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Mineral Processing in Australia
TITANIUM

by

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SUMMARY

The historical background of the Australian mineral sands industry is outlined, and the current position and future prospects of the industry covering mineral concentrates, beneficiated ilmenite, and TiO_2 pigment, is summarised from the viewpoint of production, consumption, trade, and the relative position of the industry in a global context. The conclusion reached is that internation tariff barriers and the lack of a significant domestic market will constitute a continuing impediment to the commercial production of titanium sponge and TiO_2 pigment (by a chloride process) in Australia. However, the availability of cheap, by-product chlorine would make viable the domestic production of titanium tetrachloride with Japan providing the major market outlet.

MINERAL PROCESSING IN AUSTRALIA

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INTRODUCTION

Following Cabinet Decision No. 189 of May 1968 an interdepartmental committee consisting of representatives of the Department of Trade and Industry, Treasury, and National Development, was set up to study the degree to which minerals produced in Australia are processed locally, and to explore possibilities for further processing.

At the initial meeting of the Committee convened on 5 June 1968 it was decided to compile a preliminary review of the current position of mineral processing in Australia and to indicate those sectors where additional processing seemed possible. The Bureau of Mineral Resources prepared a conspectus of minerals produced in quantity in Australia and amenable to processing. A short-list of minerals warranting further study was suggested. At the Committee's second meeting held on 15 July 1968 it was decided that the next step should be the preparation of more detailed papers on tin, titanium and salt processing.

This Record provides relevant data concerning the domestic titanium industry.

HISTORICAL BACKGROUND TO THE AUSTRALIAN INDUSTRY

Rutile

The earliest commercial exploitation of heavy-mineral sands along the Australian coast was between 1870 and 1900 when "black sands" at Ballina (N.S.W.) were worked intermittently for their gold content. In 1932 zircon concentrates were produced in the recovery of gold, platinum and tin, but it was not until 1934 that Zircon-Rutile Ltd went into comparatively large-scale production at Byron Bay (N.S.W.) emphasis being on the production of zircon. Until 1940 Zircon-Rutile Ltd and the Titanium Alloy Manufacturing Company (Cudgen) were the only mineral sands producers in Australia; at that time the only recovery of rutile was in a mixed concentrate which was exported.

Demand for rutile increased rapidly with the outbreak of World War II and in 1944 the Commonwealth Government banned the export of mixed concentrates by any new producers, and established conditions under which it was necessary for existing exporters of mixed concentrates to install equipment for final separation in Australia.

Demand weakened after the war and it was not until the early 1950's that the market showed signs of recovery. By 1954 production of titanium metal in the United States was increasing and following the placing by the General

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Services Administration of contracts for the production of titanium sponge, stockpiling of rutile by United States consumers commenced, with resultant upward pressure on the price.

By 1956 the number of Australian rutile producers had increased to twenty nine, and spot sales as high as £140 per ton f.o.b. were recorded. A record production level of 129,000 tons of rutile was established in 1957 - this level was not reached again until 1963. However, in late 1957 a reassessment of the potential use of titanium in the construction of military aircraft caused the demand for rutile to ease markedly and this, coupled with the extent of accumulated stocks, caused prices to fall sharply.

With a continuation of the steady downward trend in prices (and the elimination of most of the smaller producers) attempts were made by the remaining producers in 1960 and early 1961 to rationalize their approach to production and marketing. It was not until the latter part of 1961 that a measure of stability was restored to the industry (spot prices for rutile in the meantime having fallen below £20 per ton), partly as a result of the amalgamation of certain producing companies, partly by the depletion of overseas stocks of rutile, but more particularly, as a result of the decision by E.I. du Pont de Nemours and Company Inc. to extend its titanium pigment production capacity, using Australian rutile in the chlorination process, and in effect opening up a new market.

Under the stimulus of additional long-term contracts for rutile placed by other United States pigment producers and more recently by United Kingdom producers, the position has been consolidated and the east-coast mineral sands industry has attained a degree of stability and rationalization unknown in earlier years.

Ilmenite

Metallurgical tests carried out on Western Australian ilmenite in the late 1940's confirmed that it would be satisfactory for the production of TiO_2 pigments. However, it was not until the mid-1950's that reserves were proved on a scale large enough to make practicable the establishment of a full-scale mining industry. In November 1956, Cable (1956) Ltd began mining a dune deposit on the shores of Koombana Bay, near Bunbury, using dry plant facilities acquired from Ferron Brothers Pty Ltd. Western Titanium N.L. commenced operations south of Capel in December 1956, and was followed by Ilmenite Minerals Pty Ltd at Wonnerup in mid 1958 and Westralian Oil Ltd at Yoganup early 1960. Western Mineral Sands Pty Ltd began production north of Capel in 1964. Unfortunately, the inception of the industry coincided with a period of slackened demand for ilmenite on world markets, and the early years of the domestic industry were marked by marketing difficulties. Ilmenite prices were depressed and local producers were hard put to gain a share of the markets in which established world producers were firmly entrenched. From the early 1920's to the late 1930's, Indian ilmenite had enjoyed a position of near monopoly on world markets; during the 1930's about two-thirds of world requirements of ilmenite were supplied from the beach deposits of Travancore. In post-war years those deposits lost much of their former significance as a result of government export restrictions and the increased competition from cheaper, higher-grade ilmenite from other sources. In contrast, Australia in recent years has gained an increased share of world markets, and is now responsible for about 20 percent of the total ilmenite output of the non-Communist world. However, it was not until 1960 that Australian ilmenite shipments exceeded 100,000 tons a year. By 1967, annual

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rate of production had been increased to over 500,000 tons. Early in 1968, Western Titanium N.L. commenced the commissioning of a beneficiation plant at Capel, W.A. Current capacity of 10,000-15,000 t.p.a. will be increased to 100,000 t.p.a. if demand for the product justifies the expansion.

Titanium Dioxide Pigments

The domestic TiO_2 pigment industry dates from 1949 when Australian Titan Products Pty Ltd a subsidiary of the United Kingdom firm, British Titan Products Company Ltd commissioned a plant at Burnie (Tas.). Domestic pigment production was originally based on ilmenite imported from Travancore (India) and Malaya, but subsequently was changed to ilmenite from Western Australia. Domestic production capacity was further expanded by the commissioning of a plant by Laporte Titanium (Australia) Ltd at Bunbury (W.A.) at the end of 1963. Domestic production capacity is currently rated at about 37,000 tons a year. Both plants use Western Australian ilmenite exclusively and produce both anatase- and rutile-type pigments by the sulphate method. At Burnie, Australian Titan Products employs a batch method of production and uses sulphuric acid supplied by Electrolytic Zinc Company of Australasia Ltd from its Risdon works. At Bunbury, Laporte uses a continuous process and manufactures its own sulphuric acid from imported brimstone.

CURRENT POSITION AND FUTURE POTENTIAL

Production

Rutile. Salient statistics of the rutile and ilmenite industries in recent years are given in Table 1.

Table 1. Titanium Minerals: Salient Statistics

	1963	1964	1965	1966	1967
Rutile concentrates					
Production	183,260	182,371	217,330	243,850	273,425
Exports -					
Tonnage	154,508	193,893	239,454	231,289	258,791
Value ($'000 f.o.b.)	10,632	14,080	17,134	17,844	19,692
Domestic consumption (t.p.a.)	2,000	1,700	2,850	2,700	2,200
Ilmenite concentrates					
Production	201,530	304,284	441,414	198,604	539,674
Exports -					
Tonnage	152,040	246,056	360,719	356,462	384,300
Value ($'000 f.o.b.)	1,480	2,328	3,476	3,721	3,896
Domestic consumption (t.p.a.)	33,000	49,700	63,000	65,000	70,000

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Domestic production of rutile concentrates is currently running at about 300,000 tons a year. This high level of production has been achieved by rationalization and by improved efficiency and advanced technology within the industry in the face of increased operating costs and the treatment of lower-grade ore. However, there is a limit to efficiency and a stage has now been reached where the rapid e pansion of recent years is expected to ease and production to settle at an annual rate just in excess of 300,000 tons before declining in the mid-1970's. At projected production levels, reserves economic at to-day's prices could be exhausted in fifteen to twenty years.

Ilmenite

Domestic production of ilmenite concentrates has levelled out at about 500,000 tons a year. However, further production increases are expected both from established operations in Western Australia as well as from new production from the central Queensland coast. If sufficient demand is forthcoming, domestic output of ilmenite concentrates could reach a level of 800,000 tons a year by the mid-1970's.

Indications are that an increasing proportion of domestic ilmenite output will be further processed to beneficiated ilmenite before shipment abroad. As mentioned previously, Western Titanium N.L. plans to produce 100,000 tons of beneficiated ilmenite a year, and at Gladstone (Qld). Murphyores Holdings Ltd is operating a 2 ton-per-day pilot plant, the beneficiated product of which is being evaluated by potential consumers. Subject to further commercial testing, production of beneficiated ilmenite of rutile grade is planned for 1971 at an initial rate of 50,000 tons a year.

TiO_2 Pigments

Salient statistics of the domestic TiO_2 pigment industry in recent years is given in Table 2.

Table 2. Domestic TiO_2 Industry: Salient Statistics

	1960	1961	1962 (tons)	1963	1964	1965	1966	1967
Production	11,482	11,604	12,600	16,125	24,000	29,700	30,300	34,000
Consumption	16,600	16,300	17,200	19,000	22,000	22,500	22,000	22,000
Imports -								
rutile - type	1,522	2,562	2,308	3,241	2,351	1,574	789	469
anatase - type	3,491	2,542	3,560	1,831	465	523	508	446
titanium white	41	35	79	14	59	70	52	195

Consumption

Rutile. Domestic consumption of rutile is confined to its use as a coating for electric welding rods. Annual consumption is of the order of 2,000-3,000 tons (Table 1). No significant increase in rutile consumption by this end use is seen in the short term.

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Ilmenite. Domestic consumption of ilmenite concentrates, currently about 70,000 tons a year, is restricted to the local pigment industry. Limited tonnages of high-chrome ilmenite produced as a by-product of rutile mining on the east coast are used for sand-blasting. Domestic consumption of ilmenite is not expected to exceed about 80,000 t.p.a. unless production capacity by the sulphate process is expanded significantly.

TiO_2 Pigments. Domestic consumption of TiO_2 pigments is currently about 22,000 t.p.a. The consumption growth rate has been virtually static over the last four years, possibly because of adverse climatic conditions e.g. drought, and because of improved efficiency of modern paints. However, in the period 1958-1964 domestic consumption of TiO_2 pigment increased at an annual rate of 6.7 percent, and it is reasonable to expect a future growth rate of about 5% p.a.

Statistics of the end use distribution of TiO_2 pigments in Australia are not complete (Table 3), but sufficient data are available to indicate that paint and varnish are responsible for at least 80 percent of total consumption; this compares with a figure of about 63 percent for the United States.

Table 3. Domestic Consumption of TiO_2 Pigments by End-Use

Fiscal Year ended 30th June

End Product	1959	1960	1961	1962	1963	1964	1965	1966
			(Tons of TiO_2 consumed)					
Paints & varnish	12,829	13,821	13,596	14,980	15,880	17,514	18,234	18,438
Inks & polish	260	297	292	330	335	421	434	442
Other (i)	n.a.	n.a.	n.a.	n.a.	313	194	181	195
TOTAL (i)	n.a.	n.a.	n.a.	n.a.	16,528	18,129	18,849	19,075

(i) incomplete
n.a. Not available

Overseas Trade

Rutile. Virtually all domestic output of rutile concentrates is exported (Table 4). In 1967 more than half the total rutile exports were directed to the United States where increased production of TiO_2 pigments by the chloride process has resulted in increased demand for rutile.

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Table 4. Exports of Rutile Concentrates - 1967

Destination	Quantity (tons)	Value f.o.b. ($'000)
Argentina	640	61
Austria	646	55
Belgium - Luxembourg	4,779	198
Brazil	897	80
Bulgaria	446	38
Canada	4,838	308
Chile	25	3
China - Formosa	378	35
Colombia	157	15
Finland	179	16
France	7,796	665
Germany F.R.	10,217	856
Greece	398	37
Hong Kong	400	39
India	578	51
Iran	454	42
Iraq	10	
Italy	7,139	582
Japan	19,387	2,462
Korea, R.O.	298	28
Mexico	502	47
Netherlands	18,780	1,436
New Zealand	437	39
Norway	126	11
Pakistan	34	3
Papua - New Guinea	100	9
Peru	45	4
Phillipines	193	17
Poland	4,498	361
Portugal	204	19
Romania	601	50
South Africa	2,307	188
Spain	5,654	492
Sweden	3,077	246
Switzerland	935	145
Thailand	45	4
Turkey	2,543	188
U.A.R.	1,530	123
U.K.	15,948	1,285
U.S.A.	130,376	9,336
Yogoslavia	1,045	89
Rhodesia	10	0.9
Unknown	339	29
TOTAL	258,791	19,692

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Ilmenite. Except for shipments made to domestic pigment producers, Australian output of ilmenite concentrates is exported (Table 5), the bulk under long-term contracts. In 1967, the United Kingdom (43.4%), France (21.1%), and Japan (16.1%) were the chief markets for Australian ilmenite.

Table 5. Exports of Ilmenite concentrates - 1967

Destination	Quantity (tons)	Value f.o.b. ($'000)
Belgium	36	0.7
China, Formosa	182	3
France	80,959	795
Italy	9,989	101
Japan	61,850	597
Netherlands	5,907	115
South Africa	10,000	89
Spain	60	1
U.K.	166,700	1,771
U.S.A.	48,617	423
TOTAL	384,300	3,896

TiO_2 Pigments. Australia imports limited quantities of some special grades of TiO_2 pigments (Table 2). Imports in 1967 were mainly from Japan, the United States, and the United Kingdom. In recent years Australia has developed a small export trade in pigments, presumably to south-east Asia. However, details of exports in this category are not recorded separately.

WORLD POSITION OF THE AUSTRALIAN INDUSTRY

Rutile

Production of rutile by non-Communist countries in recent years is given in Table 6.

Table 6. World Production of Rutile (tons)

	1963	1964	1965	1966	1967
Australia	183,260	182,371	217,330	243,858	273,425
Sierra Leone	-	-	-	-	24,000
United States	10,638	7,200	(e)5,400	(e)5,000	(e)5,000
Others (e)					
World total (e)	198,100	189,000	224,000	251,000	304,900

(e) estimated

In 1967 Australia was responsible for approximately 90 percent of non-Communist supplies of rutile. Sierra Leone is expected to be supplying about 100,000 t.p.a. by 1970 when the plant of Sherbro Minerals Ltd reaches planned capacity. Despite the dominance of Australia as a rutile producer over the last twenty-five years, we must expect considerable tapering off in production by 1980 with the exhaustion of higher grade reserves, and the Australian industry to move from a position of pre-eminence to one which, while still important, is much more vulnerable to competition from other sources of titania.

However, it might be noted that possible offshore resources, particularly those suspected off the central east coast of Australia, could prolong major production should both reserves and commercial exploitation be demonstrated in the next decade.

Ilmenite

Production of ilmenite by principal producing countries is given in Table 7.

Table 7. World Production of Ilmenite: Principal Producing Countries (a)

	1963	1964	1965 (tons)	1966	1967
Australia	201,530	304,284	441,414	498,604	539,674
Canada (b)	817,286	1,239,520	1,327,666	1,129,181	1,288,000
Finland	93,000	114,230	105,000	115,703	124,900
India	25,553	10,579	29,582	29,691	40,900
Malaysia (c)	146,718	129,222	121,566	116,368	89,372
Norway	238,429	267,727	280,000	363,887	420,000
United States	793,214	893,868	865,588	861,945	860,000

(a) Excludes large tonnages of ilmenite - magnetite ore produced in the U.S.S.R.

(b) Ore shipment for the production of titanium dioxide slag. Production of slag (70% TiO_2): 1963, 338,677 tons; 1964, 486,358 tons; 1965, 487,425 tons; 1966, 468,547 tons; 1967, 537,906 tons.

(c) Exports.

Australia is the principal world producer of alluvial ilmenite and contributes about 20 percent of total world supplies of ilmenite. The ilmenite deposits now being mined in Western Australia are high-grade by world standards, and, although no precise data on costs are available, actual costs of mining and of concentration are believed to compare favourably with those of other countries. If Australian producers maintain their current share of world ilmenite markets (and there is every reason to expect that they will), annual demand for Australian ilmenite should increase to about 700,000 tons by 1975.

TiO_2 Pigments

The domestic TiO_2 pigment industry is small by world standards. Details of capacities of world TiO_2 plants are given in Appendix A.

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OVERSEAS CONTROL OF THE AUSTRALIAN MINERAL SANDS INDUSTRY

Over the years, foreign groups have acquired a controlling interest in some of the larger mineral sand operations. The importance of this overseas equity in providing capital, technical know-how and international sales distribution for products of the domestic industry is developed later in this paper. Appendix B details overseas equity in the Australian mineral sands industry.

SCOPE FOR ADDITIONAL PROCESSING OF MINERAL CONCENTRATES

Domestic processing of titaniferous concentrates is currently confined to the beneficiation of ilmenite concentrates, and the production of TiO_2 pigment from Western Australian ilmenite concentrates by the orthodox sulphate method. As far as beneficiation of ilmenite is concerned, one mineral sand operator has achieved production on a semi-commercial scale, another is operating on a pilot-plant scale, and at least one other it actively engaged on feasibility studies along these lines. Australian producers are acknowledged world leaders in the field of ilmenite beneficiation and it is reasonable to expect that an increasing preparation of locally-produced ilmenite concentrates will be upgraded in years to come.

There appears to be only limited scope for further expansion of domestic production capacity for TiO_2 pigment by the sulphate method. Australia is self-sufficient in this type of pigment, and the two domestic producers are actively engaged in promoting an export trade to take up surplus production. However, world markets are intensely competitive and excess sulphate capacity is already evident (Appendix A). The main aim for Australian exporters is the market of South East Asia already supplied by Japan.

As yet there has been no domestic production of TiO_2 pigments based on a chloride process, of titanium sponge, nor of titanium tetrachloride, the intermediate chemical stage of both these products. The feasibility of producing and disposing of these products is now discussed.

TITANIUM TETRACHLORIDE ($TiCl_4$)

Production

Titanium tetrachloride is produced by the chlorination of titaniferous material in the presence of carbon. Above 700°C the main reaction is:

$$TiO_2 + 2C + 2Cl_2 \rightarrow TiCl_4 + 2CO.$$

In a continuous process, rutile ore, mixed with powdered coke or anthracite, is chlorinated to completion in a fluidized state in a shaft furnace at 900°C. Titanium tetrachloride, ferric chloride, and chlorides of other contaminating metals and impurities are formed simultaneously, volatilized, and removed as a gaseous mixture from the furnace. On discharge from the furnace the gaseous mixture is cooled to 250°C and admitted to the base of a scrubber column connected at the lower end to a reboiler and at the upper end to a reflux condenser. The titanium tetrachloride and silicon tetrachloride which together with the entrained solids, ferric chloride and zirconium tetrachloride, from the gases are washed down the column to the reboiler. From the reboiler, the titanium tetrachloride is recovered by redistillation and from the gases leaving the condenser by cooling to -10°C.

Raw Materials

Most titaniferous materials can be chlorinated, at least on a laboratory scale, for the production of $TiCl_4$. A list of possible feeds include rutile, sphene, ilmenite, titanium slag, red mud (from the caustic treatment of bauxite), and titanium carbide. In commercial practice, feed specifications are most stringent. The feed should be high in TiO_2 and low in iron, and content of calcium, magnesium, sodium and potassium must be negligible as these elements react to produce non-volatile chlorides which coat the reactant grains thus impeding the formation of $TiCl_4$. Low concentrations of aluminium, silicon, iron, tin, zirconium, and even chromium are permissible as the chlorides and oxychlorides of these elements are volatile and can be separated from the $TiCl_4$ by fractional distillation. The exception is vanadium which forms an oxychloride of which the boiling point is similar to that of $TiCl_4$, and which involves chemical treatment for its removal.

Production of $TiCl_4$ in the United States is based almost exclusively on Australian rutile. The exception is du Pont which augments supplies of Australian rutile with a mixture of ilmenite, leucoxene, and rutile produced from its Florida deposits. In the past, Japanese producers have based their industry on titanium slag, but are now reported to be switching to natural rutile. Future, large-scale output of $TiCl_4$ by the United Kingdom producers, British Titan Products Company Ltd and Laporte Titanium Ltd will be based on Australian rutile at least until the mid-1970's.

In recent years it has become increasingly evident that world demand for natural rutile will soon outstrip supplies. Forward projections indicate that, by the mid-1970's world consumption of titania for $TiCl_4$ production for use in pigment and metal production could increase to about 700,000 t.p.a. This compares with projected annual supplies of about 400,000 tons of natural rutile. It follows that other sources of high-grade titania e.g. beneficiated ilmenite, will be needed to supplement future supplies of natural rutile. Tests recently carried out by potential overseas consumers indicate that beneficiated ilmenite from Western Australia will prove to be an acceptable feed for the production of $TiCl_4$.

The other main requirement for the economic production of $TiCl_4$ is the availability of cheap chlorine. The overseas experience is that $TiCl_4$ plants are invariably located within or near to a chemical complex where by-product chlorine is available at relatively low cost.

The Australian Position

Australia is well-placed with regard to supplies of titaniferous ore, particularly rutile. However, it must be borne in mind that increasing demands are being made on domestic rutile supplies by overseas consumers in the pigment, sponge, and welding-rod industries. Although there is no immediate danger of exhaustion of rutile reserves, those presently known are limited. It would therefore be more realistic to base a long-term project such as that involving the production of $TiCl_4$ on a more sustained supply of titaniferous feed including beneficiated ilmenite as well as natural rutile.

A list of prospective sites for $TiCl_4$ plants in Australia (Table 8) has been drawn up on the basis of availability of beneficiated ilmenite and potential supplies of beneficiated ilmenite and potential supplies of cheap chlorine.

Table 8. Possible Sites for $TiCl_4$ Plants in Australia

Site	Company	Potential source of raw materials		Power
		Titaniferous feed	chlorine	Availability
Gladstone (Qld)	Murphyores Holdings Ltd	beneficiated ilmenite (96-97% TiO_2) (probably, plus rutile)	cheap by-product chlorine available if caustic plant erected at Gladstone to supply caustic requirements of Queensland Alumina Ltd.	Power costs relatively high at present, but costs will be reduced significantly if planned industrialization of the area is brought into effect
Kwinana (W.A.)	Western Titanium N.L. and Westralian Oil Ltd	beneficiated ilmenite (93% TiO_2) from Capel plant of West. Titanium and possibly leucoxene from W.O.L. Yoganup operations	by-product chlorine if caustic plant installed to supply requirements of alumina plant of Alcoa.	from W.A. State grid system. Kwinana power station to be changed from coal to oil.
Newcastle (N.S.W.)	Rutile & Zircon Mines (Newcastle) Ltd	beneficiated ilmenite from Westport area (N.Z.)	Chlorine from I.C.I. caustic works at Botany Bay (N.S.W.)	relatively low-cost power from N.S.W. grid system.

Of the three sites listed, the Gladstone area seems to have the greatest potential as far as natural resources are concerned. The potential of the area as a site for a $TiCl_4$ plant is described in more detail below.

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Beneficiated Ilmenite. Murphyores Holdings Ltd plans to commence mining operations at Point Richards (south of Gladstone) and treatment of concentrates at Barney Point (Gladstone) in early 1969 with an initial output of 58,000 tons of ilmenite, 28,000 tons of zircon, and 6,000 tons of rutile a year. At Gladstone, the company is operating a 2 ton-per-day pilot plant, the beneficiated product of which is being evaluated by potential consumers. Subject to further commercial testing, production of beneficiated ilmenite of rutile grade is planned for 1971 at an initial rate of 50,000 t.p.a.

Chlorine. At capacity of 1.8 million tons of alumina a year, the Gladstone plant of Queensland Alumina Ltd will require about 320,000 tons of 50% NaOH a year. If a caustic plant was installed at Gladstone, approximately 140,000 tons of co-product chlorine a year would be available. Such an alkali plant would presumably be based on the brine deposits of Port Alma which contain about 9 percent salt compared with 3 percent salt in sea-water. According to studies carried out by the Office of Secondary Industry, salt from this source could be delivered at Gladstone for below $3.00 a ton which is cheap by world standards. The Office of Secondary Industry estimates that co-product chlorine from the alkali plant would be available for about $40-50 a ton as compared with the current Australian list price of $130 a ton and transfer prices around $80 a ton. Such a price level would make the local cost of chlorine comparable with that of the United States and Europe and less than the price in Japan.

Power. Although the production of $TiCl_4$ is not power intensive, the electrolysis of brine is - and this controls the cost of caustic and chlorine. In general, the electrolysis of 1.75 tons of salt requires 3,000 KWh of electricity for a yield of 1 ton of chlorine and 1.15 tons of caustic soda. According to the Office of Secondary Industry, the S.E.C. has indicated that the price of electricity to high load factor users could be as low as 3 mills. based on a 800 MW coalfield power station. Even if this figure is somewhat on the optimistic side, it still seems likely that, if the full industrial potential of the Gladstone area is realized, power will be available to the area at competitive prices.

However, the costs suggested above warrant close checking with industry to better establish feasibility; power costs are vital for a wide range of industries, including the production of aluminium, and costs of not more than 3 mills. per kw/h for major consumers in the Gladstone area would appear to be a most worthwhile target. But it is well to realise that this would probably mean reducing by half the cheapest power costs available to any major consumer in the area at the present time.

It may be concluded from the foregoing that $TiCl_4$ could be produced in Australia at competitive cost if low-cost chlorine was to be made available within specific areas. Assuming that this will eventually become a reality, it is pertinent to this exercise to examine possible outlets for the locally-produced product.

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Outlets for Titanium Tetrachloride. Titanium tetrachloride is used mainly for the production of TiO_2 pigments (via a chloride process), and for the production of titanium sponge. Commercial production of $TiCl_4$ in Australia will be dependent on the development of a domestic market for $TiCl_4$ which will in turn depend on the development of plant for the production of TiO_2 pigment (via a chloride process) and/or of titanium sponge. The feasibility of producing chloride pigment and titanium sponge in Australia is discussed later in this paper.

Prospects of developing an export market for $TiCl_4$ appear good. Strong consumer resistance might be expected within the integrated markets of the United States and Europe, but the Japanese market should provide a ready outlet for $TiCl_4$ of Australian origin. Japan is a major world producer of titanium sponge and potentially a large chloride process operator. In 1967, Japan was the second largest importer of Australian rutile (Table 4) and the third most important importer of Australian ilmenite (Table 5). Costs of salt and of electricity are both comparatively high in Japan with the result that chlorine is a significant cost item to the Japanese chemical industry. Although $TiCl_4$ of Australian origin would face an import tariff of 12% ad valorem into the Japanese market, the geographical proximity of the two countries would moderate c.i.f. charges to a degree where the landed cost of Australian $TiCl_4$ should be competitive with the domestic Japanese list price.

Anhydrous titanium tetrachloride is a colourless liquid (S.G. of about 1.74 at normal temperatures) which fumes strongly in moist air. Although it presents transport problems because of the readiness with which it hydrolyses, such problems can be overcome by the use of special tankers.

TITANIUM DIOXIDE PIGMENT

Methods of Production

Briefly, the sulphate process for the production of TiO_2 pigments involves the digestion of titaniferous ore (usually ilmenite or Sorel slag) in sulphuric acid with the formation of titanyl and ferrous sulphates. The temperature of the solution is reduced and the ferrous sulphate separated out by fractional crystallization. The filtrate is hydrolysed and the titanium hydrate precipitate is filtered, dried and calcined to titanium dioxide. In contrast to the sulphate process, the chloride process is conducted substantially under dry conditions and many of the operations are carried out in the vapour phase. In brief, a soft, finely divided titanium dioxide of excellent pigment properties is produced from the burning of vaporized titanium tetrachloride in oxygen at temperatures above 1,000°C with the recovery of chlorine.

Although the chemistry of both processes is relatively simple, the recovery of titanium dioxide and subsequent treatment to convert it to a saleable product requires a high degree of technological expertise, particularly in the case of the chloride process.

Chloride Versus Sulphate Process

The viability of an operation involving the production of TiO_2 pigments by the chloride process in Australia will be dependent on many factors, but first and foremost the infant industry will need significant markets for its output. Whether these markets are local or overseas, the product will have to compete in a highly competitive field where pigments produced by the sulphate process are well entrenched. It is therefore pertinent to examine the competitive position of the relatively new chloride process vis a vis the more orthodox sulphate process.

The main advantages of the chloride process are summarized below:

(1) Lower capital cost. Data are not available concerning the capitalization involved in the two processes, but it is generally accepted within the industry that capital costs of a chloride-process plant are significantly lower than those of a sulphate-process plant. Indications are that a chloride plant with a capacity of 10,000 to 12,000 t.p.a. would cost about $US9 to $US12 million. Large plants with capacities of 24,000 to 25,000 t.p.a. would require investments of $US15 to $US20 million.

(2) Lower operating cost. With Australian rutile available at about $100 per ton c.i.f. (contract price), and with low-cost by-product re-agents (e.g. chlorine), operating costs of chloride process plants are at least competitive with those of sulphate process plants. Sulphate plants have been placed at a greater disadvantage in this regard with the increase in sulphur prices and the concomitant rise in sulphuric acid costs.

(3) Flexibility in scale. It is generally accepted that sulphate process plants require an operating capacity of at least 50,000 t.p.a. to achieve worthwhile economies of scale. Optimum capacity of chloride-process plants is said to be as little as 20,000 t.p.a. In fact, it is possible that chloride-process plants of 2-3,000 t.p.a. will be operated using purchased titanium tetrachloride.

(4) Higher-grade pigment. Despite improvements achieved in producing higher-grade pigment by the sulphate process, chloride-process pigment continues to be regarded as the highest grade of TiO2 pigment available.

(5) Lack of effluent problems. The sulphate process is bedevilled, particularly in urban areas, with the effluent problem associated with the disposal of ferrous sulphate. Ferric chloride constitutes the only effluent problem of the chloride process, and, if a high TiO_2 ore e.g. rutile is used, the volume of ferric chloride produced is negligible.

Disadvantages of the chloride process are:

(1) Restricted supply of raw material. Until beneficiated ilmenite is proved to be a suitable economic feed for the chloride process, the process is restricted to natural rutile, supplies of which, as pointed out above, appear likely to be inadequate in the long term.

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(2) Requirement of high degree of technological expertise. Many years of research and millions of dollars have been spent on the development of chloride processes with varying degrees of success. Of the five chloride-process plants commissioned in the United States in recent years, only three (those of du Pont, National Lead and American Potash and Chemical Corporation) are fully functional. Those of Cabot Corporation and American Cyanamid are currently shut down pending plant modification.

(3) Product limitation. To all purposes and intent the chloride process produces one grade of TiO_2 pigment and this a particularly high quality one. In contrast, the sulphate process allows for a wide range of pigments of varying grades. Basically, the sulphate process produces an anatase-type pigment which can be further processed to the better-quality rutile-type pigments. The chloride process produces a rutile-type pigment, direct.

(4) Market limitation. The overall market is restricted for chloride-type pigment because of the exceptionally high quality of the pigment. In contrast, sulphate-process pigments are adequate, cheaper and preferred for many uses where a high-quality pigment is not necessary. In the United States, chloride-process pigment is used principally in high-quality paints and supplies only about 15 percent of the overall market for TiO_2 pigments.

Raw Materials

Assuming that a cheap supply of $TiCl_4$ is readily available, the only other important reactant required is oxygen which should be available at reasonable cost from a chemical complex on the scale of that visualized for the Gladstone area. Oxygen requirements for the central Queensland area are currently met by supplies from the Brisbane works of Commonwealth Industrial Gases Ltd (C.I.G.). The company plans to establish an oxygen plant at Gladstone if demand warrants.

Technical Know-How

As mentioned above, commercial production of TiO_2 pigment via a chloride process requires a high degree of technical know-how and a prerequisite for production in Australia would be the acquisition of the necessary patent rights. Several large, integrated, overseas organizations are either actively engaged in mineral sand mining in Australia or are associated with Australian mineral sand operators through long-term contracts involving the supply of mineral concentrates. Contract details are summarised in Appendix C. One might therefore expect that the necessary production flow-sheets and techniques could be made available either as plant commissioned and operated by overseas pigment manufacturers, or to domestic producers under licence from overseas groups.

Markets for Potential Domestic Output

The limited domestic market for TiO_2 pigments is currently supplied by sulphate-process pigment produced in Australia. Accordingly, any additional

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sales of chloride-produced pigment would, in the main, be achieved at the expense of sulphate pigment sales. Failing a marked increase in the overall level of domestic consumption, it is unlikely that chloride process pigment would gain any significant portion of the local market, at least in the short term. Both of the Australian TiO_2 pigment producers are wholly-owned subsidiaries of United Kingdom-based organizations (Appendix B). Both companies are installing large-scale capacity for the production of chloride-process pigment in the United Kingdom and it is only reasonable to expect that any inroads made by chloride pigments on the captive markets of the companies in Australia will be supplied from stocks in the United Kingdom.

Possible future exports of chloride-process pigment would have to make their way in a highly competitive sector of world trade. In this regard, marketing facilities offered by the international sales organization of large overseas groups (Appendix C) would be a useful adjunct if not a prerequisite of success in this field. Australia's competitive position in the principal world markets viz. United States, Japan, United Kingdom, and the European Economic Community would suffer further disadvantage by tariff barriers raised against the imports of titanium products into these areas. Levels of protection afforded titanium products are outlined in Table 9.

Table 9. Tariffs on Imports of Titanium Products
Tariff (% ad valorem)

Country or Area	Titanium Sponge	TiO_2 Pigment	$TiCl_4$
U.K. (a)	10	15-12-7.5	25
E.E.C.	6(b)	15-9.6-6(c)	12-9.6-6(c)
U.S.A.	20-19.5-18	15-13-7.5	15-13-7.5
Japan	15	15-12-7.5	15-12-7.5

(a) rate for imports from Commonwealth sources is free
(b) under suspension
(c) reductions depend upon adjustments made to U.S. selling prices

NOTE: Where three tariff levels are shown, the first represents the rate existing before cuts were agreed to in the Kennedy Round tariff negotiations, the second the rate now in force, and the third the rate to be in force from the end of the reduction period i.e. from 1 January 1972.

TITANIUM SPONGE

Method of Production

The production of titanium is an intricate operation due to the fact that the hot metal combines with oxygen, nitrogen, and moisture in the air, with carbon, and with most construction materials. Accordingly, titanium tetrachloride is reduced to sponge by bubbling the gaseous $TiCl_4$ through molten magnesium under an atmosphere of helium or argon at around 800°C. Titanium sponge is recovered from the magnesium and magnesium chloride by vacuum distillation. Although the actual reaction is probably complex, the net reduction is represented by the equation,

$$TiCl_4 + 2\ Mg \rightarrow Ti + 2\ MgCl_2 \ + \text{heat}$$

or theoretically 4 tons of $TiCl_4$ is reduced by 1 ton of magnesium to 1 ton of titanium sponge and 4 tons of magnesium chloride.
In practice, excess magnesium is used to prevent side reactions, and the magnesium efficiency does not exceed 90 per cent.

The titanium sponge is melted in electric furnaces, the melt cooled in water-jacketed moulds and cast into billets and ingots of up to 5 tons. Specifications for the use of titanium in aircraft components require that the sponge be double-melted.

Raw Material Requirements

The production of 1 pound of titanium sponge requires approximately 2.5 pounds of rutile (or some other titaniferous material of equivalent TiO_2 content), 5 pounds of chlorine, 1.25 pounds of magnesium, and about 0.9 cubic feet of inert gas. If magnesium and chlorine are recovered, about 0.2 pounds of magnesium and one pound of chlorine are required. Power requirements vary from 6 to 15 kilowatt hour per pound of sponge. The major power requirement includes that for recovering the reductant metal (magnesium) and chlorine.

Local Availability of Raw Materials

Assuming that a cheap supply of $TiCl_4$ is available, the other principal requirements for a sponge plant will be magnesium and a local source of cheap power. No magnesium is produced in Australia although BHP did produce magnesium as a wartime measure in the period 1941-1944 by the thermal reduction of calcined magnesite with calcium carbide.

If necessary, magnesium could be recovered from say the salt bitterns of the Port Alma (Qld) salt operation. However, the bulk of magnesium used in the reduction of $TiCl_4$ is subsequently reclaimed and it is doubtful if the requirements of a titanium sponge plant, alone, would warrant the installation of an ancillary magnesium plant. Australian magnesium requirements are limited, and in 1967 domestic imports of unworked magnesium and magnesium-base alloys amounted to only 615 tons.

Availability of cheaper power is essential for the economic production of titanium sponge where electricity is required in most stages of the process for the production of chlorine, melting of the sponge and final recovery of magnesium and chlorine.

Capital Investment

Production of titanium sponge is a capital intensive business. Cost of plant depends to a large degree on the scale of operations, and estimates of capital costs range upward from about $3,500 per installed ton capacity of sponge, exclusive of the cost of such ancillary plant as magnesium cells etc.

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Technical Know-How

As in the case of TiO_2 pigment production via the chloride process, titanium production requires special techniques. Here again, affiliation of Australian mineral producers with overseas metal producers could prove most advantageous in acquiring the necessary expertise, and in offsetting the time, talent and heavy expenditure involved in producing titanium sponge on a commercial scale.

Because of the special problems associated with the production of titanium sponge, world output is confined to a handful of producers (Table 10) and some experts predict that, notwithstanding the burgeoning demand for titanium which is expected to be a feature of the 1970's, future production will in the main, be confined to established producers.

Table 10. Titanium Sponge Producers

Company	Annual Capacity (short tons)	Production 1967 (est.) (short tons)	Expansion Plans
U.S.A. -			
Titanium Metals Corporation of America	12,000	16,000 (combined U.S.A.)	Sponge capacity of Henderson (Nev.) plant currently being expanded to 16,000 t.p.a.
Reactive Metals Inc.	6,000		Sponge capacity of Ashtabula (Ohio) plant to be increased to 8,500 t.p.a. by 1970
Oregon Metallurgical Corp.	2,000		Sponge capacity to be increased to 4,500 t.p.a. by mid-1969.
Japan -			
Osaka Titanium Co. / Toho Titanium Co.	8,900	8,000	
U.K. -			
Imperial Chemical Industries Ltd	3,000	2,000	

Supply and Demand

Non-Communist world production of titanium sponge increased to an estimated 27,000 short tons in 1967 of which the United States and Japan were responsible for 24,000 short tons, and Western Europe the balance.

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The United States continues as the world's leading producer of titanium and constitutes the only significant market for sponge in the Western World. In 1967, U.S. domestic supplies were augmented by imports of foreign sponge which increased significantly to 8,125 short tons (5,889 short tons in 1966); approximately 19 percent from the U.S.S.R. and most of the balance from Japan. Additional supplies were made available by sales of titanium from the U.S. Government stockpile which totalled 700 short tons in 1967.

In contrast to increased supplies, demand fell short of expectations due mainly to a slow-down in the United States supersonic transport programme. By the end of 1967 industry stocks of sponge had increased to 3,860 short tons (826 short tons at the end of 1966). Consumption of titanium sponge in 1967 was unchanged at about 20,000 short tons although consumption of titanium ingot increased to 25,384 short tons (22,317 short tons in 1966). Jet engine requirements remained the major source of demand in 1967 accounting for about 54 percent of the total market. Airframes consumed about 34 percent (26 percent military and 8 percent commercial), space applications and missiles 6 percent, and non-aerospace uses the balance of 6 percent. Industry projections indicate that demand should double by the early 1970's, but that planned capacity will be more than sufficient to cope with increased consumption.

Market Restrictions

Australian titanium requirements are very limited. Small amounts of fabricated metal are imported mainly for use as chemical equipment and in the electroplating industry. A worthwhile domestic market would be dependent on the development of supersonic aircraft plant, chemical equipment plant (including desalination equipment), or the installation of fabrication facilities for the output of titanium mill products. Specialized equipment to process the metal at elevated fabricating temperatures is required and it is interesting to note that such steel specialists as United States Steel Corp., Allegheny Ludlum Steel Corp., Crucible Steel Company of America and Armco Steel Corp. are already directly connected with the production and fabrication of titanium. B.H.P. comes to mind as a potential domestic fabricator.

As far as overseas markets are concerned, the United States constitutes the only significant outlet for titanium sponge; and this market is already over-supplied despite a tariff barrier of 20 percent ad valorem on imports of sponge. In fact, dumping changes laid by U.S. domestic producers against sales of Russian sponge in the United States were upheld by the United States Tariff Commission in mid-1968.

VALUE ADDED BY MINERAL PROCESSING

It is difficult to ascribe any exact figure to the value added by processing titaniferous concentrates to the titanium products discussed in the foregoing. The exact domestic price of mineral concentrates are in the main quoted nominally; the cost of by-product re-agents depends largely on company transfer prices; and landed costs of basic raw materials vary according to c.i.f. charges. However, some idea of the order of value added by further processing of mineral concentrates can be gleaned from Table 11 which compares domestic prices and prices quoted on the United Kingdom and United States markets.

Table 11. Base Prices of Titanium Ores and Products

	Australia ($A)	U.K. (£stg)	U.S.A. ($U.S.)
rutile concentrates	$88-92 per ton f.o.b. (nom)	£48-50½ per ton 95-97% TiO_2 c.i.f.	$121-125 per short ton 96% TiO2 f.o.r. Atlantic ports delivered within 12 months.
ilmenite concentrates	$9-10 per ton f.o.b. Bunbury (nom.)	£7½-9½ per ton 52-54% TiO2 (Malaysian) c.i.f.	$20-21 per long ton 54% TiO2 f.o.b. Atlantic ports.
beneficiated ilmenite	future price estimated as $70 per ton f.o.b.	-	-
Titanium tetrachloride	no published price	£136 per ton c.i.f.	$300 per tonne c.i.f. (Japanese origin)
titanium dioxide pigments	$449 per ton (anatase grade) $552 per ton (rutile grade)	£163 per ton (anatase) £199 per ton (rutile)	U.S. 25 cents per lb. (anatase) U.S. 27 cents per lb. (rutile)
titanium sponge	-	10/6 per lb. (99.3% max. 120 Brinell hardness)	$1.32 per lb. (domestic) $1.20-1.25 per lb. (Japanese origin)
titanium mill products	-	not available	billet (Ti-6Al-4V) $2.53 per lb. bar (Ti-6Al-4V) $3.63 per lb. sheet and strip (Ti 50 Al) $5.85 per lb. plate (Ti 65 Al) $4.00 per lb. wire (Ti 50 Al) $7.80 per lb.

CONCLUSIONS

It has been suggested from time to time that Australian mineral sands producers should further extend the vertical integration of their industry with culmination in the domestic production of titanium metal. Until recently, such a project would have been based of necessity on natural rutile; the development of synthetic rutile from ilmenite has now opened up an additional source of raw material.

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Australia is pre-eminent as a world producer of titaniferous ores and hence the domestic production of titanium pigment, from the chloride process, and of titanium metal would be a logical development of the Australian mineral sands industry. However, this analysis of extended mineral processing of titanium ores in Australia suggests that the production in Australia of either TiO_2 pigment by a chloride process or of titanium metal should still be regarded as a future development rather than as an immediate target.

The difficulties lie in markets and cost of production rather than in capital requirements or technical knowhow; these difficulties should become less formidable as domestic demand grows, with greater population and the establishment of a supersonic aircraft industry, and as world needs for titanium products increase.

However, the analysis is not without encouragement as it emphasises the possibility of extending mineral processing along the route toward pigment and metal to the intermediate stage of producing $TiCl_4$ for which overseas markets should present less difficulty than for higher processed products. Production of $TiCl_4$ from rutile or beneficiated ilmenite would need to be based on low cost chlorine, provided by a chemical complex which itself would require low cost salt and power and a market for other products, chiefly caustic soda. Such a complex has already been mooted at Gladstone where the possibilities of fulfilling the requirements for the commercial production of $TiCl_4$ appear worthy of more detailed investigation of the industries involved.

Appendix A. Non-Communist World TiO_2 Pigment Production Capacity

Country/Company	Location of Plant	Annual Capacity	Type of Process	Expansion Plans
United States -				
National Lead Company	Sayreville, N.J.	167,000 short tons	sulphate	
	St. Louis, M.O.	36,000 " "	chloride	
E.I du Pont de Nemours & Co. Inc.	Edgemoor, Del.	108,000 " "	sulphate	
	New Johnsonville, Tenn.	75,000 " "	sulphate & chloride	
	Baltimore, Md.	68,000 " "	sulphate	sulphate process is to be discontinued at the Baltimore plant.
	Antioch, Calif.	27,000 " "	chloride	
Glidden Corporation	Hawkins Point, Md.	56,000 " "	sulphate	25,000 t.p.a. capacity to be installed by 1970 using chloride process under licence from American Potash and Chemical Corp. (AMPOT)
American Cyanamid Co.	Savannah, Ga.	72,000 " "	sulphate	
		20,000 " "	chloride	
The New Jersey Zinc Company	Gloucester City, N.J.	46,000 " "	sulphate	
American Potash and Chemical Corp.	Hamilton, Miss.	30,000 " "	chloride	
Cabot Titania Corp.	Ashtabula, Ohio.	20,000 " "	chloride	
Pittsburgh Plate Glass Co.	Natrium, W.Va.	-	chloride	20,000 t.p.a. chloride plant to be commissioned in 1969.
Sherwin Williams Co.	Ashtabula, Ohio.	-	chloride	25,000 t.p.a. chloride process plant under licence from du Pont to be brought on stream 1969-70.
Canada -				
Tioxide of Canada Limited	Ville-de-Tracy, Quebec.	27,000 " "	sulphate	
Canadian Titanium Pigments Limited	Varennes, Quebec.	30,000 " "	sulphate	a 10,000 t.p.a. extension of the Varennes plant, based on a chloride process to be commissioned towards the end of 1968.
		-	chloride	
United Kingdom -				
British Titan Products Company Ltd	Grimsby, Lincs.	90,000 long tons	sulphate, part chloride	B.T.P. to install 30,000 t.p.a. of chloride capacity at Greatham.
	Billingham, Durham.	20,000 " "	sulphate	
Laporte Titanium Ltd	Stallingborough, Lincs.	50,000 " "	sulphate	plant capacity to be expanded by 40,000 t.p.a. based on chloride process developed by AMPOT.

France -				
Societe des Fabriques de Produits Chimiques de Thann et de Mulhouse	Thann, Haut-Rhin.	20,000 tonnes	sulphate	chloride capacity to be installed
Les Produits du Titane S.A.	Le Havre	36,000 "	sulphate	
British Titan Co. Ltd. (Tioxide S.A.)	Calais	25,000 "	sulphate	
Germany -				
Farbenfabriken Bayer, A.G.	Uerdingen, Westfalen.	60,000 "	sulphate	
Titangesellschaft GmbH	Leverkusen, Westfalen.	80,000 "	sulphate	17,000 t.p.a. chloride capacity to be commissioned at the Leverkusen plant in 1969.
Pigment Chemie GmbH	Homberg, Niederrhein.	24,000 "	sulphate	
Belgium -				
Societe Chimiques des Derives du Titane	Langerbrugge, Sas Van Ghent	15,000 "	sulphate	
Italy -				
Montecatini-Edison S.p.A.	Spinetta Morengo Bovisa, Milano Scarlino.	40,000 " 15,000 "	sulphate sulphate	
Spain -				
Union Quimica del Norte de Espana, S.A.	Axpa-Erandio, Bilbao.	7,000 "	sulphate	capacity to be doubled.
Chromogenia & Quimica Curtiente, S.A.	Barcelona	2,500 "	sulphate	
Portugal -				
La Pigmentos de Titanium, Lda	Cabo de Sines, Estremadura	6,000 "	sulphate	
Finland -				
Vuorikemia Oy	Mantyluoto, Otanmaki	16,000 "	sulphate	
Norway -				
Titan Co., A/S	Fredrikstad	15,000 "	sulphate	
Netherlands -				
N.V. Titaandioxyde - Fabrick Tiofine	Botlek, Rotterdam.	12,000 "	sulphate	capacity to be doubled in 1968.
Mexico -				
Pigmentos y Productos Quimicos S.A. de C.V.	Tampico, Tamaulipos	7,000 "	sulphate	
Argentina -				
Titanit Compania Industrial de Pigmentos y Afines S.A.	Pilar (near Buenos Aires)	5,000 "	sulphate	

<u>Brazil</u> -				
Comnania Quimica Industrial C.I.L., S.A.	Engenheiro Trinidade, San Paulo	5,000 tonnes	sulphate	
<u>South Africa</u> -				
South African Titan Products Pty Ltd	Umbogintiwini, Natal	15,000 "	sulphate	being expanded to 20,000 t.p.a., eventual capacity of 34,000 t.p.a. planned.
<u>India</u> -				
Travancore Titanium Products Ltd	Trivandrum, Kerala	15,000 "	sulphate	capacity to be increased to 22,500 t.p.a. by 1970.
<u>Japan</u> -				
Isihara Sangyo Kaisha Co.	Yokkaichi, Mie Pref.	45,000 "	sulphate	currently being expanded to about 65,000 t.p.a.
Furukawa Mining Co. Ltd	Osaka, Osaka Pref.	12,000 "	sulphate	
Teikoku Kako KK	Saidaiji, Okayama Pref.	12,000 "	sulphate	
Fuji Titanium Industry Co. Ltd	Kobe, Hyogo Pref.	10,000 "	sulphate	
Sakai Chemical Industry Co. Ltd	Sakai, Osaka Pref.	11,000 "	sulphate	
Titan Kogyo KK	Ube, Yamaguchi Pref.	5,000 "	sulphate	
Mitsui Mining & Smelting Co. Ltd	Hibi, Tamano	2,000 "	sulphate	
Toho Titanium Co.	Chigasaki, Kanagawa Pref.	2,500 "	sulphate	
<u>Australia</u> -				
Australian Titan Products Ltd	Burnie, Tas.	25,000 long tons	sulphate	
Laporte Titanium (Australia) Pty Ltd	Bunbury, W.A.	12,000 " "	sulphate	capacity to be expanded to 18,000 t.p.a. by the end of 1969.

Appendix B. Ownership of Australian Mineral Sands Industry

Operating Company	Shareholding	Overseas Ownerships	Local Ownership (a)	ANNUAL PRODUCTION (TONS) Rutile	Zircon	Ilmenite
Associated Minerals Consolidated Ltd (Includes Wyong Minerals Ltd which became a wholly owned subsidiary of Associated Minerals as from mid-1967)	60% Consolidated Gold Fields (Australia) Ltd (CGFA) (b) 40% local residual	46% Consolidated Gold Fields of U.K. through its 77.3% holding in CGFA	14% through 22.7% holding in CGFA 40% as a residual 54%	88,000	87,000	7,000
Mineral Deposits Ltd	85% National Lead Company 15% local residual	85% National Lead Company of U.S.	15% as residual	45,000	35,000	-
Queensland Titanium Mines Pty Ltd	50% National Lead Co. 50% Titanium Metals Corp of America	50% National Lead Co. 50% TMCA	Nil	20,000	15,000	-
Rutile and Zircon Mines (Newcastle) Ltd	50% Peko-Wallsend Investments Ltd 50% Coffs Harbour Rutile N.L. which is 94.5% owned by Kathleen Investments (Aust) Ltd	Nil	100%	48,000	33,000	8,000
Titanium and Zirconium Industries Pty Ltd	100% Conzine Riotinto (Australia) Pty Ltd	85% Riotinto Zinc Corp. through its 85% holding in CRA	15% through local shareholding in CRA	16,000	13,000	-
Consolidated Rutile Ltd	Public controlled company	Nil	100%	19,000	18,000	-
Cudgen R.Z. Ltd	Public controlled company	Nil	100%	28,000	35,000	-
Northern Rivers Rutile Pty Ltd (c)	Private Company	Nil	100%	3,000	3,000	-
Murphyores Holdings Ltd	Public controlled company	Nil	100%	20,000	18,000	-
Western Titanium N.L.	9% Commonwealth Mining Investments (Aust) Ltd 12% Mining Traders Ltd 79% local residual	3.6 Consolidated Gold Fields Pty Ltd of U.K. through CGFA's 55% interest in Commonwealth Mining Investments (Aust) Pty Ltd	96.4% as Residual	8,000	15,000	200,000
Westralian Oil Ltd	Public controlled company	Nil	100%	-	13,000	75,000
Western Mineral Sands Pty Ltd	66 2/3% Australian Titan Products Pty Ltd 33 1/3% Westralian Oil Ltd	66 2/3% British Titan Products Pty Ltd through its wholly-owned subsidiary Australian Titan Products Pty Ltd	33 1/3%	-	-	120,000
Cable (1956) Ltd	100% Kathleen Investments (Aust) Ltd	Nil	100%)	-	8,000	140,000
Ilmenite Minerals Pty Ltd	100% Kathleen Investments (Aust) Ltd	Nil	100%)			

(a) It is possible for shares of local companies quoted on Australian stock exchanges to be held by foreign investors.
(b) Consolidated Gold Fields (Aust) Ltd must maintain a shareholding of not less than 50%.
(c) The company has sold its northern leases to Dillingham Corporation of Honolulu and Signal Oil and Gas Co. of Los Angeles.

Appendix C. Company Association of Chloride TiO_2 Manufacturers and Australian Mineral Sand Producers

TiO2 Manufacturer	Plant			Australian Operator	Association with Pigment Manufacturer
	Location	Annual Capacity (tons)	Date of Commissioning		
American Cyanamid Co.	Savannah, Ga.	20,000	1965	Cudgen R.Z. Ltd	Long-term contract for supply of rutile.
American Potash & Chemical Corp.	Hamilton, Miss.	30,000	1966	Associated Minerals Consolidated Ltd	Existing contract (210,000 tons for period 1963-1973) increased by additional 105,000 tons for delivery 1971-1974.
Cabot Titania Corp.	Ashtabula, Ohio.	20,000	1964	Murphyores Holdings Ltd	Long term contract for supply of rutile.
Glidden-Durkee, division of SCM Corp.	Baltimore, Md.	25,000	1970	Rutile & Zircon Mines (Newcastle) Ltd	Supply of up to 97,500 tons of rutile in period 1969-1974.
National Lead Co.	St. Louis, Mo.	36,000	1966	Mineral Deposits Ltd	National Lead subsidiary.
E.I. du Pont de Nemours & Co. Inc.	New Johnson-ville, Tenn.	75,000	1959	Rutile & Zircon Mines (Newcastle) Ltd	Renewal of contract for 1968 and 1969 involving annual delivery of 40,000 tons of rutile.
	Antioch, Calif.	27,000	1964	Rutile & Zircon Mines (Newcastle) Ltd	
Sherwin Williams Co.	Ashtabula, Ohio.	25,000	1970	Rutile & Zircon Mines (Newcastle) Ltd	Supply of 100,000 tons of rutile in the period 1969-1974.
British Titan Products Company Ltd	Greatham, Durham.	30,000	1970	Titanium and Zirconium Industries Pty Ltd	Subsidiary of Riotinto Zinc Corp. (R.T.Z. has a substantial shareholding in B.T.P.)
				Westralian Oil Ltd	Five year contract for annual supply of 70,000 tons of ilmenite a year to B.T.P.
				Western Mineral Sands Pty Ltd	Subsidiary of British Titan Products through its wholly owned subsidiary Australian Titan Products Pty Ltd.
Laporte Titanium Ltd	Stalling-borough, Lincs.	40,000	1970	Western Titanium N.L.	Long-term contract for the supply of ilmenite (approximately 1 million tons over 20 years). Laporte associated with Western Titanium in the development of ilmenite beneficiation process.