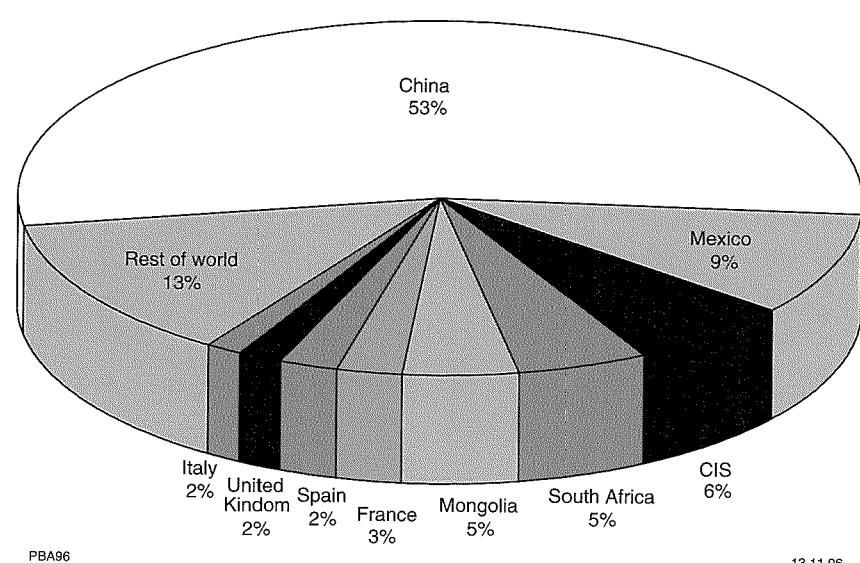
Figure 18. Global fluorspar production by country — 1994. (Source of data: US Bureau of Mines, Mineral Commodity Summaries, 1995)
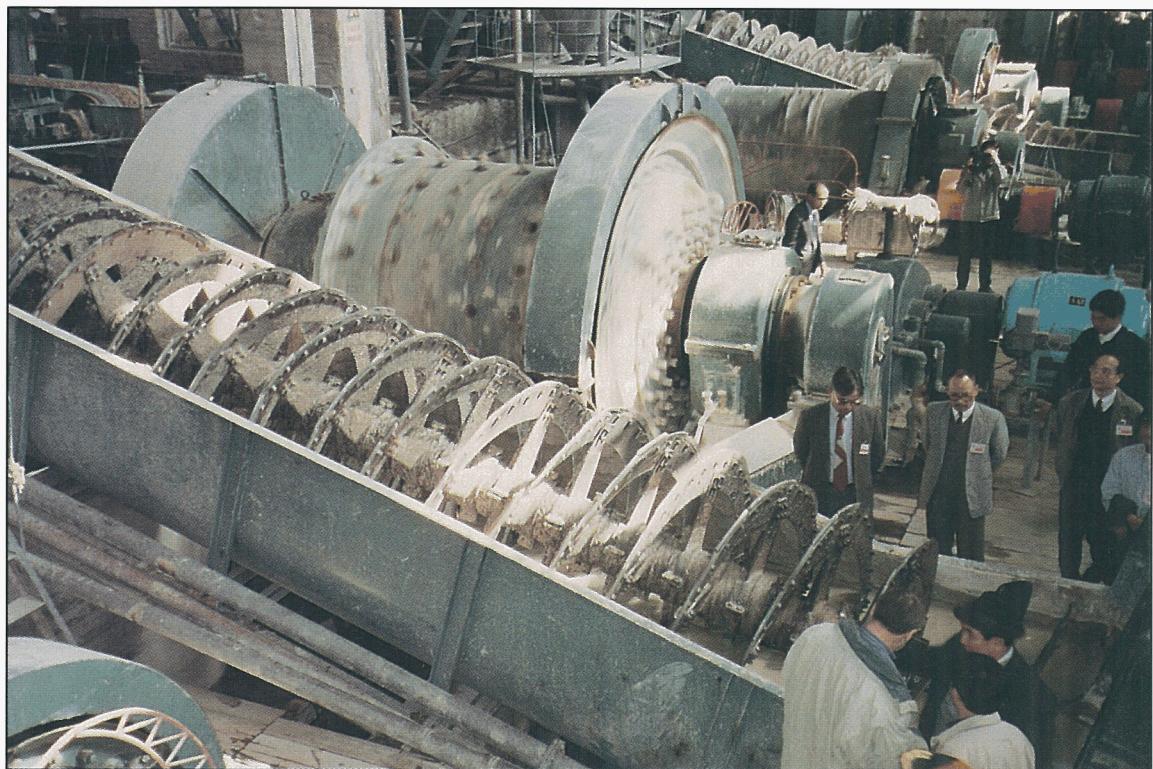
Figure 19. Ball mill and spiral classifier circuits, Dong Feng Fluorspar Company, Zhejiang Province, China
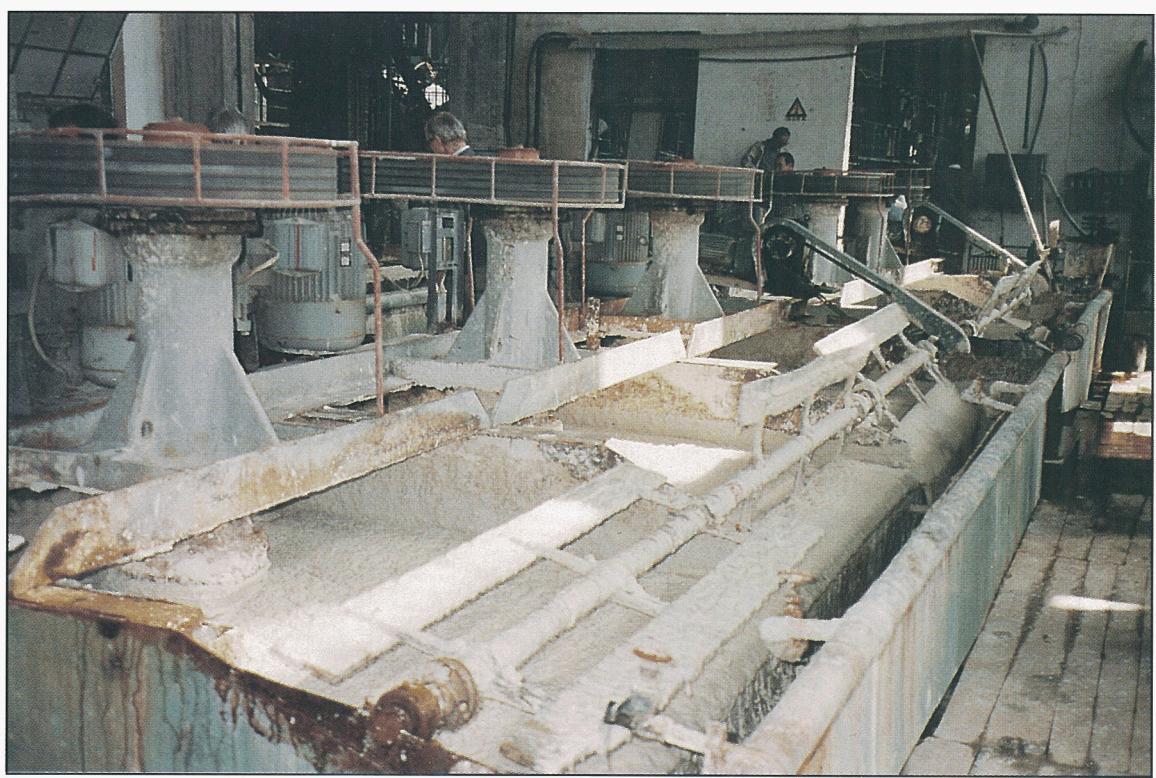
Figure 20. Fluorspar flotation circuits, Dong Feng Fluorspar Company, Zhejiang Province, China

PBA 143

04.06.97

Figure 21. Veins of green and purple fluorite cut by white quartz veinlets in a fluorspar mine in the Wuyi–Donyang area, Zhejiang Province, China

zones in Mesozoic sericite schist, quartzite, and shale in an area also containing a number of intrusive bodies.

The main company operating in Mexico is Cia Minera Las Cuevas SA de CV. Some of the other production companies are Fluorita de Mexico SA and Cia Minera La Valenciana. A reduction in demand during the last few years resulted in a slowing down of production from a number of companies. Some of these companies were Minera San Francisco del Oro SA de CV (Frisco), Zinc de Mexico SA (IMMSA), Fluorita de Rio Verde and Sesa Fluorspar Inc. Silesa, which produced 5000–6000 t of acidspar in 1992, has now ceased production.

Mongolia

Mongolia has been a major producer of fluorspar from the 1970s, with production ranging from around 300 000 t in 1975 to a peak of 790 000 in 1986. By 1994, production had dropped to 180 000 t. Throughout the development of the fluorspar industry in Mongolia, the countries that supplied the hardware and associated technical support were the former Eastern Bloc countries. The industry is therefore strongly influenced by these countries, with production dominated by two 50/50 joint venture operations, Mongolsovietsmet (MGS) and Mongolczechoslovak-metal (MCSM). Mongolia is still one of the major suppliers of fluorite to eastern Europe (Skillen, 1993).

There are approximately ten fluorspar mining sites in Mongolia. The most significant acidspar production is controlled by MGS, which has operations centred on a large underground mine at Bor Ondor, 290 km southeast of Ulaanbataar, which supplies around 210 000 t per year to the associated flotation plant. Approximately an equal amount is produced from smaller satellite operations at Adag, Hanuu–Ulaan, Zuun Cagaan Del, and Hamar Us. The other major producer is MCSM which extracts ore from an openpit operation at Chulut Cagaan Del. Approximately 240 000 t of ore with a grade of 42–48% CaF_2, is extracted annually to produce around 75 000 t of products.

According to Skillen (1993), Mongolia is unlikely to continue at high levels of production because of logistical problems such as its dependence on transportation through China or the CIS. The fact that Mongolia's production has dropped from 400 000 t in 1992 to 180 000 t in 1994 would seem to endorse this view. The country remains the world's fourth largest producer, in equal place with South Africa.

CIS (formerly USSR)

Annual production of fluorspar from the CIS has declined progressively from around 550 000 t in 1985 to about 250 000 t in 1994, but is still ranked as the third largest producer in the world at present. Major deposits are

located at Kalanguyskoye, Abagayuyskoye, Usuglinskoye, and Solonechonye in the Trans-Baikal region; Suppatashskoye, Khaydarkanskoye and Naugarzanskoye in Soviet Central Asia; Khinganskoye, Pogranichnoye, and Voznesenskoye in the Soviet Far East; and the Tyrny-auz deposit in the North Caucasus. Fluorspar is also mined at Yaroslov by openpit methods with an approximate annual production of 285 000 t of concentrate averaging 91.7% CaF_2. The estimated total reserves in the CIS are in the region of 95 Mt. However, the former USSR imported approximately 50% of its annual requirements. The main source of imports was Mongolia, with some from Thailand and China (Burger, 1991; Skillen, 1993).

South Africa

South African production of fluorspar increased from around 200 000 t in 1975 to about 520 000 t in 1980, but has since declined to about 190 000 t in 1994. South Africa now ranks equally as the fourth-largest producer along with Mongolia.

The bulk of known fluorite deposits in the African continent are in South Africa, which has estimated reserves of 160 Mt. Large deposits occur in a rift zone between the Great Dyke in Zimbabwe and the Bushveld Igneous Complex in South Africa. The mineralization is thought to be Precambrian and related to the Bushveld granite (Harben and Bates, 1990b).

The main companies operating in South Africa are Vergenoeg Mining Co. Pty Ltd and Phelps Dodge Mining Pty Ltd.. Buffalo Fluorspar, which was a subsidiary of Transvaal Mining and Finance Co. Ltd, operated an integrated mining and processing facility at Naboom-spruit, in central Transvaal, but closed down in February 1994 as a result of a deteriorating business environment (Industrial Minerals, 1994).

Vergenoeg Mining Co. Pty Ltd, wholly owned by German-based Bayer AG, produces fluorspar from an openpit mine situated some 70 km northeast of Pretoria, in Transvaal Province, with a rated annual capacity of 120 000 t. The mushroom-shaped deposit contains hematite and fluorite, and occupies a volcanic vent within the Bushveld Complex. Reserves are estimated to be sufficient for at least another 50 years with head grades ranging from 25–80% CaF_2.

Phelps Dodge Mining Pty Ltd produces ore from the Witcop mine, near Zeerust, which has an annual prod-uction capacity of 108 000 t. Mineralization of the bedded-replacement type occurs in association with dolomites of Precambrian age which are unconformably overlain by shale and quartzite of the Pretoria Series. Metamorphism of the dolomite by emplacement of the Bushveld Complex has resulted in the development of minerals such as talc, chlorite, and phlogopite. In addition, fluorite occurs as massive pockets or pipe-like bodies in brecciated zones, or as stratiform bodies. The deposits of commercial significance are the stratiform

bodies, occurring in the upper part of the dolomite, approximately 15 m below the basal chert of the Pretoria Series. The main body of mineralization varies from 300–600 m in width and from 2–30 m in thickness, with an average of 6 m. Three ore types with CaF_2 ranging from 1–75% occur. They are:

Dolomitic or algal ore: with a grade ranging from 8–40% CaF_2, is the most abundant type in the mine. Minor amounts of pyrite, pyrrhotite, sphalerite, galena and chalcopyrite are present.

Rockspar ore: is usually high grade (40–75%) and consists of coarse granular fluorite with a silica matrix.

Kokoman ore: consists of the approximately 40% by weight of poorly soluble fluorite found to fill cavities and fissures developed in rectangular joints of dolomitic ore bodies, along with residual manganiferous soil and weathered dolomite. This fluorite, named Kokoman by local miners, has been hand screened in the past to produce a metallurgical lumpy fluorspar grading about 80% CaF_2.

Crude ore produced from the mine has an average grade of 15% CaF_2, but the end product after processing has grades of 85% and 97.5% CaF_2. Impurities in the concentrate are $CaCO_3$ (1%), Fe_2O_3 (0.4%), SiO_2 (0.2%), Na_2CO_3 (200–500 ppm), S (50–100 ppm), and P_2O_5 (300 ppm) (Harben and Bates, 1990b; Burger, 1991; Skillen, 1993).

The Buffalo mine was located at Buffelsfontein Farm, 8 km north of Naboomspruit. Rocks in the area consist of granite, granulite, and felsite of the Bushveld Complex, overlain by sandstone and conglomerate of the Stormberg Series. Economically exploitable fluorite occurs in granulite as composite or simple veins up to 0.6 m thick that contain coarse-grained, purplish fluorite. Although impurities in the veins include quartz, feldspar, calcite, monazite, bastnaesite, allanite, apatite, hematite, pyrite, sericite, and relics of granulite, the fluorite is free of inclusions. Mineralization is thought to be related to the Bushveld Granite, which was intruded 2000 million years ago. Ore was processed by crushing, heavy-media separation, milling and flotation to provide products with a minimum of 80%, 97.2% and 98% CaF_2 for metspar, acidspar, and ceramic grades respectively. At the time of closure, the mine was reported to have two years of easily accessible reserves.

France

Until 1991, France was the leading producer of fluorspar in Europe with production ranging from around 318 000 t in 1975 to 200 000 t in 1991. However, 1992 production of 100 000 t fell behind estimated German production of 135 000 t, and remained at 100 000 t in 1994.

In France, fluorite deposits of vein type are found in Hercynian massifs; the Massif Central, the Vosges, the

axial zone of the Pyrenees, the crystalline massifs of Provence, and the outer Alps.

The main producing companies in France are Société Industrielle du Centre, Sté Générale de Rechèrches et d'Exploitations Minières (Sogerem), which is 100% owned by Pechiney, Sté d'Enterprises, and Carrières et Mines de l' Estérel (Secme) which is 100% owned by Sogerem.

Société Industrielle du Centre produces ore from a 1000 m-long vein at its Rossignol Mine, in Chaillac. This operation has a capacity to process 50 000 t of crude ore per year with an annual output of 25 000 t of metspar and 15 000 t of acidspar. Ore is treated by float and sink separation, to yield two size grades of metspar: 1–6 mm at 90% CaF_2 and 6–15 mm at 85 % CaF_2.

Sogerem operates one underground mine at Le Burg and two openpits at Montroc and Le Moullinal. These mines produced a total of 342 000 t ore in 1989 and 333 000 t ore in 1990. Secme's (owned by Sogerem 100%) mining operations are now at a standstill, as the company's opencast operation at Escaro, in the Pyrenees–Orientale district, ceased active production in mid-1991. The associated flotation plant at Olette was processing the stockpiled material in early 1993 but is now closed. Secme also operates a plant at Trebas, processing ore from the Le Burg mine (Burger, 1991; Skillen, 1993; Industrial Minerals, 1993).

Spain

The production of fluorspar from Spain decreased progressively from around 300 000 t in 1985 to around 70 000 in 1992, then rose erratically to 80 000 t in 1994. Commercial deposits of fluorspar are found in Asturias in the north and Andalusia in the south.

In Asturias, the major fluorite deposits are related to transition zones between Palaeozoic basement and Permo-Triassic strata, which are dominantly detrital sediments (Iglesias and Loredo, 1994). Two main types of fluorite deposits are distinguished in this area.

Vein-type fluorite, related to the unconformity between the Carboniferous basement and thick Permo-Triassic cover, is found in fractures and faults, though minor stratabound deposits are also found. Commercial production of vein-hosted fluorspar is restricted to three areas: Berbes–Caravia; La Collada; and Villabona–Arlos. The second type of fluorite mineralization is commercially unimportant. It consists of vein deposits associated with faults and fractures usually related to anticlinal structures in Palaeozoic rocks.

The Villabona–Arlos deposits contain stratiform fluorite deposits in Triassic limestone interbedded with clay, marlstone, and terrigenous material, distributed over an area of approximately 13 km². The average thickness of the bed is 3 m and mineralization grades 25–45% CaF_2.

Both stratiform and vein-type deposits occur in the Berbes–Caravia area. Stratiform deposits that occur in carbonate beds of Triassic age are located at the unconformity between Palaeozoic basement and the Triassic rocks. Vein deposits are mainly in faults and shear zones and may reach widths of up to 30 m, although the average is about 6 m. The ore is generally well crystallized and grades 40–50% CaF_2. The La Collada district has mineralization similar to that of Berbes–Caravia, but contains relatively richer stratiform deposits.

Current Spanish production is limited to one producer, the 50-year-old Minerales y Productos Derivados SA (Minersa), with mining activities concentrated at Moscona mine, in the Villabona district, and Emilio mine, at Berbes–Caravia. A plant located at Berbes has an annual capacity in excess of 140 000 t, although 1992 production was only around 70 000 t (Harben and Bates, 1990b; Skillen, 1993).

Thailand

Production of fluorspar from Thailand has declined from around 245 000 t in 1975 to 100 000 t in 1992. Many fluorite deposits are found in western Thailand in granitic mountain ranges and in contact zones between granite and sedimentary rocks. Faults, shear zones, and breccias have acted as channelways for hydrothermal solutions that deposited fluorite along with gangue minerals such as quartz, chalcedony, calcite, barite, galena, pyrite, chert, and siderite. Most production has come from the provinces of Lamphun, Mae Hong Son, and Chang Mai. In these areas, both fissure-vein and replacement type deposits are known. The replacement deposits, which are relatively low grade – high tonnage, are hosted by limestone, sandstone, conglomerate, and shale. The fluorite is typically coarsely crystalline and massive. In Kanchanaburi, Phetchaburi, and Ratchaburi provinces, fluorite occurs in fissure veins, pegmatites, and replacement deposits, which are generally of lower grade.

The main metspar producer in Thailand, Universal Mining Co. Ltd, mines from deposits at Mae La-Luang (Mae Hong Son), and Mae Tha (Lamphun). Tip Mines Co. Ltd is also believed to produce 75–80% CaF_2 metspar at two locations in Omkoi District of Chiang Mai Province, and Sai Yoke District of Kanchanaburi Province. Acidspar production is mostly from Krabi International Fluorite Co. Ltd (Harben and Bates, 1990b; Burger, 1991; Skillen, 1993).

Germany

German production has decreased steadily from around 165 000 t in 1975, to 135 000 t in 1992, making Germany the largest producer in Europe.

Fluss-und-Schwerspatwerke Pforzheim GmbH, a wholly-owned subsidiary of Bayer AG, operates Kafersteige mine located in the Black Forest near Pforzheim. The deposit is a vein type averaging 12 m in

width and extending several kilometres. With estimated reserves totalling several million tonnes, the deposit is thought to be one of the largest of its kind in Europe. More than one kilometre of the deposit is now being exploited by the company by sublevel caving. Crushing is carried out underground, and a modern ramp system enables trucks, scheduled by a computerized loading system, to transport crushed ore to the surface. The ore is then processed to a grade of 97% CaF_2 at a plant at Karlsruhe on the Rhine.

Sachtleben Bergbau GmbH and Co. produces fluorspar from a mine at Wolfach. Although the operation has a capacity to produce around 35 000 t annually, these targets are not being achieved due to market competition from the increasing quality and quantity of Chinese material. Output in 1992 was 23 000 t and the targeted output for 1993 was 12 000 t (Skillen, 1993).

Italy

Italian fluorspar production, which declined progressively from around 188 000 t in 1984 to 50 000 t 1992, increased marginally to 60 000 t in 1994. The main producing area is centred around Gerrari, approximately 40 km from Cagliari, on Sardinia. Italy's largest producer, Nuova Mineraria Silius SpA, operates an underground galena/fluorite deposit in this region. Beneficiation of the ore in a flotation plant at Assemini yields around 75 000 t of acidspar and 13 000 t of galena per year. Ore reserves are expected to last for another 20 years.

United Kingdom

Production of fluorspar from the UK, which has declined from around 167 000 t in 1985 to around 65 000 t in 1994, is confined to the Pennine district of northern England. Fluorite and barite, the primary mineral products in the area, are associated with deposits of lead, zinc, and iron.

The Pennine district is generally divided into the Northern and Southern Pennine Orefields (NPO and SPO). The NPO covers most of County Durham and west Yorkshire, and the SPO is in Derbyshire. Mineralization in the NPO is related to the easterly elongated Alston Block and occurs as narrow, steeply dipping fissure veins confined to Carboniferous rocks consisting of alternating limestone, sandstone, coal measures, and shale intruded by the quartz dolerite Whin Sill. Fluorite is found in veins trending in a west-northwesterly direction.

The SPO is dominated by a complex of Carboniferous limestone with interbedded chert and contemporaneous volcanic rocks forming the South Pennine Dome. Ore deposits are confined mainly to easterly fractures in upper levels of the limestone. The most important deposit style (named 'rakes') is major mineral veins, formed by wrench faulting, that are up to several kilometres long.

The main operators in the UK are Laporte Minerals and Swan Industrial Minerals. The latter acquired the mineral rights of Derbyshire-based Deepwood Mining, Matlock Barytes and Horace Taylor Minerals. Other operators include Biwater Pipes Ltd and Weardale Fluorspar Ltd.

Laporte produces ore from openpit and underground operations in Derbyshire. Swan Minerals owns several orebodies in the Derbyshire fluorspar field and another mine at Middleton. Biwater Pipes Ltd operates a small metspar operation at its Milltown quarry near Ashover, while Weardale's operations are currently centred on the Frazers Grove Complex.

Australia

Fluorspar production in Australia is insignificant, and there has been no recorded production since 1964. Total production from 1915 to 1963 was 47 270 t. Of this, Queensland produced 32 237 t, New South Wales 10 109 t, Victoria 4 222 t, and South Australia 702 t, with no recorded production from the other States and Territories.

Queensland

Significant deposits of fluorite in Queensland are associated with Carboniferous–Permian granites in the Mungana, Bullock Creek, Almaden–Emuford areas, and also with Proterozoic granite in the Mary Kathleen area.

Most production has been from deposits associated with Carboniferous–Permian granites in the following localities:

- Mungana–Dargalong area — deposits are aligned in a west-northwesterly direction over a distance of 23 km from Dargalong, 16 km west-southwest of Chillagoe. Most lodes are in gneissic granite. Fluoric Lode is a typical deposit in the area
- McCords Lode — situated 42 km south-southwest from Chillagoe by road
- Bullock Creek area — deposits are mostly located downstream from the Etheridge railway crossing on the Rocky Tate River
- About 15 km southwest of Almaden
- Perseverance Lode — situated on the banks of Crooked Creek, approximately 5 km from Fluorspar siding, about 11 km northwest of Almaden
- Emuford area — production in the Emuford area, situated 50 km west of Herberton, has been from the Mistake mine

The deposits associated with Proterozoic granite 8 km east of Mary Kathleen consist of lenses of green fluorite up to 13 m long and 1.5 m wide associated with minor quartz. These deposits constitute about 10% of a northerly trending shear approximately 4 m in width, extending over a distance of about 2 km (McLeod, 1965; Simpson, 1976).

New South Wales

Although fluorite deposits in New South Wales are generally small, they have been commercially exploitable in the past but mineable high-grade deposits are unknown. Deposits of any significance in the State are associated with:

- silver–lead mineralization in the Broken Hill and Carboona areas
- tin–tungsten mineralization in the New England area
- lead–copper mineralization in the Yass area

The bulk of New South Wales production came from the Carboona mine in the Tumbarumba district and the Woolgarloo mine in the Yass district, but there has been no production from either locality since 1920. Production also occurred in the Broken Hill and New England districts.

At the Carboona mine, located 26 km west-southwest of Tumbarumba, fluorite occurs with quartz as a gangue in a pyritic silver–lead lode. Country rocks consist of Late Ordovician quartzites, mica schists, greywackes with minor shale, sandstone, and tuffaceous beds of the Kiandra Beds that have been intruded by granites of Ordovician and Devonian age.

In the Yass district, fluorite occurs with galena, silver and copper sulfides and carbonates in siliceous lodes hosted by Devonian sediments. The Woolgarloo deposit, about 18 km southwest of Yass, produced 3000 t of fluorite but is now inundated by water behind the Burrinjuck Dam.

In the Broken Hill area, fluorite generally occurs in association with quartz, galena, and sphalerite, and locally dominates gangue in the main lode. However, most production has come from the Mount Elite–Mount Robe area, approximately 35 km north-northwest of Broken Hill where fluorite is present in thin lenticular masses along a well-defined fissure, ranging in width from a few centimetres to a metre, and more than 0.8 km in length. The fluorite, with grades ranging from 71 to 90% CaF_2, is commonly associated with quartz and occasionally with galena and sphalerite. At Mayflower, located about 29 km north-northwest of Broken Hill, fluorite is intimately associated with quartz within wide shear zones in retrograde schists. Fluorspar has also been produced from Yancowinna, situated 29 km northeast of Broken Hill, and from the Thackaringa area, located 32 km west-southwest of Broken Hill.

Fluorite occurs in several localities in the New England district. The most important is The Gulf, situated 23 km northwest of Emmaville, where fluorite occurs in tin–tungsten bearing quartz lodes in the Permian Mole Granite close to its contact with Permo-Carboniferous metasedimentary rocks. Fluorite occurs as a minor gangue constituent with quartz, feldspar, chlorite, topaz, biotite, and minor monazite and tourmaline. In the Torrington district, fluorite occurs as a minor constituent of siliceous pegmatite veins in a roof pendant situated close to an intrusive quartz–topaz rock (McLeod, 1965; MacNevin, 1976).

Victoria

Victoria's fluorite production has been limited to Pine Mountain in the northeast of the State, 40 km northeast by road from Cudgewa and approximately 7 km south of the Murray River. The fluorite occurs along a steeply southerly dipping shear zone along the contact between Ordovician schists and a quartz porphyry dyke which occupies the contact between the schists and a grey biotite granite. Three separate mineralized shoots extend over a distance of 0.8 km. Workings were restricted to a siliceous zone, 8 m wide and 120 m long and carrying fluorite in trace to moderate amounts. The high-grade portion extends along 90 m of the footwall with an average width of 1.7 m. Overall grade is about 40–50% CaF_2 and the main impurities are quartz, silicified country rock, galena, and some sphalerite.

Veins containing fluorite are also associated with Middle Devonian limestone at a locality north of Buchan (McLeod, 1965; Bowen, 1976).

South Australia

The only fluorspar production in South Australia was from a deposit within Precambrian metasediments at Plumbago, 56 km north of Mannahill, where veins of quartz and purple fluorite were worked over a distance of 100 m. One vein having a width of one metre assayed 78.3% CaF_2 and 19.5% SiO_2. Approximately 1.5 km to the west, a similar vein about 80 m long within granite contained massive purple fluorite. A channel sample at the widest point of the vein assayed 97.7% CaF_2 and 1.5% SiO_2 (McLeod, 1965; Olliver, 1976).

Western Australia

Western Australia has no recorded production of fluorspar, but several large deposits of commercial significance have been discovered at Speewah in the Kimberley Basin and at Meentheena in the Pilbara Craton. These deposits and other occurrences in Western Australia are discussed in the next chapter.

Prices and outlook

Prices

According to dollar value of the day prices quoted in the journal *Industrial Minerals*, the price of acid-grade fluorspar has gone up from around $160 per tonne in 1984 to around $370 in 1995. There was a notable price rise from 1984 to 1986, and then a steady increase from 1989 to 1994. The price of metallurgical-grade fluorite has remained within the range $85–115 per tonne from 1983 to 1990 with a relatively sharp rise to $185 in 1991 (Fig. 22). In 1995, the price of metallurgical-grade fluorite was around $215 per tonne. The price of ceramic-
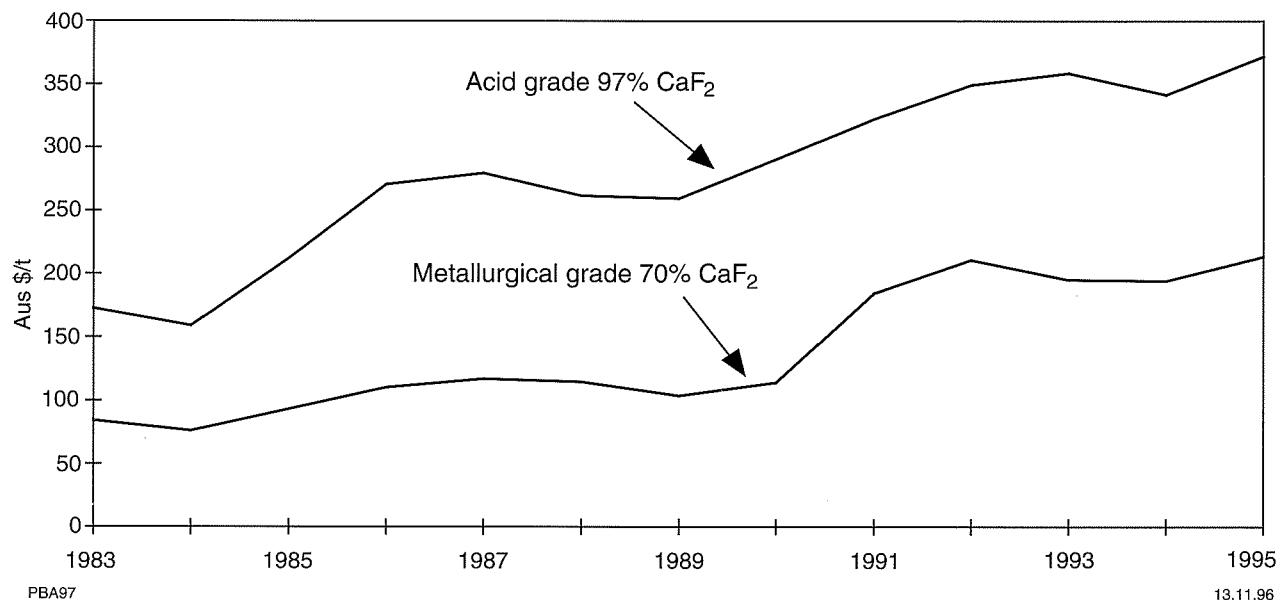
Figure 22. Fluorspar prices 1983–1995 ($ value of the day). (Source of data: Industrial Minerals Journal, 1983 to 1995)

grade fluorite has not been quoted in *Industrial Minerals*, but it can be assumed to be between acid and metallurgical grades.

Outlook

Prior to 1990, there was moderate demand for fluorspar due to strong markets for acidspar for the chemical and aluminium industries, and for metspar for the steel and allied industries. During the second half of 1990, there was an apparent decrease in demand for acidspar due to the impact of the September 1987 Montreal Protocol which called for consumption restrictions on specified chlorofluorocarbons (CFCs). Further restrictions were imposed at the International Ministerial Conference in London in March 1989. At the UNEP working party meeting in Nairobi towards the end of 1989, EEC representatives called for a 50% reduction of CFCs by the end of 1996 and a total ban by the year 2000. Later moves called for an even earlier phase out of CFCs, by the end of 1996. Because HCFC-22 is not a fully halogenated CFC and has a much lower ozone-depletion potential, it will be phased out at a later date, but earlier than had originally been proposed. German CFC producers have taken the lead in Europe in banning the production and use of fully halogenated CFCs by 1995 and have already cut production significantly (Griffiths, 1990; Hodge, 1990, 1991). As the market for aerosols using CFC propellants has virtually disappeared, there has been a significant cut-back in hydrogen fluoride (HF) capacity. The European Community Manufacturers of Domestic Refrigerators and Freezers (CECED) announced that new fridges will contain 50% less CFCs in foam insulation, and in commercial refrigeration specifications, CFC 12 is being replaced with HCFC 22.

Although the abolition of CFCs has adversely affected the market, replacement fluorocarbon materials are expected to experience a market growth of 1–2% per year throughout the 1990s (Skillen, 1993). From 1994 it is anticipated that there will be an improvement in the demand for HF in line with the introduction of new fluorocarbon compounds. However, marketing trends during 1991 indicated that the future is uncertain due to factors such as the smaller than anticipated demand for more fluorine (per unit) for alternatives to CFCs due to cost and technical factors encouraging reclamation/ recycling and substitution. Griffiths (1993) observed that the trends in 1992 and 1993 were continuing to be gloomy with declining demand being experienced for fluorocarbons, uranium hexafluoride processing, petroleum alkylation, and production of chemical derivatives. A countering factor is the potential for growth in consumption for both CFCs and alternatives by developing countries, notably China and India, who are not signatories to the Montreal Protocol and its revision. Indian consumption of CFCs is predicted to be around 20 000 t by 1996 and 45 000 t by 2010 (Industrial Minerals, 1995).

There are other positive signs for acidspar outside the CFC and CFC replacement markets. For instance the market for polytetrafluoroethylene (PTFE — the largest volume fluoropolymer), is showing growth in developing countries such as China and India, and demand for fluorinated ethylene propylene (FEP), used in high-performance cable insulation, is growing at over 20% per annum in the USA (Industrial Minerals, 1995).

About 3% of the non-captive HF produced in North America is consumed in the manufacture of aluminium fluoride for alumina production. The market has now softened due to a decrease in production and lower prices

of aluminium but it has been predicted that the aluminium industry will increase its demand for fluorspar in the western world, from 465 000 t in 1993 to an estimated 535 000 t by the year 2000 (Griffiths, 1990, 1993).

Consumption of metallurgical-grade fluorspar by the steel industry also decreased sharply in 1991 due to an overall drop in steel output and also to continuing changes in technology, improvement in efficiencies, and tighter raw material specifications (Miller, 1991).

Hodge (1993) stated that, although the supply/demand situation apparently moved towards equilibrium during 1992, there is no room for complacency or undue optimism because world fluorspar consumption is likely to remain in a trough ranging from 3.92 to 4.01 Mt per year until 1996. While forecasting a modest recovery to 4.48 Mt in the year 2000, Hodge cautioned that there would be no room for new operations, and even suggested that there may be additional casualties amongst existing producers without an improvement in the prevailing adverse market conditions.

A concern to producers in relation to maintaining viable operations is price cutting by Chinese acidspar suppliers. The European Community decided during February 1993 to impose a preliminary anti-dumping duty of ECU10.9/t (US$13/t at an exchange rate of ECU1 = $1.20), on the cif price of Chinese acidspar imports, as a step towards improving market conditions in Europe. A minimum floor price was subsequently fixed at ECU93.4/t (US$ 112/t) . In April 1993, the Mexican Government imposed a provisional 16% *ad valorem* duty on the price of imported Chinese acidspar, although such measures can apparently be circumvented.

Fluorite in Western Australia

Introduction

Although fluorite occurs in many regions of Western Australia (Fig. 23), no production has been reported. The only two potentially viable fluorite deposits in Western Australia are located at Speewah and Meentheena, both of which were discovered in the early 1970s. Both deposits, and most of the other known fluorite occurrences in Western Australia, are vein-type deposits related to hydrothermal processes.

For this discussion, the fluorite occurrences in Western Australia are grouped under the following tectonic units:

Kimberley Basin
Pilbara Craton
Southern Cross Province – Yilgarn Craton
Tectonic units with minor occurrences
Eastern Goldfields Province – Yilgarn Craton
West Yilgarn (Murchison area) – Yilgarn Craton
West Yilgarn (southwestern area) – Yilgarn Craton
Gascoyne Complex
Albany–Fraser Orogen
Halls Creek Orogen
King Leopold Orogen
Ashburton Basin
Musgrave Complex
Ord Basin

Kimberley Basin

Regional geology

The Kimberley Basin covers an area of 160 000 km² in the northern, western and central Kimberley region. The main components of its largely Early Proterozoic sedimentary succession are shown on Figure 24 and the main geological units are the Hart Dolerite, Crowhurst Group (youngest sedimentary unit), Bastion Group, Kimberley Group, and the Speewah Group (oldest sedimentary unit).

The oldest unit, the Speewah Group, is exposed on the upturned southeastern and southwestern margins of the basin. The unit is about 1 km thick and consists of a sequence of quartzose and feldspathic arenite, interbedded with mudstone and minor acid volcanics.

The Kimberley Group consists of a basal fluvial sandstone, separated by a local unconformity from overlying, mature and laterally uniform, shallow marine sandstone and siltstone, tholeiitic basalt and beds of dolomite.

The Bastion Group, confined to the eastern Kimberley, consists of purple and green shale, siltstone, and small amounts sandstone and dolomite, overlain by massive quartz sandstone. Conformably overlying the Kimberley Group are dolomite, purple and green shale, siltstone and sandstone of the Crowhurst Group.

' The Early Proterozoic Hart Dolerite consists of several composite sills with individual thicknesses of up to 1800 m. These are typically tholeiitic, differentiated, and have up to 250 m of granophyre at the top. The dolerite intrudes the Speewah and Kimberley Groups, the former more extensively than the latter. A more detailed description of the geology of the Kimberley Basin is given by Griffin and Grey (1990).

The largest fluorite deposit in Western Australia is located at Speewah in the Kimberley Basin.

Speewah

Location: Lat. 16°24'27"S, Long. 127°59'02"E (A)

Historical background

Fluorite was first recorded in the Speewah area of the upper Dunham Valley in about 1905 (Simpson, 1951). In 1927, T. Blatchford visited the area and found two main occurrences of fluorite mineralization. One was 19 km north-northwest of Mount Yates, east of the upper Pentecost River, the other was about 11 km south-southwest, about 4 km northwest of Speewah Homestead.

Fluorite in the first occurrence is in parallel veins varying from 25 cm to 60 cm in width, with a northerly strike and vertical dip. Although some fluorite veins contain patches of galena, much of their bulk is pure fluorite, varying in colour from colourless to white and bluish green. At the second locality, three northerly striking fluorite veins occur in a brecciated zone. The veins are persistent along strike but are generally narrow and contain appreciable galena as an impurity, although pure fluorite is also present (Blatchford, 1928).
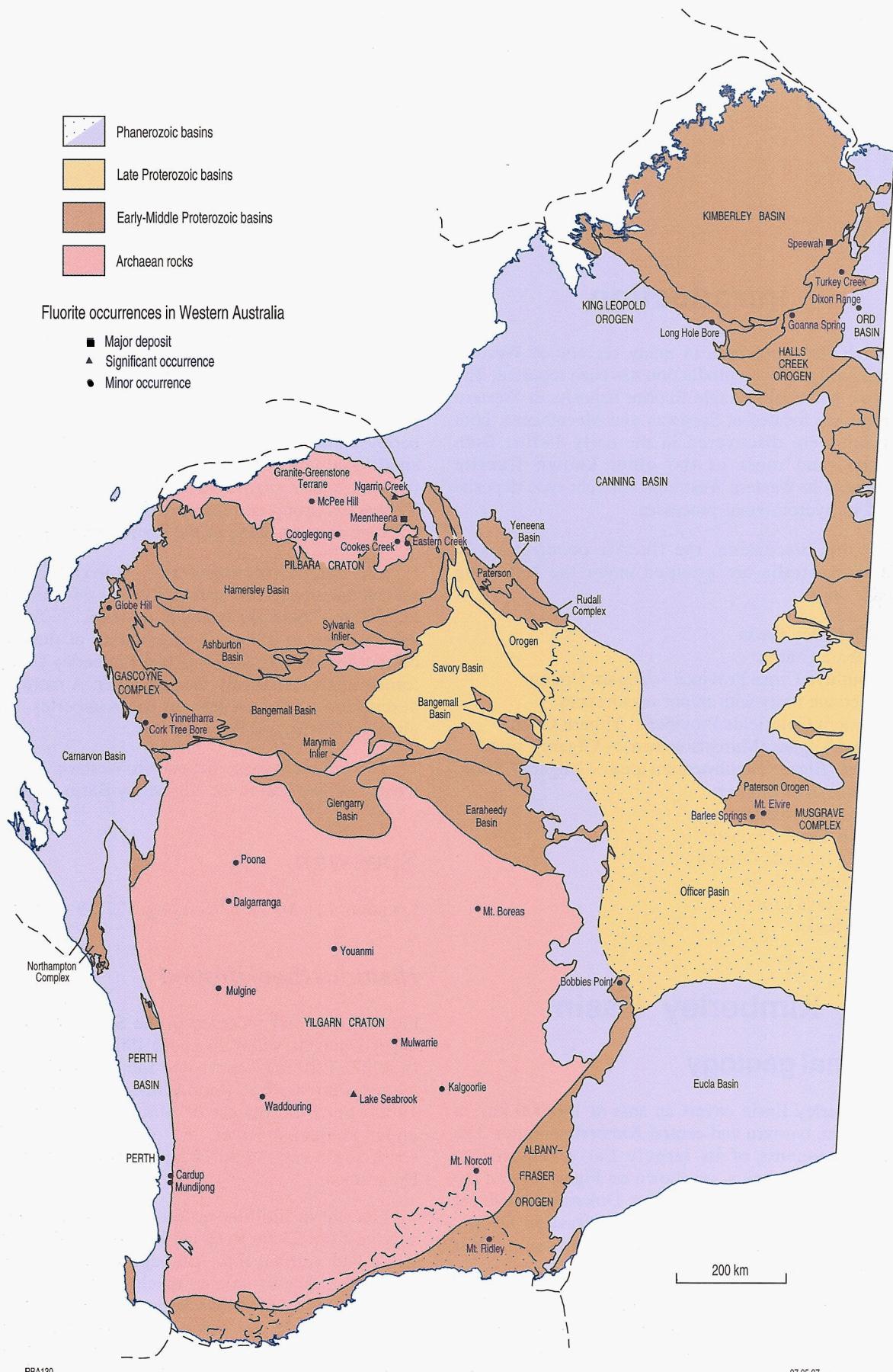
**Figure 23. Fluorite occurrences in Western Australia**
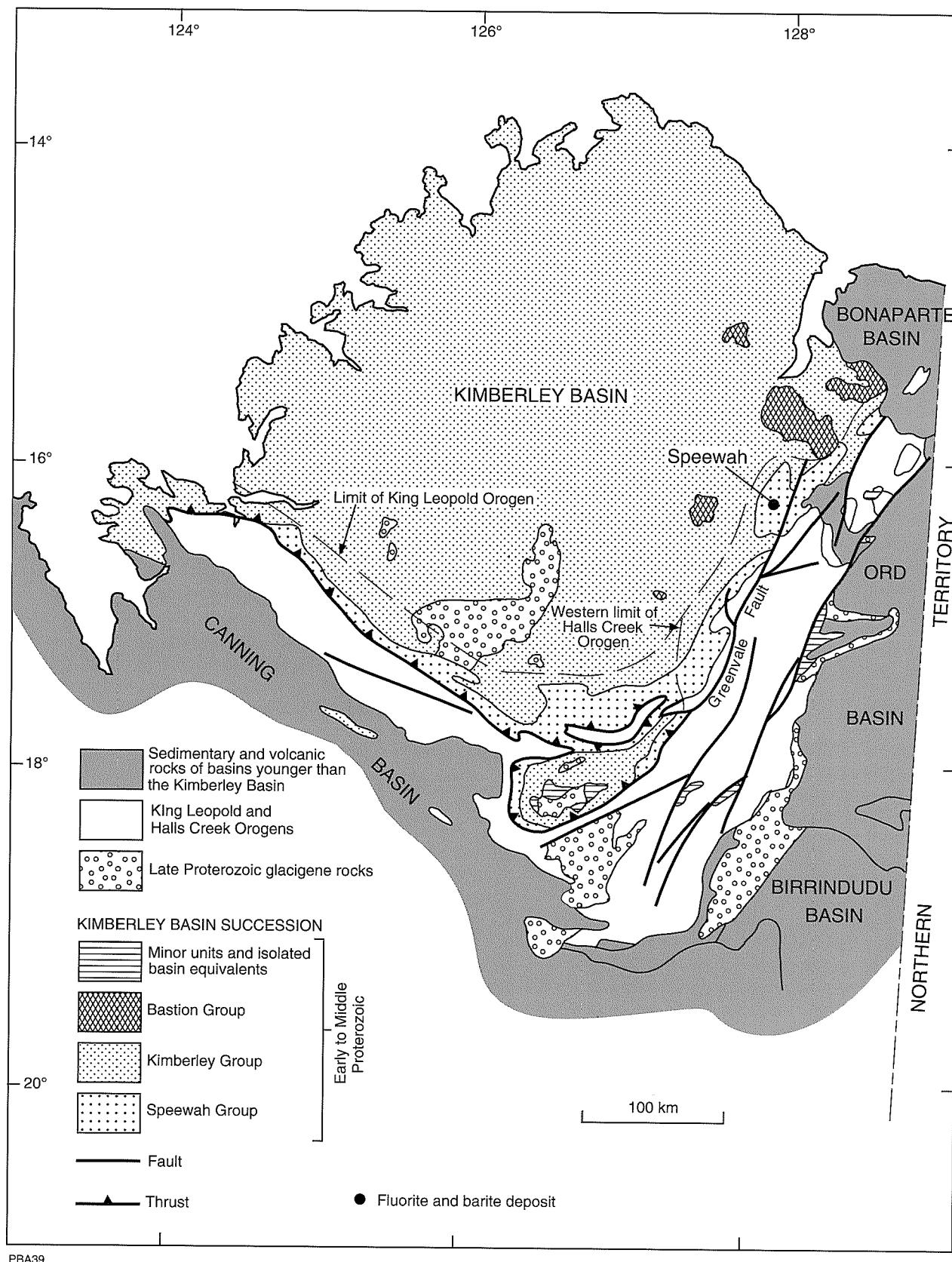
Figure 24. Simplified geological map of the Kimberley region (*after* Griffin and Grey, 1990)

The area was subsequently explored by a number of companies for base metals, uranium, and fluorite. Some of the prospectors or companies which held tenements in the area were Durack and Martin, Planet Gold Ltd and Pacific Mines Ltd (later amalgamated with Durack Mines Ltd), Whim Creek Consolidated NL, Northwest Mining NL, Haoma Gold Mines NL, Uranium Consolidated and Shane Holdings NL, Gem Exploration and Minerals Limited, Mining Advisers Pty Ltd, Stafford Holdings, Great Boulder Mines, North Kalgurli Mines and Western Mining Corporation.

Exploration by Great Boulder Mines Ltd/North Kalgurli Mines Ltd during 1972 led to the discovery of most of the fluorite deposits in the area (Schultz, 1972). Work included 24 diamond drill holes, 86 airtrack holes and 15 costeans in the Main Zone area.

The Speewah Prospect, which contains the main area of fluorite mineralization, was acquired in 1987 by the current tenement holder Elmina NL. During 1989, Elmina completed 28 RC holes and four diamond holes, and in 1990 the company commissioned Gemell Mining Engineers to carry out a study on commercial aspects of the deposit. At the end of 1995, Elmina's project area remained extensive, with three mining leases over the defined fluorite deposits, and numerous exploration licences covering the surrounding area. The important zones of fluorite mineralization are indicated on Figure 25.

Geology

The Speewah Valley, located within the Kimberley Basin close to the western edge of the Halls Creek Orogen (Fig. 24), is incised into the Hart Dolerite, which occupies the core of the Speewah Dome (32 km long, 13 km wide and trending 010°). The dolerite intrudes feldspathic arenite, chloritic siltstone and minor acid volcanics of the Speewah Group.

The Speewah area is dominated by a system of intersecting faults striking about 180° and 210° which appear to be splays of the Greenvale Fault (Fig. 24). In the Speewah deposit, the main mineralized areas (Main Zone, and principal barite zone), are confined to a single fracture zone striking 210°. Faults trending 180° can be traced as narrow zones of brecciation with easterly or westerly dips which are known to contain fluorite and some barite mineralization (Fig. 25).

Earlier workers assumed the source of fluorite to be the upper granophyric phase of the Hart Dolerite. Later work suggested that this rock is related not to the Hart Dolerite but rather to a major granite intrusion (Elmina, 1989). Further geological mapping, petrographic work, multi-element analyses and geophysical work indicated that the granites are pink, coarse grained, equigranular and locally granophyric or magnetite-rich, with distinct alkalic chemistry. It was recognized that the mineralized ridges are characterized by the presence of a potash feldspar–biotite rock, which may represent either shoshonitic lamprophyre dykes or metasomatized dolerite/gabbro. At least two generations of quartz veining were identified in

the mineralized area, the second of which is associated with fluorite mineralization. Minor galena and chalcopyrite are present in fault and brecciated zones.

A poorly sorted, red-brown, lithic sandstone which contains clasts of quartz, K-feldspar, alkali granite, 'lamprophyre', chert and fine-grained sediments occurs within fault blocks of dolerite. Euhedral fluorite crystals are occasionally observed in the sandy matrix of the sandstone. Thin basaltic flows and tuffs are interbedded with the sandstone, which higher in the sequence becomes arkosic, less lithic and contains well-preserved ripple marks.

More recent work by Elmina has identified extensive epithermal quartz (together with fluorite, barite and carbonate) vein and breccia systems within the Speewah Dome. It is thought that these veins and breccias may represent a large upper-level hydrothermal system associated with volcanic vent-like bodies which may also be prospective for gold and base metals.

This work, combined with studies of airborne magnetic data, and analysis of fracture patterns, has led to the development of a new model to explain the origin of the Speewah Dome. This proposes that the Speewah structure was a resurgent dome in a caldera complex. Recently identified fracture patterns are thought to be indicative of caldera collapse, resurgence and subsequent rifting. These fractures are thought to be conduits for later hydrothermal fluids which formed the epithermal quartz–carbonate–fluorite–barite vein systems containing anomalous values for gold, silver and base metals. (Rogers, 1996).

Mineralization

Narrow, tabular, near-vertical fluorite veins occur generally in variable-width shear zones locally flanked by chloritically altered, lower grade material in stockworks and stringer veins. When fresh, fluorite is grey or white, but weathers to pale green.

Fluorite mineralization is known in four areas; Main Zone, West Zone, Northwest Zone and Central Zone (Fig. 25 and Elmina, 1993). Veins in these zones consist of mainly fluorite (20–80% in tabular veins), with quartz, and occasional barite and silicified fragments of country rock. Shears in the Northwest and West Zones are marked by higher barite contents. Chalcopyrite is commonly associated with wall-rock stringer veins and stockworks and galena is found only in the West Zone. A total of 14 fluorite veins are known: A to G, Cross, East, South, West, West Extended, North and Central. Of these, A and B in the Main Zone have been the focus of exploration and ore-reserve estimates.

Rogers (1996) has proposed a new age for the fluorite mineralization previously considered related to the Early Proterozic Hart Dolerite. Recent field mapping has located fluorite veins intruding the Early Cambrian Antrim Plateau Volcanics clearly showing that the emplacement of the fluorite was post-Early Cambrian and furthermore, samples of galena collected from all
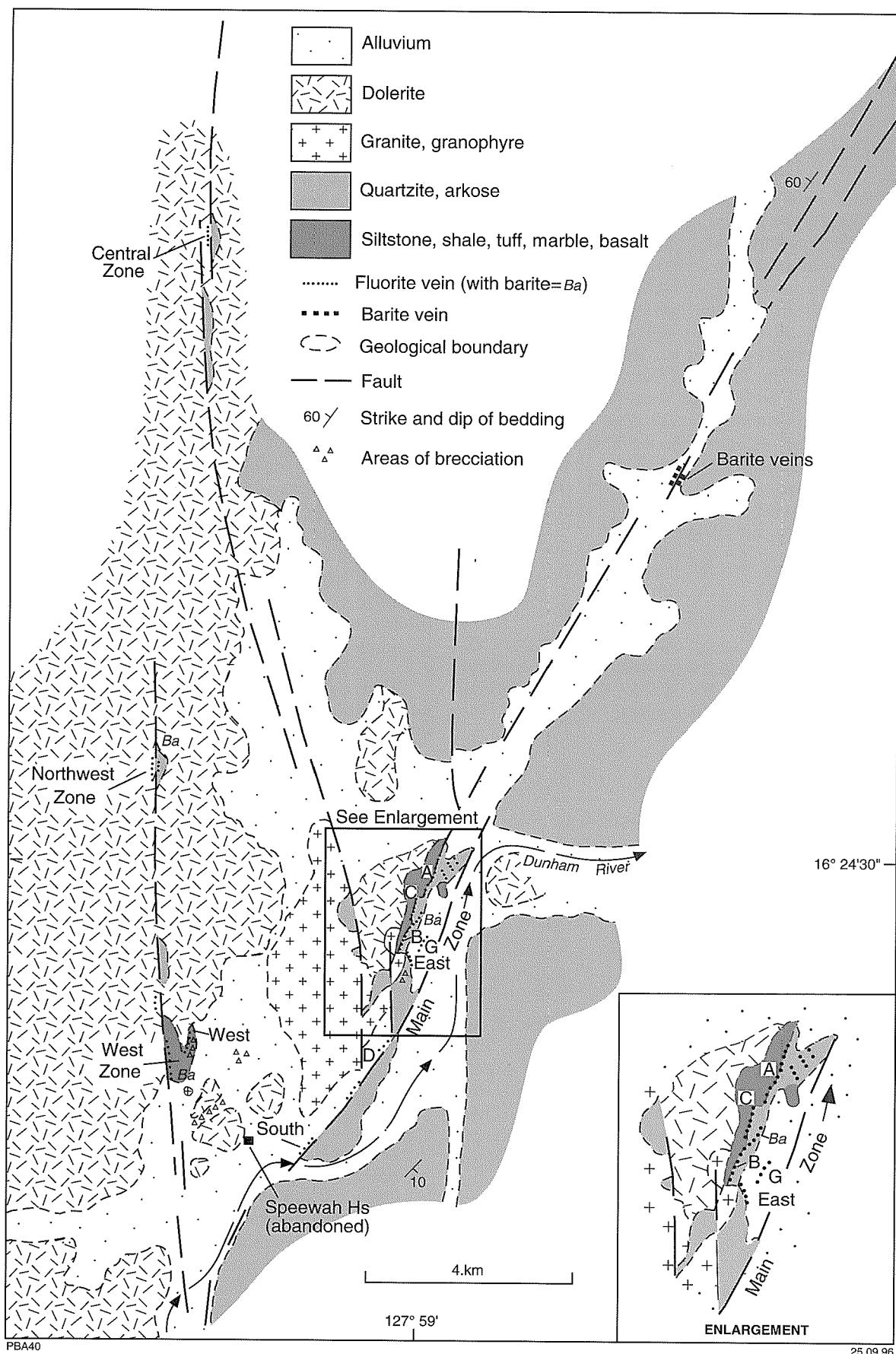
Figure 25. Simplified geological map of the Speewah area showing zones of fluorite and barite mineralization (modified *after* Elmina NL, 1990)

known fluorite occurrences shown in Figure 25, have consistently given age dates from Mesozoic to Tertiary (131 to 15 million years). Work is continuing to date the fluorite directly.

1. Main Zone

The Main Zone (Fig. 25) is underlain by massive Hart Dolerite in the west, and in the east by granophyre containing metasedimentary xenoliths. On the eastern edge of the granophyre are areas of siltstone and arkose. A major north-northeasterly trending shear zone forming a splay of the Greenvale Fault, cuts through the area along or immediately adjacent to the granophyre–sediment contact and contains at least ten fluorite veins over a strike length of 7 km. The main fluorite veins are within or adjacent to this zone. Three veins A, B and C within this zone form a prominent linear ridge over 2 km long (Fig. 26). A and B veins are about 800 m and 700 m in length respectively, with widths of 20–25 m, and are interpreted to have northerly plunges with variable dips from 75° west to 50° east (Fig. 28). C vein is smaller and occurs between veins A and B.

2. West Zone

This 1–3 m-wide zone, approximately 5 km southwest of the Main Zone, outcrops discontinuously over a northerly trending strike length of at least 200 m. Veins of unknown extent occur in subparallel fault zones.

3. Northwest Zone

Located about 6 km west-northwest of the Main Zone, the Northwest Zone consists of three northerly trending subparallel veins containing both fluorite and barite which outcrop intermittently over a total strike length of 500 m. Veins vary from 3 m to 6.5 m in width.

4. Central Zone

This zone, situated about 14 km north-northwest of the Main Zone, contains a narrow fluorite and quartz vein. The northern end of the vein comprises brecciated quartz dolerite with traces of galena, and to the south the vein is brecciated with fluorite cement and fine fluorite veinlets. The associated shear zone outcrops discontinuously for about 150 m along the western edge of a northerly trending ridge.

Origin

The geology, mineral assemblages, alteration patterns, and mode of occurrence of mineralized veins suggest that the fluorite mineralization is related to hydrothermal fluids derived from the granophyre or alkali granite. Upward-moving mineralizing fluids could have been trapped in favourable structures such as shear and fracture zones.

Quality

Blockley (1972) estimated from surface inspection and sampling that the ore grade from the main deposits was high, but there was a marked discrepancy in grade between surface samples and those from drill holes. Surface samples had an average grade of 75% CaF_2 over an average width of 2.6 m, whereas the average of five drill intersections was only 34% CaF_2 over 3.5 m. Blockley's observations were based only on drill samples from A vein (the only results available at the time). He suggested that the difference may be due in part to the leaching of gangue minerals from outcrop, thereby enhancing the grade of fluorite obtained in surface samples. Furthermore, he suggested that drill samples probably included some lower grade stringer veins marginal to the main shear which may not have been included in surface samples. Another possible reason for the difference was a decline in fluorite grade at depth in the veins.

Later work indicated that CaF_2 content (of 29 samples) varied from 4% to 91% with an average of 41% (Elmina, 1993). Ore samples from the footwall, hanging wall, and other veins associated with A, B, C and D veins were tested by heavy-media separation and flotation to ascertain amenability of this fluorite to beneficiation. These tests revealed that an acid grade concentrate of minimum 98% could be achieved by flotation techniques.

Elmina (1993) gave the following summary of the anticipated metallurgical processes which would be undertaken in a processing facility:

- Run-of-mine feed would be delivered from a stockpile to a crushing circuit consisting of primary and secondary crushers in closed circuit with a screened product being delivered to a ball mill.
- Ball mill product would be classified by cyclone, with underflow returning to the mill, and overflow being transferred to the flotation circuit. A series of rougher and cleaner flotation cells would provide the major concentration during the process. The reagents would possibly include a collector, starch, sodium silicate, tannin, and soda ash.
- Following thickening, the flotation concentrate would be dewatered by pressure filtrator.

Resources

An assessment by Great Boulder Mines Ltd resulted in an indicated resource of 964 000 t with an average grade of 49% CaF_2 and an inferred resource of 677 000 t with an average grade of 43% CaF_2. Low-grade near-surface ore adjoining B vein amounted to 132 000 t averaging 21% CaF_2. This assessment was based on 2014 m of drilling (25 diamond drill holes) and 1855 m of shallow percussion holes (Schultz, 1973). Further reverse circulation and diamond drilling carried out by Elmina NL in 1989 proved a larger resource of 3.87 Mt for A, B and C veins in the Main Zone, at a cut-off grade of 13% CaF_2 to a depth of 60 m below the river level datum. The
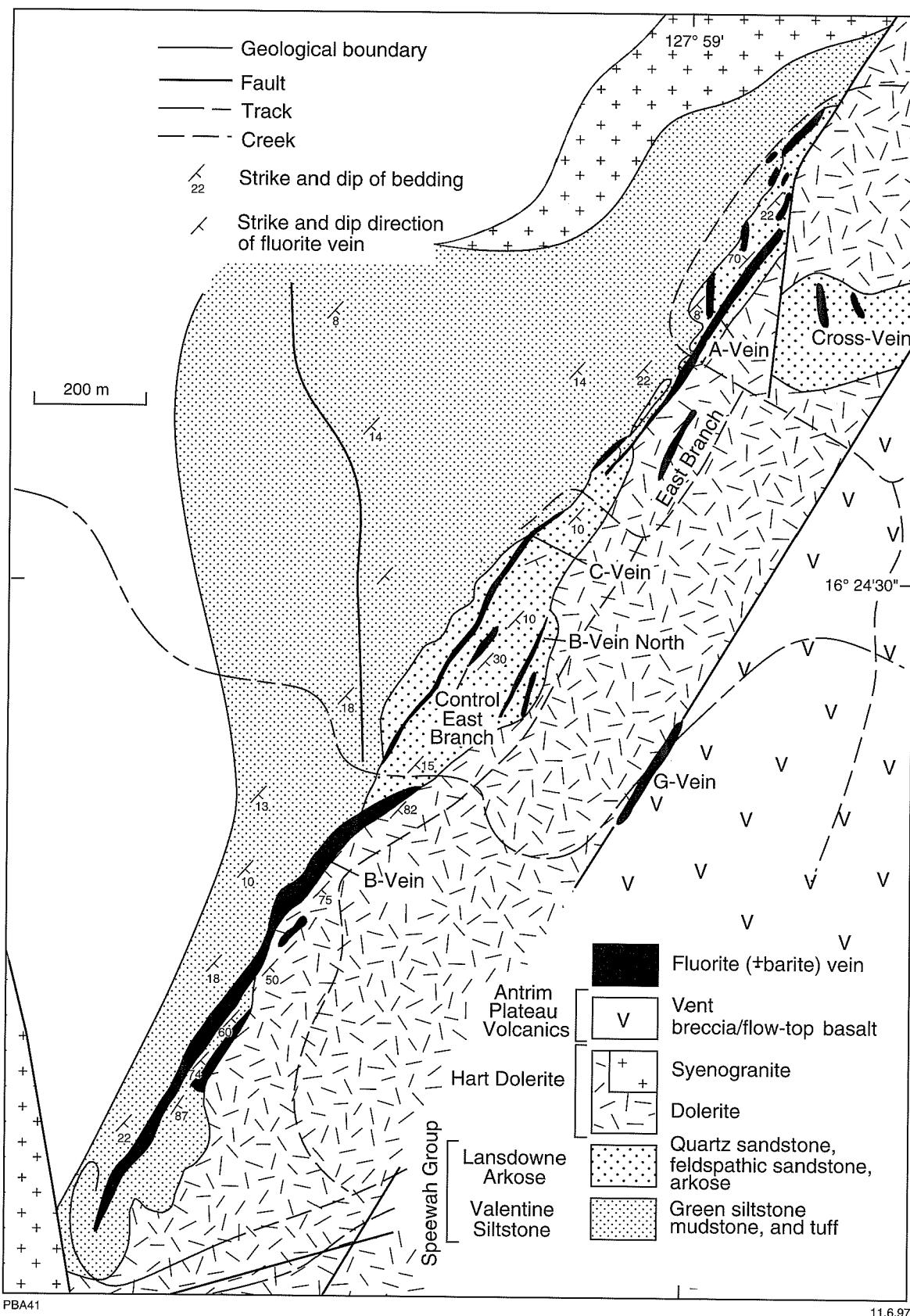
Figure 26. Geology of the A, B, and C veins, Main Zone in the Speewah fluorite deposit (modified after Elmina NL, 1994)

measured resource was 1.87 Mt at 25.8% CaF$_2$, the indicated resource 0.41 Mt at 24.2% CaF$_2$ and the inferred resource 1.59 Mt at a cut-off grade of 13% CaF$_2$.

Pilbara Craton

Regional geology

The regional geology of the Pilbara Craton was briefly discussed in Chapter 4. More detailed descriptions are given by Hickman (1981, 1983), Griffin (1990a) and Trendall (1990).

Meentheena, located within the Hamersley Basin, is the most important fluorite occurrence in the Pilbara Craton. The Eastern Creek occurrence is also in within the basin, while other occurrences at Ngarrin Creek, McPhees Range, Cooglegong, and Cookes Creek are within the Pilbara Granite Greenstone Terrane.

Meentheena

Location: Lat. 21°14'20"S, Long. 120°28'10"E (A)

Background

Meentheena is situated on the Nullagine River, 220 km east-southeast of Port Hedland and 75 km east of Marble Bar. Although a mineral was noted by station owners in the late 1960s, it was not recognized as fluorite until late 1970 (Cheeseman, 1972). The area was pegged and explored by Barakee Mining and Exploration Pty Ltd in December 1971 after an examination of the area by Dr E. A. Schiller. In December 1972, Barakee Mining and Exploration formed a joint venture with Ashburton Oil NL to carry out exploration work. The two companies subsequently formed Meentheena Fluorite Exploration Pty Ltd which carried out more exploration work in 1972–1973 (Schiller et al., 1973). This included detailed geological mapping and costeaning followed by the excavation of fluorite-bearing material. The main objective of this program was to determine the economic potential of the deposit. The mineralized area is currently held under exploration licence.

Geology

Fluorite mineralization is mainly in the form of veins and fissures in folded and faulted volcanics in the lower part of the Late Archaean Fortescue Group (Fig. 27) (Arndt et al., 1991). The stratigraphy of the Fortescue Group in the Meentheena area is given in Table 17.

All fluorite deposits are within the lowest formation of the Fortescue Group, the Mount Roe Basalt, which consists mainly of a thick sequence of agglomerate, lapilli tuff and gritty tuff to the west of Nullagine River, and

primarily basalt and andesite to the east. Towards the base of the Mount Roe Basalt unit, porphyritic basalt is predominant. Many fragments in the agglomerate, such as quartzite, chert, granite, basalt and schist, are thought to be derived from the underlying Archaean basement, and the agglomerate represents an explosive phase of volcanism which deposited pyroclastic rocks over most of the Pilbara. Hickman (1974) suggested that the underlying Archaean basement is probably no more than 100 to 200 m below the Mount Roe Basalt, and thus the fluorite deposits occur on a structural high.

The Meentheena Fault — a high-angle, northerly striking fracture with a dextral displacement of approximately 4 km — truncates the structural high zone containing the fluorite veins (Fig. 27). A well-developed conjugate system of minor faults occurs parallel and oblique to the Meentheena Fault.

Mineralization

Fluorite occurs generally as veins and fracture fillings (Fig. 29), striking 060° and 135° within the conjugate fracture system, and in general concentrated on the northwest flank of an open, irregularly shaped elongate

Table 17. Stratigraphy of the Late Archaean Fortescue Group in the northeast Pilbara (after Thorne and Trendall, in prep.)

Formation	Lithology
Jeerinah Formation	
Roy Hill Member	Carbonaceous shale, sandstone,
Warrie Member	carbonate, mafic and felsic
Woodiana Member	volcanic rock
Maddina Basalt	
Kuruna Member	Dark grey mottled basalt, some
	vesicular flows
Tumbiana Formation	
Meentheena Member	Siliceous limestone, pisolitic tuff
Mingah Member	with minor siltstone and shale
Kylena Basalt	Massive, often vesicular basalt
	and andesite

~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ unconformity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

Hardey Formation	
Bamboo Creek Member	Sandstone, conglomerate, tuff
	and shale (includes grey felsic
	porphyry, partly amygdaloidal)

~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ unconformity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

Mount Roe Basalt	Basaltic and andesitic
	amygdaloidal lava with thick
	breccia and lapilli tuff (includes
	some felsic lava)

~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ unconformity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

EARLY ARCHAEAN BASEMENT   Granite and greenstone

PBA42   14.11.96

| 500 m |

Quaternary ▨ Alluvium

Late
Archaean
Fortescue
Group

Maddina Basalt

Tumbiana Formation carbonate

Tumbiana Formation tuff

Kylena Basalt

Hardey Formation
Sandstone and grit

Tuff, shale and siltstone

Felsic porphyry
Mount Roe Basalt
Felsic lava

Agglomerate, lapilli tuff, tuffaceous grit

Shale

——————— Geological boundary

— — — Fault

_⌐15 Strike and dip of bedding

- - - - - - Track

Watercourse

▬▭▬▭▬▭ Rhyolitic dyke

···········q Quartz vein
no fluorite mineralization

Fluorite vein, wide line where
thickness exceeds one metre

Cu, Pb Copper, lead occurrences

Figure 27. Geology of the area around the Meentheena fluorite deposits (modified *after* Hickman, 1974)

Figure 28. Outcrop of steeply dipping A vein, Main Zone, Speewah deposit

PBA 144   04.06.97

Figure 29. Veins of purple fluorite with cross-cutting quartz veins — Meentheena deposit

dome. A typical vein consists of an outer zone of quartz with a wide central zone of interlayered quartz and coarse-grained massive anhedral fluorite (Hickman, 1974). Fluorite zones within the veins tend to pinch-and-swell. Fluorite in fresh exposure is white to colourless but weathers to pale to creamy brown. Schiller et al. (1973) described vein mineral assemblages from footwall to hanging wall as follows:

1. Quartz
2. Quartz–fluorite selvage
3. Fluorite 'pillows' and nodular masses with ?chert centres and a radiating crystalline structure
4. Massive fluorite with scattered sericite and minor carbonate
5. Altered rhyolite cut with late-stage fluorite
6. Propylitically altered agglomerates cut by late-stage fluorite stringers

Hickman (1976a) stated that fluorite occurs in quartz veins up to 5 m in width and up to 1600 m in length. Some veins carry bodies of pure fluorite 2 m wide and up to 200 m long (Fig. 27). Associated minerals in some localities are galena, malachite, brochantite, and atacamite. Thick veins of calcite are present at the periphery of the mineralized area, but barite is not detected. Schiller et al. (1973) noted that the fluorite veins are located within an area of 4.5 km × 3.0 km and occur as groups or clusters rather than as individual linear features.

Origin

Schiller et al. (1973) suggested that fluorite mineralization is genetically related to brecciated and hydrothermally altered rhyolite dykes and sills. They noted that fluorite continues into the host rock basalt for short distances, and is associated with a sulfide halo comprising minor galena, chalcopyrite and chalcocite.

However, Hickman (1974) stated that the structural environment of the Meentheena fluorite deposits is similar to that of many other fluorite mining areas, and concluded that the fluorite is epigenetic and was deposited in a fracture system from ascending hydrothermal solutions. He suggested that the source of fluorite was either a deep seated Proterozoic alkali intrusion beneath the Meentheena area, or a fluorite-rich Archaean granite underlying the area of the deposits.

Grade and reserves

Trial mining of a vein west of the Nullagine River gave a recovery of 500 t of ore grading on average 75% CaF_2. Previously this material had been visually estimated to be over 90% CaF_2 (Schiller et al., 1973) but microscopic examination of the ore revealed the presence of inclusions of lower grade fluorite intergrown with quartz with a maximum of 60% fluorite. Analyses of three samples collected from veins in costeans are given on Table 18. These samples contain significant quartz and the analyses

indicate 27% F and 5.93 to 36% SiO_2. The chemical compositions suggest a CaF_2 percentage of around 55%, although it is not possible to estimate a precise value due to the impure nature of the samples.

Hickman (1974) estimated reserves of the larger veins at 13000 t per vertical metre of 50% CaF_2 ore, and minimum total reserves of the entire Meentheena area at 30 000 t per vertical metre of mostly low-grade ore.

Schiller et al. (1973) calculated that there are 132 450 t of fluorite at 80% CaF_2 from all the veins in the prospect if mined to a depth of 17 m, assuming a

Table 18. Chemical analyses of Meentheena fluorite

GSWA no.	117397	117398	117399
		%	
SiO_2	7.45	36.00	5.93
TiO_2	0.03	0.02	0.03
Al_2O_3	0.67	3.02	0.45
Fe_2O_3	<0.05	0.28	<0.05
FeO	<0.05	<0.05	<0.05
MgO	0.31	0.38	0.30
CaO	65.10	40.80	67.60
Na_2O	0.08	0.12	0.07
K_2O	0.21	1.00	0.15
MnO	<0.01	0.04	0.01
P_2O_5	0.05	0.03	0.04
S	<0.01	<0.01	<0.01
CO_2	0.29	0.07	<0.10
F	27.00	27.00	27.00
H_2O^+	0.28	0.71	<0.01
H_2O^-	0.04	0.09	0.08
Trace elements (ppm)			
Ag	<2	<2	<2
As	<4	<4	<4
Ba	619	952	235
Bi	<4	<4	<4
Cd	<5	<5	<5
Ce	19	20	12
Co	<4	4	<4
Cr	8	8	5
Cu	13	11	11
Ga	<3	11	<3
Ge	<3	<3	<3
La	36	6	9
Mo	14	7	2
Nb	<7	<7	<7
Ni	4	8	6
Pb	7	77	4
Rb	11	56	8
Sb	<4	<4	<4
Sn	<4	<4	<4
Sr	169	49	55
Ta	<6	<6	<6
Te	8	<6	<6
Th	<2	<2	<2
U	<2	<2	<2
V	5	7	9
W	<4	<4	<4
Y	51	31	29
Zn	<3	10	4
Zr	<5	8	8

Analyses: Chemistry Centre (W.A.)
Sample locations — 21°14'20"S, Long. 120°28'11"E
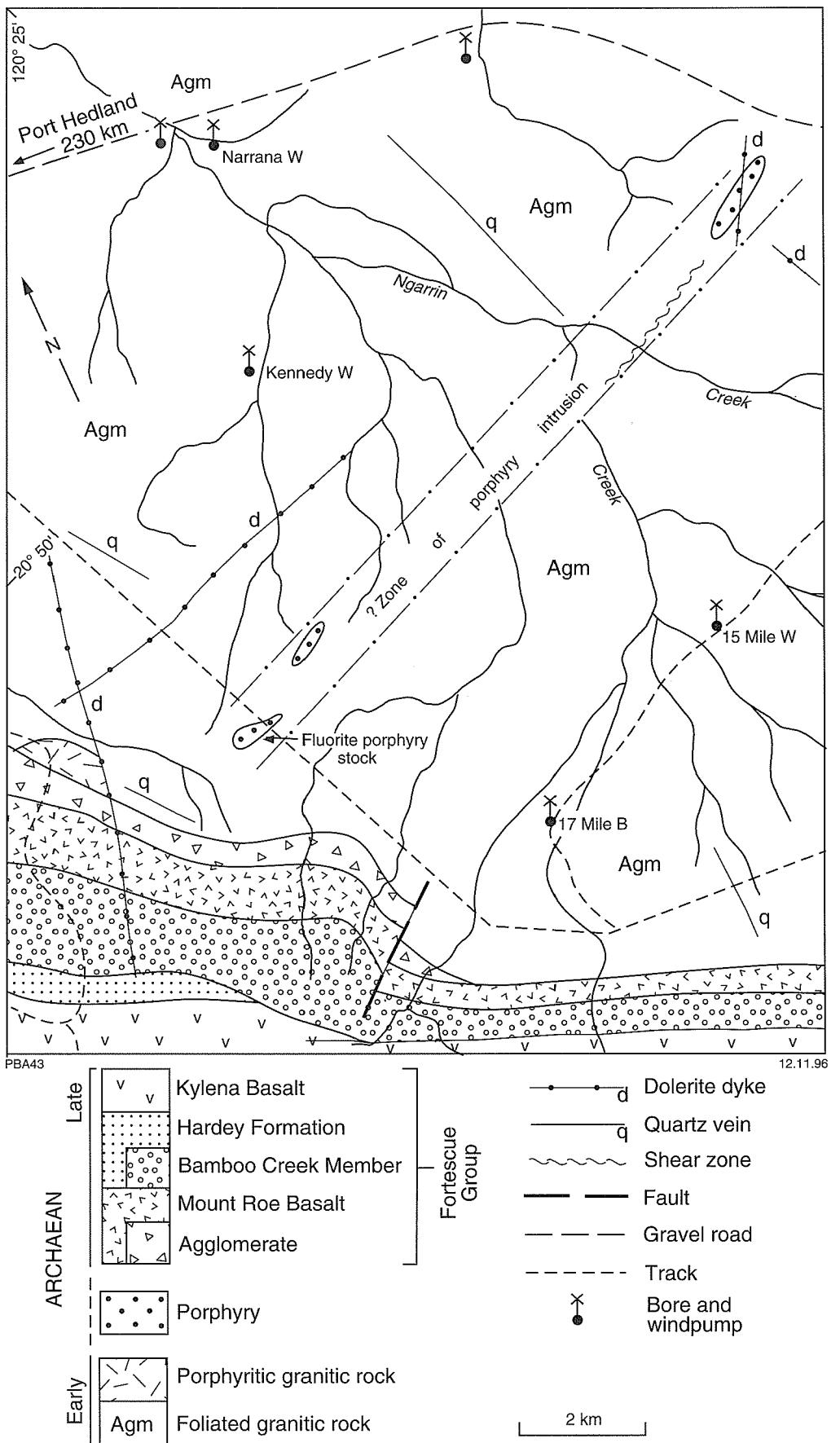
Figure 30. Geology of the area around Ngarrin Creek fluorite occurrence (modified *after* Hickman, 1976b)

stripping ratio of 4, a tonnage factor of 0.31 m³/t, and an average width of the veins varying from 0.3 m to 2 m. If the stripping ratio is reduced to 3, tonnage would increase to 118 840 at 80% CaF_2.

Some 8000 t of high-grade ore have been extracted from the deposit (Hickman, 1976a), but there is no record of it being marketed.

Ngarrin Creek

Location: Lat. 20°52'00"S, Long. 120°25'00"E (B)

An occurrence of fluorite was discovered approximately 27 km south-southwest of Callawa Homestead during systematic geological mapping of the YARRIE 1:250 000 Sheet in 1974 (Hickman, 1976b; Hickman et al., 1983).

Geology

The fluorite occurs within a dacitic porphyry stock exposed as a prominent hill west of 17 Mile Bore (Fig. 30). The stock, which consists of two distinctive rock types, is considered to be a Late Archaean or Early Proterozoic intrusion into the surrounding migmatitic adamellite of a large Archaean batholith. To the south of the stock is a series of east–west trending, mainly mafic lavas interbedded with terrigenous and volcaniclastic sediments. This sequence represents the lower part of the Late Archaean Fortescue Group in the northeast Pilbara Sub-basin (Table 17).

The two distinctive rock types that comprise the dacitic porphyry stock are:

• Coarse porphyry containing large phenocrysts of quartz, feldspar and vugs of dark blue fluorite up to 50 mm across.
• Fine porphyry containing phenocrysts of 3 mm in diameter with microscopic fluorite. This rock type occurs within northeasterly trending dykes of the coarse porphyry at the southwestern end of the hill. In other places the intrusive relationship is obscure.

Petrographic studies of fluorite ore from the coarse porphyry indicate plagioclase, a few euhedral perthite crystals up to 1 cm long and quartz phenocrysts 1–4 mm across, which together constitute about 40% of the rock. Microphenocrysts of biotite up to 1 mm across are common within a groundmass consisting of a fine grained, quartzofeldspathic aggregate. Amygdales from 2–6 mm across are filled by mosaic quartz, quartz and biotite, clay minerals and fluorite. Although most fluorite grains are coloured, some are clear, and in places an irregular zoning is developed. Fluorite also occurs with biotite, chlorite, and as stringers in the feldspar.

Petrographic studies of fluorite ore from the fine porphyry indicate that most phenocrysts in the fine-grained matrix are quartz with some perthite. The altered phenocryst phases, often surrounded by carbonate, are interpreted to be plagioclase and biotite. Patches of fluorite form about 0.5% of the rock. Whole-rock mineralogy suggests a rhyodacite.

Geochemistry

Whole-rock geochemistry of the two rock types (Table 19) indicates that they are similar except for slightly higher Al_2O_3, CaO and Na_2O in the fine porphyry. The trace-element determinations also indicate conspicuously higher F, Li, Sn, U and Nb in the fine porphyry. The unusually low K/Rb and high K/Ba ratios suggest that the stock has originated from a highly fractionated magma (Hickman, 1976b).

Economic potential

Hickman (1976b) concluded that the Ngarrin Creek occurrence appears to have little economic potential as a fluorite deposit because fluorite is disseminated in the stock, and also because brief field examinations failed to locate any veins. However, he suggested that any future prospecting should be concentrated on the zone of porphyry intrusion indicated on Figure 30 and also in the porphyritic granitic body (*Agp*) about 2.5 km west, and in the Bamboo Creek porphyry about 4 km south of the porphyry intrusion.

Minor occurrences

Minor occurrences of fluorite in the Pilbara Craton are described in Table 20.

Southern Cross Province – Yilgarn Craton

The boundaries of Southern Cross Province have recently been revised as a result of on-going tectonostratigraphic terrane analysis of the Yilgarn Craton. To the north, the province is unconformably overlain by rocks of the Glengarry Basin, and to the south it is in tectonic contact with the Albany–Fraser Orogen. To the east is the Eastern Goldfields Province, and to the west is the West Yilgarn, which for the purposes of this Bulletin, is divided geographically into the Murchison area and the Southwestern area (Fig. 31).

The principal rock types of the Southern Cross Province are greenstone, gneiss, and granitoids, ranging in age from 3.1 to 2.5 Ga. A description of these rocks is given by Griffin (1990b).

Large deposits of fluorite are unknown in the Southern Cross Province. The only known occurrences are at Lake Seabrook, Waddouring, and Youanmi.

Table 19. Whole-rock and trace-element geochemistry of coarse and fine porphyry from Ngarrin Creek

Sample no.	Coarse porphyry					Fine porphyry					
	20560	20558	20562	42921A	42921B	20563	20559	20561A	20561B	20561C	20561D
						%					
SiO_2	77.1	nd	nd	nd	nd	76.5	nd	nd	nd	nd	nd
Al_2O_3	11.7	nd	nd	nd	nd	12.7	nd	nd	nd	nd	nd
Fe_2O_3	0.7	nd	nd	nd	nd	0.8	nd	nd	nd	nd	nd
FeO	0.77	nd	nd	nd	nd	0.64	nd	nd	nd	nd	nd
MgO	0	nd	nd	nd	nd	0	nd	nd	nd	nd	nd
CaO	0.75	nd	nd	nd	nd	1.13	nd	nd	nd	nd	nd
Na_2O	2.94	nd	nd	nd	nd	3.32	nd	nd	nd	nd	nd
K_2O	4.5	nd	nd	nd	nd	3.8	nd	nd	nd	nd	nd
H_2O^+	0.3	nd	nd	nd	nd	0.6	nd	nd	nd	nd	nd
H_2O^-	0.22	nd	nd	nd	nd	0.17	nd	nd	nd	nd	nd
CO_2	0.3	nd	nd	nd	nd	0.5	nd	nd	nd	nd	nd
TiO_2	0.1	nd	nd	nd	nd	0.06	nd	nd	nd	nd	nd
P_2O_5	0.06	nd	nd	nd	nd	0.04	nd	nd	nd	nd	nd
MnO	0.06	nd	nd	nd	nd	0.06	nd	nd	nd	nd	nd
Total	**99.8**					**100.3**					
					Trace elements (ppm)						
Ba	334	nd	nd	nd	nd	254	nd	nd	nd	nd	nd
Be	7	6	7	nd	nd	9	8	7	14	14	8
Li	6	10	8	nd	nd	10	8	30	52	48	30
Mo	1.6	1	0.5	5	10	1.2	1	1	3	1.5	0.5
Rb	436	nd	nd	nd	nd	590	nd	nd	nd	nd	nd
Sn	10	10	10–100	<10	<10	10–100	10–100	10–100	100	100	100
SO_3	270	nd	nd	nd	nd	210	nd	nd	nd	nd	nd
Sr	44	nd	nd	nd	nd	68	nd	nd	nd	nd	nd
U	6	4	10	nd	nd	16	14	4	12	12	6
W	4	2	5	<3	<3	6	5	2	6	5	8
Nb	31	35	45	nd	nd	62	55	65	65	85	70
F	3600	3700	3300	3900	5500	4600	2300	32500	7100	12400	2200
Cu	nd	nd	nd	220	50	nd	nd	nd	nd	nd	nd

nd = not determined
Source: Hickman (1976b)

Lake Seabrook

Location: Lat. 30°51'00"S, Long. 119°33'00"E (B)

Scheelite and fluorite mineralization in sheared ultramafic rocks is known at the Lake Seabrook prospect located 58 km north-northeast of Southern Cross and 10 km southeast of Koolyanobbing (Fig. 31). The prospect was initially pegged by the Morton family in 1967, under a prospecting agreement with Metals Exploration NL. During 1968, a joint venture was formed between Freeport of Australia Inc., Barrier Exploration NL, Metals Exploration NL and the Mortons. Subsequent exploration work was mostly concentrated in areas considered to be favourable for base metals and gold. However, after carrying out geophysical work and geological mapping in an area of the prospect, Morton (1975) suggested that some fluorite and copper mineralization was 'typical of [an] acid pneumatolytic origin'.

Geology

The area is adjacent to a northwest-trending 'crushed zone' (Morton, 1975) between Archaean granite and gneiss to the west and an easterly dipping sequence of Archaean rocks, comprising basic amphibolites, intermediate to acid volcanics and tuff, and banded iron-formation, to the east. There is widespread development of talc schist at the contact zones due to alteration of tremolite–actinolite rocks (Morton, 1976). A quartz vein about 1.6 km long and 100 m wide occurs at the 'crushed zone', and at the southern end of this zone is a wedge of sheared and chloritic, mineralized ultramafic rock approximately 25 m wide. Costeans in a distance of more than 3 km in this 'crushed zone' indicate scheelite mineralization. Fine, powdery fluorite mineralization is associated with scheelite for a distance of about 500 m, hosted mainly in biotite schist. Some samples collected from the costeans contain over 6% CaF_2 associated with anomalous scheelite

Table 20. Minor occurrences of fluorite in the Pilbara Craton

Locality	Lat. (S); Long. (E)	Remarks	References
Cooglegong	21°32'20"; 119°25'00" (B)	Almost pure fluorite occurring as a gangue mineral has been described from a small vein of galena in a mine known as Boddingtons Lead Mine. The colour of the mineral varies from colourless to deep violet, the latter colour being more common. Fluorite associated with tin mineralization is also known at a location 20 km east of Cooglegong (Lat. 21°32'25"S, Long. 119°36'20"E), and 3.5 km south-southeast of Split Rock	Simpson (1951)
Cookes Creek	21°39'05"; 120°26'50" (A)	Fluorite veins occur in mafic and granitic rocks located approximately 2 km southwest of Cookes Creek. Fluorite is associated with tungsten minerals such as scheelite and wolframite. Flotation tests of a sample from Cookes Creek have indicated that high-grade fluorite could be produced which would meet acid-grade fluorspar specifications. This sample contained 77.91% CaF_2, 10.81% $BaSO_4$, 9.52% SiO_2 and 0.73 % Pb	Hickman (1978)
Eastern Creek	21°47'10"; 120°48'05" (A).	Fluorite occurs at two locations, 8 km apart, around Eastern Creek, approximately 56 km east-northeast of Nullagine. Fluorite is coarsely to rather finely granular with very few impurities except a small amount of galena and occasional barite. There is a wide range in colour varying from colourless to almost transparent, milk white and less translucent, pale to deep amber yellow, light brown, bottle green, and lavender to very dark violet	Simpson (1951)
McPhees Range (possibly McPhees Hill)	21°02'00"; 118°58'00" (B)	A fluorite vein carrying some galena was opened up in 1931 at a location approximately 5 km northwest of McPhees gold diggings. The fluorite is colourless or slightly iron stained, highly translucent and coarsely crystalline. Anglesite, quartz and limonite were also present in some samples	Simpson (1951)

Note: A: absolute accuracy of site <200 m
B: absolute accuracy of site >200 m
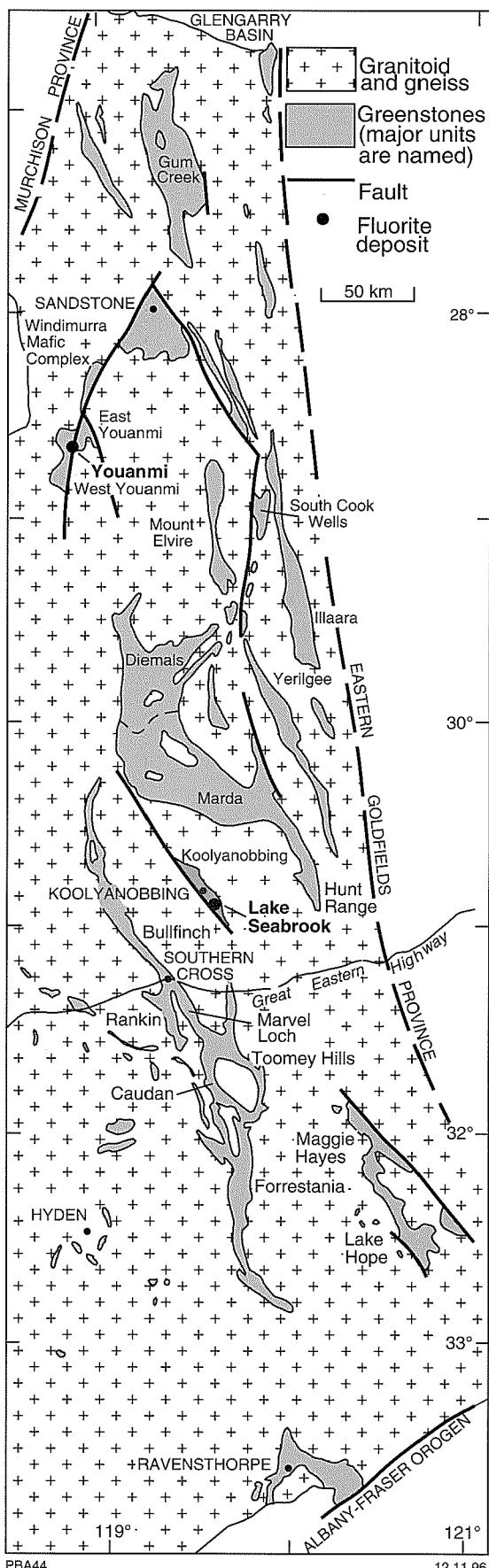
Figure 31. Granite–greenstone terrane of the Southern Cross Province (modified *after* Griffin, 1990b)

(average 0.18% WO_3). Quartz veins also occur along the southern contact of the crushed zone. These veins have variable lengths up to 150 m and widths up to 15 m, and contain malachite, azurite, chalcocite, an earthy bismuth mineral, beryl, topaz, and powellite.

Economic viability

Exploration work did not reveal any economically viable fluorite or tungsten mineralization.

Minor occurrences

Minor occurrences of fluorite in the Southern Cross Province–Yilgarn Craton are given in Table 21.

Minor occurrences in other tectonic units

Minor occurrences of fluorite are known in the following tectonic units;

> Eastern Goldfields Province – Yilgarn Craton
> West Yilgarn (Murchison area) – Yilgarn Craton
> West Yilgarn (southwestern area) – Yilgarn Craton
> Gascoyne Complex
> Albany–Fraser Orogen
> Halls Creek Orogen
> King Leopold Orogen
> Ashburton Basin
> Musgrave Complex
> Ord Basin

Available information for these occurrences is given in Table 22.

Summary

Fluorite, also commercially known as fluorspar, theoretically contains 51.1% calcium and 48.9% fluorine. It has a hardness of 4 and a specific gravity of 3.01 to 3.60 and is a glassy, translucent to transparent mineral having a wide range of colours such as yellow, blue, purple, green, rose, red, bluish and purplish black, and brown. Associated minerals include quartz, barite, calcite, galena, siderite, chalcopyrite, sulfides or phosphates.

Fluorite occurs in a wide variety of geological environments with significant concentrations in regions of gravity lows and zones of high heat flow, igneous activity, and hydrothermal effects.

Commercial fluorspar is available in three grades: acid, ceramic, and metallurgical. Acid grade contains a minimum of 97% CaF_2, less than 1.5% SiO_2, and 0.03 to 0.10% sulfur as sulfide and/or free sulfur. Ceramic grade is generally marketed as No. 1 (95–96% CaF_2),

No. 2 (85–90+% CaF$_2$), and intermediate grade (93–94% CaF$_2$) depending on the calcium fluoride content and limitations to certain impurities such as quartz, calcite etc. Metallurgical grade is generally applied to material with a minimum of 80% CaF$_2$ and a maximum of 15% silica and other contaminants.

The three main uses of fluorspar are in the chemical industry, the metallurgical industry, and the ceramic industry. In the chemical industry, the main use is in the manufacture of hydrogen fluoride, which is used to make fluorocarbons, organic and inorganic chemicals, synthetic cryolite, and elemental fluorine. In the metallurgical industry, fluorspar is used as a fluxing agent in the steel-making processes, iron foundries, and also in welding fluxes. Fluorspar is used in the ceramic industry to produce different kinds of glass, enamel, cooking ware etc.

Although there was satisfactory demand for fluorspar prior to 1990 due to strong markets for acid grades, demand has begun to decline due to the impact of the September 1987 Montreal Protocol, which called for consumption restrictions on specified chloro-fluorocarbons. Some improvement is anticipated from 1994 due to an increase in demand for hydrogen fluoride with the introduction of new fluorocarbon compounds. The demand for metallurgical grade appears to be declining due to the drop in steel output and tighter raw material specifications. The price of acid-grade fluorspar has increased from around $160 per tonne (1984 dollars) to around $370 in 1995, while metallurgical grade increased from $85 in 1983 to $215 per tonne in 1995.

Global fluorspar production has declined from 5.5 Mt in 1989 to 3.9 Mt in 1994. More than 75% of the world production comes from China, Mexico, CIS, South Africa, and Mongolia, although more than 30 countries produce fluorspar. In 1994, China produced 53% of world production. All countries except China show declines in production during recent years. The most notable is Mexico which has declined from over 1 Mt in 1981 to 0.4 Mt in 1994. Australia has not been a significant producer of fluorspar although some historic production has been reported from all States other than Western Australia, Tasmania, and Northern Territory. Queensland, followed by New South Wales, has been the major producer.

Western Australia contains two large deposits, at Speewah and Meentheena. Of these, the Speewah deposit has been investigated intensively and Elmina NL has plans to exploit the deposit on a commercial scale.

The fluorite mineralization at Speewah is found in fault zones associated with the Early Proterozoic Hart Dolerite and a granophyre. Associated rocks include feldspathic arenites, chloritic lutites, and minor acid volcanics. Mineralization is known to occur in four zones. Altogether fourteen veins have been found, but only two veins known as A and B have been the focus of exploration. The deposit contains a measured resource of 1.87 Mt at 25.8% CaF$_2$, an indicated resource of 0.41 Mt at 24.2% CaF$_2$, and an inferred resource of 1.59 Mt at 13% CaF$_2$.

At Meentheena, fluorite mineralization is mainly in the form of veins in the faulted volcanic rocks in the lower part of the Archaean Fortescue Group. All deposits are within the Mount Roe Basalt which consists of a thick sequence of agglomerate, lapilli and gritty tuff, basalt, and andesite. The tonnage potential of the deposit is considered to be 132 450 fluorite at 80% CaF$_2$ from all the veins in the prospect mined to a depth of 17 m.

The total identified fluorite resource in Western Australia is limited to the above deposits and other known occurrences are either small in volume or little known.

Table 21. Minor occurrences of fluorite in the Southern Cross Province – Yilgarn Craton

Locality	Lat. (S); Long. (E)	Remarks	References
Waddouring	30°57'00"; 117°51'00" (B)	A microcline–biotite granite containing molybdenite occurring on Waddouring Hill contains an appreciable amount of microscopic, purple fluorite. The fluorite is associated with molybdenite-bearing granite, mainly along the cleavage planes of biotite and hydrobiotite, and as discrete grains	Simpson (1951)
Youanmi	28°37'00"S; 118°50'00" (B)	Fluorite is associated with a series of dykes occurring in the main workings of Youanmi mine at Nos 5 and 7 levels. The dykes were pinkish or reddish in colour, felsitic to coarse pegmatitic and contained large pink or pale orthoclase crystals. These dykes also contained small veins of red and white carbonates	Simpson (1951)

Note: A: absolute accuracy of site <200 m
 B: absolute accuracy of site >200 m

Table 22. Minor occurrences of fluorite in other tectonic units

Locality	Lat. (S); Long. (E)	Remarks	References
Eastern Goldfields Province – Yilgarn Craton			
Mount Boreas	27°54'40"; 121°52'20" (A)	Mount Boreas Adamellite, which is widespread in the western sector of Duketon 1:250 000 geological sheet, contains disseminated fluorite in most localities. The fluorite occurs in association with secondary chlorite after biotite, and as scattered discrete grains. The discrete grains, where present, are commonly visible in hand specimen. In a small body of fine-grained granite 5 km west of Sunrise Well, fluorite forms aggregates a few millimetres across. Although these aggregates rarely exceed 1% percent of the total rock, the possibility remains for late stage concentrations of fluorite in mafic and granitic rocks	Bunting and Chin (1979)
Mount Norcott	32°07'00"; 122°00'00" (B)	A pink 'soda' granite collected from an outcrop approximately 23 km north-northeast of Norseman and close to Mt Norcott contained 0.13% fluorine. The constituent minerals were albite, quartz and microcline with minor hornblende, epidote, biotite, apatite, magnetite, calcite, titanite, fluorite, limonite, and kaolin. In thin sections, fluorite is seen as small colourless interstitial grains	(Simpson, 1951)
Mulwarrie	30°00'00"; 120°33'00" (B)	A pegmatite containing fluorite along with microcline, albite, quartz, and some muscovite has been described from GML506 at Mulwarrie. Fluorite generally occurs as scattered small purple crystals	Simpson (1951)
West Yilgarn (Murchison area) – Yilgarn Craton			
Dalgaranga	27°42'30"; 117°13'00" (B)	Fluorite occurs in association with tantalite–columbite mineralization at Dalgaranga mining centre	Watkins et al. (1987)
Mulgine	29°06'20"; 116°58'35" (A)	Minor fluorite is associated with molybdenum ore at this locality. The ore is a shattered micaceous granite impregnated with molybdenite and pyrite, locally hosting veinlets and lenses of quartz, and in places fluorite. The fluorite varies from colourless to violet black and to almost opaque. Associated minerals include muscovite, microcline, albite, quartz, molybdenite, pyrite, zircon, and titanite	Simpson (1951)
Poona	27°07'45"; 117°26'30" (A)	Hydrothermally altered biotite schist associated with emerald-bearing pegmatites in the Poona area is unusually high in fluorine (4.15%). In the same area, coarsely crystalline, highly translucent fluorite up to 3 cm in diameter is associated with a pegmatite containing quartz, green beryl, and potassic oligoclase	Simpson (1951)
West Yilgarn (southwestern area) – Yilgarn Craton			
Cardup	32°15'00"; 116°00'00" (B)	A quartz barite vein with occasional specks of galena and sphalerite occurs at Location 24, close to Cardup, in Precambrian slate, a few metres from its contact with the Darling Range granite. In one of the more siliceous sections of the vein there were small masses of fluorite from 2–3 mm to 2–3 cm in diameter, scattered through dense chalcedonic quartz. The fluorite was commonly deep violet, with some material paler violet or bright blue	Simpson (1951)
Mundijong	32° 16'00" 116° 01'00" (B)	Fluorite has been found in several parts of a lead–zinc vein located 3.2 km east of Mundijong. The vein, hosted by gneiss, mainly consists of quartz, and has been mined on a small scale several times. The fluorite varies in colour from milk white through mauve to dark violet, and is mostly fine-grained	Simpson (1951)

Table 22. (continued)

Locality	Lat. (S); Long. (E)	Remarks	References
Gascoyne Complex			
Cork Tree Bore	24°39'45"; 115°42'45" (A)	Fluorite associated with barite occurs at a location 1.5 km south-southeast of Cork Tree Bore. The occurrence is in a shear trending north-northeast in augen gneiss	Williams et al. (1978, 1983a)
Yinnetharra	24°30'40"; 116°10'00" (A)	Veins of fluorite over 1 m wide and 100 m long have been reported within Wyloo Group metasediments of the Mount Phillips area 15 km to the north of Yinnetharra. Fluorite is associated with galena, various copper minerals and orpiment in a quartz gangue. The mineralization is thought to be associated with the pegmatite phase of a 1400 Ga granite	Hickman (1976a)
Albany–Fraser Orogen			
Bobbies Point	28°58'55"; 124°40'20" (A)	Fluorite occurs in small quantities associated with a granite near Bobbies Point	van de Graaff and Bunting (1975)
Mount Ridley	33°18'33"; 122°08'07" (A)	A granite at this location contains fluorite as an accessory mineral. The main minerals present in the granite are albite, microcline and quartz, with accessory fluorite, biotite, chlorite, magnetite, ilmenite, muscovite, limonite, leucoxene, rutile, apatite, titanite, and kaolin	Simpson (1951)
Halls Creek Orogen			
Goanna Spring	17°41'25"; 127°23'55" (A)	Fluorite occurs as veins less than 10 cm thick in weathered Whitewater Volcanics near the Greenvale Fault, 3.2 km east-northeast of Goanna Spring	Gellatly and Derrick (1967)
Turkey Creek	16°55'55"; 128°09'05" (A)	Fluorite occurs in veins at a location 13 km northwest of Turkey Creek. Specimens are coarsely crystalline, highly translucent, colourless, white, and various tints of green to pale emerald. It is associated with a little galena and quartz. White and green fluorite have also been found approximately 16 km south-southwest of Turkey Creek	Simpson (1951)
King Leopold Orogen			
Long Hole Bore	17°57'55"; 126°03'30" (A)	A quartz–feldspar–muscovite dyke located 3.2 km north-northwest of Long Hole Bore, contains veins of fluorite less than 10 cm thick. This rock cuts Lamboo Complex granite	Gellatly and Derrick (1967)
Ashburton Basin			
Globe Hill	22°37'00"; 115°13'00" (B)	Fluorite grains up to several grams in weight have been collected close to a stanniferous pegmatite containing microcline, albite, quartz, and muscovite as major minerals, and fluorite, rutile, ilmenite, cassiterite, and topaz as minor minerals. The pieces collected were coarsely crystalline and the colour varied from dark violet through light grey to light green. However most specimens ranged from indigo blue to dark violet in colour	Simpson (1951)
Musgrave Complex			
Barlee Springs	26°01'00"; 127°19'00" (B)	Finely granular purple fluorite occurs as small patches in a fine-grained, dark grey, quartz porphyry collected from a location 1.6 km east of Forrests Cairn at Barlee Springs	Simpson (1951)
Mount Elvire	26°04'44"; 127°07'08" (A)	Approximately 3 km west-northwest of Mount Elvire, small lenses of purple fluorite, up to 30 m long and 2 m wide, occur in felsitized acid volcanics of the Scamp volcanic association	Daniels (1971)

Table 22. (continued)

Locality	Lat. (S); Long. (E)	Remarks	References
Ord Basin			
Dixon Range	17°32'00"; 128°39'00" (B) (Doughboy Hill)	Colourless to milk white fluorite and quartz occur as gangue minerals in veins of argentiferous galena in a locality between Dixon Range and Doughboy Hill on the Upper Ord River. Other minerals present in the gangue are limonite, psilomelane, chalcopyrite, malachite, and kaolin	Simpson (1951)

Note: A: absolute accuracy of site <200 m
       B: absolute accuracy of site >200 m

References

AMPIAN, S. G., 1985, Barite: Minerals Facts and Problems, 1985 Edition, United States Department of the Interior, Bureau of Mines Bulletin 675, p. 65–74.

ANDREWS, P. R. A., and COLLINGS, R. K., 1990, Barytes in Canada: Industrial Minerals, no. 268, January 1990, p. 46–57.

ANDREWS, P. R. A., and COLLINGS, R. K., 1993, Fluorite occurrences in Canada and processing studies at CANMET: The Canadian Mining and Metallurgical Bulletin, v. 86, no. 968, March 1993, p. 132–136.

ARIMCO, 1990, Mt Sandiman Annual Report to the Department of Mines, W.A. P09/248 and P09/249 for the period 3 November 1989 to 2 November 1990, Report by Arimco: Western Australia Geological Survey, M-series, Open file, Item 5822 (unpublished).

ARNDT, N. T., NELSON, D. R., COMPSTON, W., TRENDALL, A. F., and THORNE, A. M., 1991, The age of the Fortescue Group, Hamersley Basin, Western Australia, from ion microprobe zircon U–Pb results: Australian Journal of Earth Sciences, v. 38, p. 261–281.

AUSTRALIAN MINING, 1983, The mineral, baryte: Australian Mining, p. 62.

BEESLEY, T. J., 1971, Report on testing of the Mangaroon barite prospect, Gascoyne goldfield, Western Australia by Mallina Mining and Exploration NL: Western Australia Geological Survey, M-series, Open file, Item 1014 (unpublished).

BLACKBURN, G. V., 1978, Final report Temporary Reserve 5993H Cooke Bluff Hill, Report by Otter Exploration NL.: Western Australia Geological Survey, M-series, Open file, Item 2434 (unpublished).

BLATCHFORD, T., 1912, Mineral resources of the north-west division: Western Australia Geological Survey, Bulletin 52, p. 28–30.

BLATCHFORD, T., 1928, Geological observations made whilst travelling in west Kimberley up the valleys lying between the Pentecost and King Rivers, then eastward across the Denham and Ord Rivers as far as Argyle Station on the Behn River: Western Australia Geological Survey, Annual Progress Report for the Year 1927, p. 13.

BLOCKLEY, J. G., 1971, The lead, zinc and silver deposits of Western Australia: Western Australia Geological Survey, Mineral Resources Bulletin 9, 234p.

BLOCKLEY, J. G., 1972, The Speewah fluorite deposits: Western Australia Geological Survey, File report (unpublished).

BOWEN, K. G., 1976, Fluorite — Victoria, *in* Economic Geology of Australia and Papua New Guinea, Volume 4. Industrial Minerals and Rocks *edited by* C. L. KNIGHT: The Australasian Institute of Mining and Metallurgy, Monograph 8, p. 24–25.

BROOK, W., 1974, Big Stubby zinc deposits, *in* Excursion itinerary on the Marble Bar and Nullagine 1:250 000 Sheet areas: Western Australia Geological Survey (unpublished).

BUNTING, J. A., and CHIN, R. J., 1979, Duketon, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 24p.

BURGER, J., 1991, Fluorspar producers; Fighting for survival: Industrial Minerals no. 284, May 1991, p. 17–27.

CARPENTARIA EXPLORATION COMPANY, 1975, Mining Tenement Progress Report, 'North Pole' Mineral Claims 1392 to 1396, 1484 Pilbara Goldfield — Western Australia, Base Metal, Barite Search,

Final Report: Report by Carpentaria Exploration Company Pty Ltd.: Western Australia Geological Survey, M-series, Open file, Item 5792 (unpublished).

CHEESEMAN, D. R., 1972, Preliminary Report on Meentheena Fluorite Prospect, Western Australia for Kinetic Mining Ltd: Western Australia Geological Survey, M-series, Open file, Item 5769 (unpublished).

CHIN, R. J., and BRAKEL, A. T., 1986, Dumbleyung, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 21p.

CHIN, R. J., WILLIAMS, I. R., WILLIAMS, S. J., and CROWE, A., 1980, Rudall, Western Australia: Western Australia Geological Survey, 1:250 000 Series Explanatory Notes, 22p.

CLARK, H. B., GALLAGHER, M. J., and POOLE, F. G., 1990, World barite resources: a review of recent production patterns and a genetic classification: IMM brochure, a paper presented at the Fourteenth Congress of the Council of Mining and Metallurgical Institutions, organized by the Institution of Mining and Metallurgy and held in Edinburgh, Scotland from 2 to 6 July, 1990.

CLARKE, E. de C., PHILLIPPS, H. T., and PRIDER, R. T., 1954, The Pre-Cambrian geology of part of the south coast of Western Australia: Journal of the Royal Society of Western Australia, v. 38, p. 1–64.

CONDON, M. A., 1968, The geology of the Carnarvon Basin, Western Australia: Australia BMR, Geology and Geophysics, Bulletin 77, 64p.

DANIELS, J. L., 1971, Talbot, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 28p.

DOEPEL, J. J. G., and LOWRY, D. C., 1970, Zanthus, Western Australia: Western Australia Geological Survey, 1:250 000 Series Explanatory Notes, 19p.

DRESSER MINERALS, 1973, Summary geologic report North Pole Barite Project, Western Australia: Inter-office correspondence, Dresser Minerals, Division of Dresser Industries Inc. (unpublished).

DRIESSEN, A., 1979, Barium, *in* Australian Mineral Industry Annual Review: Australia BMR, Geology and Geophysics, p. 57–59.

DUNLOP, J. S. R., and BUICK, R., 1981, Archaean epiclastic sediments derived from mafic volcanics, North Pole, Pilbara Block, Western Australia, *in* Archaean Geology, Second International Symposium Perth 1980 *edited by* J. F. GLOVER and D. I. GROVES: Special Publication No. 7, Geological Society of Australia Incorporated, December 1981, p. 225–233.

ELIAS, M., 1982, Belele, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 22p.

ELIAS, M., and WILLIAMS, S. J., 1980, Robinson Range, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 32p.

ELMINA NL, 1989, Geological report on E80/446: Report by Elmina NL (unpublished).

ELMINA NL, 1990, Pre-feasibility study, Speewah fluorite project, production of acid-grade fluorite 100,000 tpa for export: Report by Elmina NL (unpublished).

ELMINA NL, 1993, Independent consulting geologist's and mining engineer's report: Prospectus, Elmina NL.

ELMINA NL, 1994, Speewah project, Mining Leases M80/267–269 and Exploration Licence E80/1367 East Kimberley Mineral Field WA. Combined Annual Report on exploration for 1994 (unpublished).

FINUCANE, K. J., 1939, Aerial Geology and Geophysics Survey of Northern Australia, Western Australia Report 45. The Jimblebar gold mining centre, Peak Hill Goldfield: Australia Commonwealth Government Printer, Canberra.

FLETCHER, I. R., WILLIAMS, S. J., GEE, R .D., and ROSMAN, K. J .R., 1983, Sm–Nd model ages across the margins of the Archaean Yilgarn Block, Western Australia-northwest transect into the Proterozoic Gascoyne Province: Journal of the Geological Society of Australia, v. 30, p. 167–174.

GELLATLY, D. C., and DERRICK, G. M., 1967, Lansdowne, Western Australia: Bureau of Mineral Resources, Geology and Geophysics, Canberra, 1:250 000 Geological Series Explanatory Notes, 28p.

GETTY OIL DEVELOPMENT COMPANY LIMITED, 1977, G.O.D.C.– Dresser Minerals North Pole Joint Venture, Pilbara, Western Australia: Report by Getty Oil Development Company Limited (unpublished).

GOURLAY, A. J., 1971, Barium, *in* Australian Mineral Industry 1971 Review: Australia BMR, Geology and Geophysics, p. 68–71.

GRIFFIN, T. J., 1990a, North Pilbara granite, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 128–156.

GRIFFIN, T. J., 1990b, Southern Cross Province, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 60–77.

GRIFFIN, T. J., and GREY, K., 1990, Kimberley Basin, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 293–304.

GRIFFITHS, J., 1984, Baryte: non-drilling applications: Industrial Minerals no. 201, June, p. 21–33.

GRIFFITHS, J., 1986, Oilwell drilling: survival of the fittest: Industrial Minerals no. 230, Nov., p. 21–37.

GRIFFITHS, J., 1990, Fluorspar markets in transition: Industrial Minerals no. 274, July, p. 21–31.

GRIFFITHS, J., 1992a, Barytes fillers in recession, More of a weighting game: Industrial Minerals no. 293, February, p. 39–49.

GRIFFITHS, J., 1992b, Australian minerals, Down under but not out: Industrial Minerals no. 297, June, p. 17–35.

GRIFFITHS, J., 1993, Fluorspar's future fortunes; Play it again Samine: Industrial Minerals no. 310, July, p. 21–24.

GRIFFITHS, J., 1995, Barytes supply not at oil well: Industrial Minerals no. 334, July, p. 25–33.

HARBEN, P. W., and BATES, R. L., 1990a, Barite, *in* Industrial Minerals Geology and World Deposits, 1990 Edition, Published in the United Kingdom by Industrial Minerals Division, Metal Bulletin, Plc, Park House, 3 Park Terrace, Worcester, p. 10–18.

HARBEN, P. W., and BATES, R. L., 1990b, Fluorspar, *in* Industrial Minerals Geology and World Deposits 1990 Edition, Published in the United Kingdom by Industrial Minerals Division, Metal Bulletin, Plc, Park House, 3 Park Terrace, Worcester, p. 110–119.

HICKMAN, A. H., 1973, The North Pole barite deposit, Pilbara Goldfield: Western Australia Geological Survey, Annual Report 1972, p. 57–60.

HICKMAN, A. H., 1974, The Meentheena fluorite deposits, Pilbara Goldfield: Western Australia Geological Survey, Annual Report 1973, p. 79–82.

HICKMAN, A. H., 1976a, Fluorite — Western Australia, *in* Economic Geology of Australia and Papua New Guinea, Volume 4. Industrial Minerals and Rocks *edited by* C. L. KNIGHT: The Australasian Institute of Mining and Metallurgy, Monograph 8, p. 142–143.

HICKMAN, A. H., 1976b, Fluorite porphyry at Ngarrin Creek, Yarrie: Western Australia Geological Survey, Record 1976/3 (unpublished).

HICKMAN, A. H., 1977, Barite deposits near Cooke Bluff Hill, Port Hedland 1:250 000 Geological Sheet, W. A.: Western Australia Geological Survey, Record 1976/22 (unpublished).

HICKMAN, A. H., 1978, Nullagine, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 22p.

HICKMAN, A. H., 1981, Crustal evolution of the Pilbara Block, Western Australia, *edited by* J. E. GLOVER and D. I. GROVES: Geological Society of Australia, Special Publication 7, p. 57–69.

HICKMAN, A. H., 1983, Geology of the Pilbara Block and its environs: Western Australia Geological Survey, Bulletin 127, 268p.

HICKMAN, A. H., CHIN, R. J., and GIBSON, D. L., 1983, Yarrie, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 33p.

HICKMAN, A. H., and GIBSON, D. L., 1982, Port Hedland – Bedout Island (Second Edition), Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 33p.

HICKMAN, A. H., and LIPPLE, S. L., 1978, Marble Bar, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 24p.

HICKMAN, A. H., THORNE, A. M., and TRENDALL, A. F., 1990, Excursion No. 5, Pilbara and Hamersley Basin: Excursion Guidebook, Third International Archaean Symposium, Perth 1990, Geology Department, The University of Western Australia, p. 1–58.

HIERN, M. N., 1976, Barite — South Australia, *in* Economic Geology of Australia and Papua New Guinea, Volume 4. Industrial Minerals and Rocks *edited by* C. L. KNIGHT: Australasian Institute of Mining and Metallurgy, Monograph 8, p. 27–29.

HOCKING, R. M., 1990, Carnarvon Basin *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 457–495.

HOCKING, R. M., COPP, I. A., PLAYFORD, P. E., and KEMPTON, R. H., 1996, The Cadjebut Formation: a Givetian evaporitic precursor to Devonian reef complexes of the Lennard Shelf, Canning Basin, Western Australia: Western Australia Geological Survey, Annual Review 1995–96, p. 48–55.

HOCKING, R. M., MOORE, P. S., and MOORS, H. T., 1980, Modified stratigraphic nomenclature and concepts in the Palaeozoic sequence of the Carnarvon Basin, W.A.: Western Australia Geological Survey, Annual Report 1979, p. 51–54.

HOCKING, R. M., WILLIAMS, S. J., MOORE, P. S., DENMAN, P. D., LAVARING, I. H., and van de GRAAFF, W. J. E., 1985, Kennedy Range, Western Australia: Western Australia Geological Survey, 1:250 000 Series Explanatory Notes, 31p.

HODGE, B. L., 1990, Fluorspar: Annual Review, Metals & Minerals: London, Mining Journal, p. 106–108.

HODGE, B. L., 1991, Fluorspar: Annual Review, Metals & Minerals: London, Mining Journal, p. 116–117

HODGE, B. L., 1993, Fluorspar: Annual Review, Metals & Minerals: London, Mining Journal, p. 117–118.

HODGE, B. L., 1994, Barytes; Annual Review, Metals & Minerals: London, Mining Journal, p. 102–103.

HODGE, B. L., 1995, Barytes; Annual Review, Metals & Minerals: London, Mining Journal, p. 89–91.

IGLESIAS, J. G., and LOREDO, J., 1994, Geological, Geochemical and Mineralogical Characteristics of the Asturias Fluorspar District,

Northern Spain: Exploration and Mining Geology, Canadian Institute of Mining, Metallurgy and Petroleum, v. 3, No. 1, p. 31–37.

INDUSTRIAL MINERALS, 1978, Barytes — its uses outside drilling muds: Industrial Minerals, no. 133, October, 1978, p. 33–43.

INDUSTRIAL MINERALS, 1993, World of minerals — France: Industrial Minerals, no. 315, December 1993, p. 12.

INDUSTRIAL MINERALS, 1994, World of minerals — South Africa: Industrial Minerals, no. 318, March, 1994, p. 17.

INDUSTRIAL MINERALS, 1995, Feel-good factor for fluorspar: Industrial Minerals, no. 332, May, 1995, p. 7.

KALIX, Z., FRASER, L. M., and RAWSON, R. I., 1966, Australian Mineral Industry: Production and Trade, 1842–1964: Australia BMR, Geology and Geophysics, Bulletin 81.

KENDALL, T., 1995, Mexico — promises of prosperity: Industrial Minerals, no. 336, September, 1995, p.27–40.

LI, CHANGJIANG, and JIANG, XULIANG, 1992, Minerogenetic model for two types of fluorite deposits in southeastern China: Acta Geologica Sinica, Vol. 5, No. 1 March, 1992, p. 75–88.

LIBBY, W. G., de LAETER, J. R., and MYERS, J. S., 1986, Geochronology of the Gascoyne Province: Western Australia Geological Survey, Report 20, 31p.

LIPPLE, S. L., 1976, Barite — Western Australia, *in* Economic Geology of Australia and Papua New Guinea, Volume 4. Industrial Minerals and Rocks *edited by* C. L. KNIGHT: Australasian Institute of Mining and Metallurgy, Monograph 8, p. 30–32.

McLEOD, I. R., 1965, Fluorspar *in* Australian Mineral Industry, The Mineral Deposits: Australia BMR, Bulletin 72, p. 227–234.

MacNEVIN, A. A., 1976, Fluorite — New South Wales, *in* Economic Geology of Australia and Papua New Guinea, Volume 4. Industrial Minerals and Rocks *edited by* C. L. KNIGHT: The Australasian Institute of Mining and Metallurgy, Monograph 8, p. 138–140.

MILLER, M. M., 1991, Fluorspar: Minerals Yearbook, Vol. 1, Metals and Minerals: U.S. Department of the Interior, Bureau of Mines, p. 597–612.

MORANT, P., 1995, The Panorama Zn–Cu VMS deposits, Western Australia, *in* Recent developments in base metal geology and exploration *edited by* S. E. HO and W. J. AMANN: Australian Institute of Geoscientists, Bulletin 16, p. 75–84.

MORTON, J. L., 1975, Report No. 5 on Lake Seabrook Project, Initial Report on scheelite and fluorite occurrences by Barrier Exploration NL: Western Australia Geological Survey, M-series, Open file, Item 2478 (unpublished).

MORTON, J. L., 1976, Report No. 6 on Lake Seabrook Project, Barrier Exploration NL: Western Australia Geological Survey, M-series, Open file, Item 2478 (unpublished).

MUHLING, P. C., and BRAKEL, A. T., 1985a, Mount Barker–Albany, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 21p.

MUHLING, P. C., and BRAKEL, A. T., 1985b, Geology of the Bangemall Group-the evolution of an intracratonic Proterozoic basin: Western Australia Geological Survey, Bulletin 128, 266p.

MUHLING, P.C., and LOW, G.H., 1977, Yalgoo, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 36p.

MURPHY, D. M. K., 1989, Report No. 89/15 Annual Report for M52/85: Report No. 89/15: Report by Geopeko, A division of Peko-Wallsend Operations Ltd. (unpublished).

MYERS, J. S., 1990a Albany–Fraser Orogen, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 255–263.

MYERS, J. S., 1990b Gascoyne Complex, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 198–202.

NOLDART, A. J., 1955, Report on barite deposits on M.C. 487H, Cranbrook: Annual Progress Report of the Geological Survey for the year 1953, *in* Report of the Department of Mines for the Year 1953, p. 92–94.

NORTHERN TERRITORY GEOLOGICAL SURVEY, 1976, Barite — Northern Territory, *in* Economic Geology of Australia and Papua New Guinea, Volume 4. Industrial Minerals and Rocks *edited by* C. L. KNIGHT: The Australasian Institute of Mining and Metallurgy, Monograph 8, p. 32.

OBER, A. J. 1990, Barite: Minerals Yearbook, Vol. 1, Metals and Minerals: U. S. Department of the Interior, Bureau of Mines, p. 179–189.

O'DRISCOLL, M., 1991, Moroccan barytes in Yarmouth; Mineral Industries makes the grade: Industrial Minerals, no. 290, November, 1991, p. 63.

O' DRISCOLL, M., 1994, China's minerals industry. Gathering for the great leap forward: Industrial Minerals, no. 321, June 1994, p. 19–45.

OILMIN NL, 1982, Report on operations for period ending 19th July 1982: Report by Oilmin NL: Western Australia Geological Survey, M-Series, Open file Item 2567 (unpublished).

OLLIVER, J. G., 1976, Fluorite — South Australia, *in* Economic Geology of Australia and Papua New Guinea, Volume 4. Industrial Minerals and Rocks *edited by* C. L. KNIGHT: The Australasian Institute of Mining and Metallurgy, Monograph 8, p. 141–142.

OTTERMAN, D. W., 1981, Annual report to Mines Department Temporary Reserve 7863H for Period September 12, 1980 to September 11, 1981, Amoco Minerals Australia Company: Western Australia Geological Survey, M-series, Open file, Item 2918 (unpublished).

OTTERMAN, D. W., 1982, Final report to Mines Department Temporary Reserve 7863H for Period September 12, 1981 to February 12, 1982, Amoco Minerals Australia Company: Western Australia Geological Survey, M-series, Open file, Item 2918 (unpublished).

PELHAM, L., 1985, Fluorspar: Minerals Facts and Problems, 1985 Edition, United States Department of the Interior, Bureau of Mines Bulletin 675, p. 277–290.

RICHARDS, J. R., FLETCHER, I. R., and BLOCKLEY, J. G., 1981, Pilbara Galenas: Precise Isotopic Assay and Growth-Curve Implications: Mineralium Deposita, v. 16, p. 7–30.

ROGERS, K. A., 1996, Speewah Project, mining leases M80/267–269 and exploration licences E80/1367, 1631, 1632, 1710–1714, East Kimberley Mineral Field W.A., combined report on exploration for 1994–1995: Report by Elmina NL (unpublished).

SARGEANT, D. W., 1979, Annual report on mineral claim numbers 45/8674 to 45/8684 inclusive North Pole area, Pilbara W.A.: Report by Newmont Pty Limited (unpublished).

SARGEANT, D. W., and SAMPSON, P. G.,1980, Final report on Temporary Reserve 6712H North Pole area, Pilbara Goldfield, Report by Newmont Proprietary Limited: Western Australia Geological Survey, M-series, Open file, Item 2760 (unpublished).

SCHILLER, E. A., TRASK, F., and BERVEN, R. J., 1973, Progress Report, October 1973, Meentheena Fluorite Pty Ltd and Barkee Mining Exploration Pty Ltd: Western Australia Geological Survey, M-series, Open file, Item 5769 (unpublished).

SCHULTZ, K., 1972, Kimberley fluorite project; preliminary geological report by Great Boulder Mines Limited: Western Australia Geological Survey, M-series, Open file, Item 2186 (unpublished).

SCHULTZ, K., 1973, Kimberley fluorite project, Speewah Valley, ore reserve; report by Great Boulder Mines Limited: Western Australia Geological Survey, M-series, Open file, Item 2186 (unpublished).

SIMPSON, B. R., 1976, Fluorite — Queensland, *in* Economic Geology of Australia and Papua New Guinea, Volume 4. Industrial Minerals and Rocks *edited by* C. L. KNIGHT: The Australasian Institute of Mining and Metallurgy, Monograph 8, p. 137–138.

SIMPSON, E. S., 1948, Minerals of Western Australia, Volume 1: Perth, Western Australia, Government Printer.

SIMPSON, E. S., 1951, Minerals of Western Australia, Volume 2: Perth, Western Australia, Government Printer.

SKILLEN, A., 1993 Fluorspar producers; Cracks in the Chinese wall?: Industrial Minerals, no. 307, April, p. 36–49.

SKORNICKI, E., 1989, China as a source of acid-grade fluorspar: Industrial Minerals, no. 265, October, p. 65 –67.

SOFOULIS, J., 1958, Notes on a reconnaissance of the Stirling Range area, South-East Division: Western Australia Geological Survey, Bulletin 109, p. 79.

SOFOULIS, J., 1968, Silver–lead–gold–copper prospect, M. C. 38, Kununurra area, Western Australia: Western Australia Geological Survey, Annual Report 1967, p. 47.

STEVENS, P. J., 1976, Barite — New South Wales, *in* Economic Geology of Australia and Papua New Guinea, Volume 4. Industrial Minerals and Rocks *edited by* C. L. KNIGHT: The Australasian Institute of Mining and Metallurgy, Monograph 8, p. 24–25.

TALBOT, H. W. B., and SIMPSON, E. S., 1926, A geological reconnaissance of part of the Ashburton Drainage Basin: Western Australia Geological Survey, Bulletin 85, p. 105.

THORNE, A. M., and SEYMOUR, D. B., 1991, Geology of the Ashburton Basin, Western Australia: Western Australia Geological Survey, Bulletin 139, 141p.

THORNE, A. M., and TRENDALL, A. F., in prep., Geology of the Fortescue Group:Western Australia Geological Survey, Bulletin.

TRENDALL, A. F., 1990, Hamersley Basin, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 163–191.

TURNER, F. J., and VERHOOGEN, J., 1960, Igneous and metamorphic petrology (2nd ed.): New York, McGraw-Hill Book Co., 261p.

UNIVERSAL MILLING PTY LTD., 1972, Report on geological mapping on mineral claims 1350, and 1351 by Universal Milling Pty Ltd.: Western Australia Geological Survey, M-series, Open file, Item 2192 (unpublished).

UNIVERSAL MILLING PTY LTD., 1977, Report on Barite — Mooloo Downs *by* Universal Milling Pty Ltd.: Western Australia Geological Survey, M-series, Open file, Item 2196 (unpublished).

van de GRAAFF, W. J. E., and BUNTING, J. A., 1975, Neale, Western Australia: Western Australia Geological Survey, 1:250 000 Series Explanatory Notes, 25p.

van TOLL, A., 1981, Barytes commodity review and market study: Report for Kitchener Mining NL: Western Australia Geological Survey, M-series, Open file, Item 5792 (unpublished).

VOGT, J.H., 1995, Geology of the Jillawarra area, Bangemall Basin, Western Australia: Western Australia Geological Survey, Report 40, 107p.

WATKINS, K. P., 1990, Murchison Province, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 32–60.

WATKINS, K. P., TYLER, I. M., and HICKMAN, A. H., 1987, Cue, Western Australia: Western Australia Geological Survey, 1:250 000 Series Explanatory Notes, 31p.

WATSON, I., 1982, Barytes US drilling downturn weighs heavily on the market; Industrial Minerals, no. 183, December, 1982, p. 21–45.

WEEKS, G., 1989, Inspection report on the Badja barite deposit: Report for Commercial Minerals Limited, Geological Services Division:

Western Australia Geological Survey, M-series, Open file, Item 5336 (unpublished).

WILDE, S. A., and LOW, G. H., 1980, Pinjarra, Western Australia: Western Australia Geological Survey, 1:250 000 Series Explanatory Notes, 31p.

WILLIAMS, I. R., 1987, Late Proterozoic glacigene deposits in the Little Sandy Desert, Western Australia: Australian Journal of Earth Sciences, v. 34, p. 153–155.

WILLIAMS, I. R., 1990, Bangemall Basin, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 308–329.

WILLIAMS, I. R., and TRENDALL, A. F., in prep., Geology of the Pearana 1:100 000 Sheet, Western Australia: Western Australian Geological Survey, 1:100 000 Geological Series Explanatory Notes.

WILLIAMS, I. R., and TYLER, I. M., 1991, Robertson, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 36p.

WILLIAMS, I. R, WALKER, I. M., HOCKING, R. M., and WILLIAMS, S. J., 1983, Byro, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 27p.

WILLIAMS, S. J., 1986, Geology of the Gascoyne Province, Western Australia: Western Australia Geological Survey, Report 15, 85p.

WILLIAMS, S. J., WILLIAMS, I. R., CHIN, R. J., MUHLING, P. C., and HOCKING, R. M., 1978, Explanatory notes on the Mount Phillips 1:250 000 geological sheet Western Australia: Western Australia Geological Survey, Record 1978/13 (unpublished)

WILLIAMS, S. J., WILLIAMS, I. R., CHIN, R .J., MUHLING, P. C., and HOCKING, R. M., 1983a, Mount Phillips, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 29p.

WILLIAMS, S. J., WILLIAMS, I. R., and HOCKING, R. M., 1983b, Glenburgh, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 25p.

Index of barite and fluorite localities in Western Australia