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Applied Clay Science 20 (2002) 243–253

Applied Clay Science

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# Categorization of industrial clays of Australia and New Zealand

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Received 16 October 2000; accepted 10 January 2001

**Abstract**

Categorization of industrial clays is a useful guide to assessing the level of technical and economic inputs required to develop the resource. Based on resource studies in Australia, New Zealand, and elsewhere, four categories of industrial clay resources are recognized. Category 1: clays of high quality requiring major capital investment to supply large tonnage, international markets. Category 2: unique specialty clays for which advanced technologies are required to produce small tonnages for niche markets. Category 3: moderate quality clays requiring relatively low technologies, to supply predominantly local markets. Category 4: clays of low quality requiring little or no processing. Categories 1 and 2 clay projects require extended development times (from green-field to investment decisions) and significant pre-development capital investment. On the other hand, the development of Categories 3 and 4 clays requires shorter times and lower levels of capital investment.


*Keywords:* Australia; New Zealand; Kaolinite; Halloysite; Bentonite; Palygorskite

## 1. Introduction

Population growth, together with urbanization and industrialization, within Australia and New Zealand during the 20th century have prompted much interest in developing indigenous clay resources. In the early to middle part of the century, such developments typically began on a small scale and from a low technology base with the initial market focus being on construction materials and utilitarian ceramic products. As industrialization progressed however, the level of technology and product sophistication increased, with the objectives of achieving products of consistent and higher quality.

The past 20 years (1980–2000) have seen the exhaustion of many natural resources in Europe and North America, along with mature local markets characterized by low growth. In addition, high labour costs and environmental issues increasingly constrain proposals for new resource development. This has encouraged interest and investment in developing the resources in less populated and/or less developed nations. Australia and New Zealand are rich in clay resources potentially capable of supplying both the indigenous and export markets. Emphasis has been given to supply the Asian market where significant industrial growth is predicted to occur during the first half of the 21st Century.

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0169-1317/02/$ - see front matter 
PII: S0169-1317(01)00075-8

In the 1960s and throughout the 1980s, the paper industries, both in Australia and New Zealand, developed to become the largest consumer of high quality industrial clays. This prompted several significant developments in kaolin production in Australia at Scottsdale, Pittong and Weipa, and in Northland, New Zealand. Since then, however, the entry of high quality, moderate-cost Brazilian kaolin into the Asian market in the 1990s, together with the increased use of calcium carbonate by paper manufacturers, have resulted in a tight export market for kaolin. These factors contributed to a decline in Australian kaolin paper clay production at the end of the 20th century, with the closure of the Weipa and Scottsdale operations.

The experience of kaolin producers with respect to the paper industry contrasts with the steady increase in the production of clays for fiberglass manufacture, plastics, paints and adsorbent applications, and the successful development of niche markets as exemplified by the export of high brightness halloysite clays from Matauri Bay (Northland, New Zealand) for the manufacture of quality ceramics.

The categorization of industrial clays is a useful precursor to undertaking any technical and economic evaluations of potential resources. It can also assist in identifying the most suitable development strategy and work programme. However, previous attempts at categorizing industrial clays based solely on mineral characteristics (e.g., Gaskin et al., 1979) have some limitations as to their applicability. Here, we propose new criteria to categorize the clay resources of Australia and New Zealand. The implications of timetables, development costs, and process economics are also discussed.

## 2. New categorization of industrial clay resources

Four categories of industrial clay resources are proposed based on their potential economic impacts (i.e., resource volume, market size and investment amount) and level of technological input (i.e., processing and product quality requirements).

### *2.1. Category 1 clays*

Category 1 clays are of high quality and technology. Major capital investment is required for producing a large tonnage to supply both local and international markets. Category 1 clays set product quality standards for others to follow. Currently, there are three regions around the world where Category 1 kaolin clays are produced, namely Georgia in the United States, Cornwall in the United Kingdom, and the Amazon Basin in Brazil. This limited number of identifiable kaolin resources of Category 1 confirms the rarity of this class of clays on the world scene.

### *2.2. Category 2 clays*

Category 2 clays are unique specialty clays. Advanced technologies are required to produce small tonnage for niche markets, locally and internationally. Although clays in the category are relatively rare, they are a valuable resource for specialized industrial applications. The clay deposits are typically of high purity and are found in somewhat uncommon geological settings. One example is hectorite, which is the product of hydrothermal alteration of lithium-rich volcanic rocks. The most significant hectorite deposits are located in Nevada, USA (Odom, 1992; Pulliam-Fitzgerald and Kendall, 1996) where basaltic ash, containing high concentrations of magnesium and lithium, has been hydrothermally altered to a lithium-rich smectite (bentonite). Hectorite, either wet- or dry-processed, is used in a wide variety of industries (coatings, greases, adhesives and paints) where properties of high viscosity, high gel strength, and stability over a wide temperature range are required.

Another example is white bentonite which is rare in nature and commands high prices in colloid applications, detergents, pharmaceuticals and ceramics. For some specialty applications, this type of clay may be wet-processed or surface-modified to achieve the desired quality and surface properties for such applications.

### *2.3. Category 3 clays*

Category 3 clays are of moderate quality. Relatively low level technologies are required for their production, to supply mainly local markets. Clays in this category must try hard to match the quality standards set by Categories 1 and 2 clays. They are further sub-divided into:

- Category 3A, denoting moderate quality clays which may be adequate to meet the specifications for some paper coating or similar markets; and
- Category 3B, which are relatively low quality clays suitable for most filler applications.

Category 3 resources are numerous and widespread throughout the world. Since their specifications are typically not rigid, only a moderate level of processing is usually needed, sufficient to meet market requirements of quality. The price they command will not normally support high processing costs. All of the known Category 1 resources contain large tonnages of Category 3 clays that are too impure, or fail to meet other specifications for Category 1 requirements. Examples of large exploited resources of Category 3 clays associated with Category 1 clays are the filler kaolins of Georgia, USA, and Cornwall, England.

Other international Category 3 resources include the kaolin clays of the Czech Republic, Ukraine, and Germany, the filler grade kaolins of Indonesia, and many of the calcium bentonite resources of Wyoming and the southeastern United States.

### 2.4. Category 4 clays

Category 4 includes low quality clays requiring little or no processing to produce a large tonnage for local markets. In addition, they may include clay resources whose production is constrained by physical, political or geographic factors that make them currently uneconomic.

## 3. Categorization of Australian and New Zealand clays

In this section, we classify selected clay deposits of Australia and New Zealand, shown in Fig. 1, into the four categories (Table 1). Fig. 1 shows the location of Categories 1, 2 and 3 resources and that of Category 4 clay that has the potential of being upgraded if constraints of quality or geographical factors can be overcome. The locations of Category 4 clay of low quality has been omitted since they are too numerous and of only local economic significance.

### 3.1. Category 1

The Weipa kaolin in northern Queensland, Australia, may be placed in Category 1. This resource formerly supplied kaolin to the paper industry in Asia but production ceased in 1998, mainly because of market pressure from other kaolin suppliers combined with the view that the market offer limited opportunity to significantly expand future operations. Although production from the area may resume, this is unlikely to occur in the near future.

The Skardon River kaolin deposit, located to the north of Weipa in Northern Queensland, is a potential Category 1 deposit. Development of this resource would require access to markets that will yield a satisfactory return on investment. This has proved difficult because of the current over-supply of kaolin to the paper industry.

### 3.2. Category 2

There are few resources that can be classified under Category 2. The halloysite deposits of Northland, New Zealand, fall into this category. These deposits contain an uncommonly pure halloysite formed by low-temperature hydrothermal alteration of volcanic ash (Harvey and Murray 1993; Harvey, 1996). The halloysite is wet-processed and finds a niche market for high-quality ceramics (Harvey, 1997).

Hydrothermally altered massive sillimanite bodies near Williamstown in South Australia have been mined since the early 1900s to produce a mixed kaolin/sillimanite product from a small resource base. This high alumina kaolin, marketed as "kaosil", has a niche in the production of specialist refractories and insulating ceramics capable of resisting high thermal shock (Barnes, 1990).

Within the vast kaolin resources in weathered Proterozoic granites on Eyre Peninsula in South Australia, there are localised areas of highly crystalline kaolinite which have been identified near Poochera. When calcined, the meta kaolin has exceptionally high brightness. Bulk sampling and surveys of potential markets are in progress.

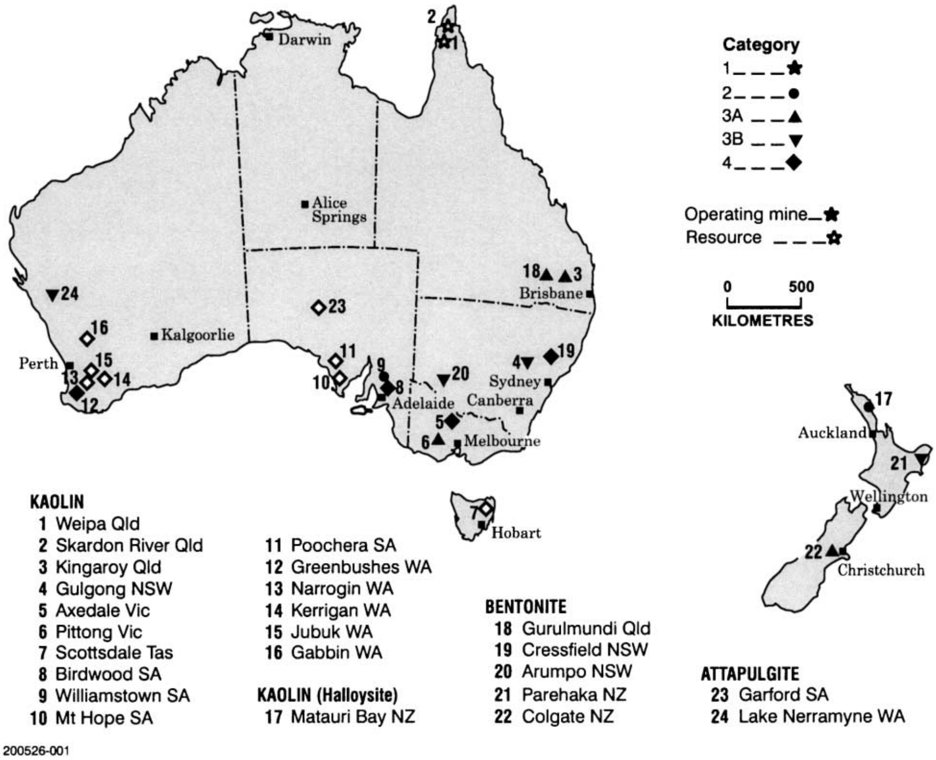


Fig. 1. Location of Australian and New Zealand clay deposits.

No deposits of hectorite are known in either Australia or New Zealand, although the geological setting of the North Island of New Zealand is in many ways similar to that of Nevada. Both Nevada and the central North Island of New Zealand have extensive areas of hydrothermally altered acid to basic volcanic rocks.

No high grade white bentonites have been identified in either Australia or New Zealand. Certain Australian bentonites such as Miles and Arumpo are not naturally white, although they can be processed to give a very pale coloured product. The application of currently available processing technologies to achieve such qualities is not a commercial proposition at the present time.

### 3.3. Category 3

The Weipa kaolins in Australia have never been exploited as Category 3 clays because of their remote location from suitable markets. The Ballarat region of Victoria contains primary kaolin resources derived from the weathering of Devonian granites. Areas of higher grade kaolin near Pittong are mined and processed to produce a range of coating and filler-grade materials for the paper industry and for the manufacture of fibreglass (McHaffie and Buckley, 1995). About half the production is exported. These clays are classed as Category 3A clays. Similarly, sedimentary kaolin resources near Kingaroy in south-east Queensland are classed as Category 3A clays. These clays are processed into a range of products including a delaminated kaolin suitable for paper coating. Sedimentary and primary kaolins derived from weathered basement rocks in the Gulgong district of New South Wales are examples of Category 3B clays. They are wet-processed mainly for ceramic and filler markets.

Australian bentonite production is dominated by several deposits near Miles in southern Queensland (Carmichael, 1995). These bentonites are formed from

Table 1
Schedule of Australian and New Zealand clay resources

| Category | Name | Proven resource (Mt) | Possible resource (Mt) | References |
|---|---|---|---|---|
| 1 | Weipa Kaolin (A) | 11.2 | 36 | Roskill (1996) |
| | Skardon River Kaolin (A) | 2.6 | 22 | Minerals Gazette (1997) |
| 2 | Northland Halloysite (NZ) | Confidential | Confidential | Harvey and Murray (1993) |
| | Williamstown Sillimanite (A) | 0.02 | Not determined | Barnes and Olliver (1989) |
| 3A | Pittong Kaolin (A) | Confidential | Confidential | McHaffie and Buckley (1995) |
| | Gurulmundi Bentonite (Unimin Australia) (A) | 3 (Na) | 12 (Na + Ca) | Carmichael (1995) |
| | Coalgate Bentonite (NZ) | Confidential | 11 | Carleson and Rodgers (1975) |
| 3B | Kingaroy Kaolin (A) | 10 | 20 | Wallis (1998) |
| | Greenbushes Kaolin (A) | 0.04 | Not determined | Abeysinghe and Fetherston (1999) |
| | Gulgong Kaolin (A) | Not determined | 1 | Driessen (1990) |
| | Lake Nerramyne Attapulgite (A) | 4 | 10–100 | Rakich (1990) |
| | Gurulmundi Bentonite (Integrated Mineral Technology) (A) | 8.3 | 23 | Carmichael (1995) |
| | Arumpo Bentonite (A) | Not determined | 70 | Browns Creek Gold NL (1993) |
| | Parehaka Bentonite (NZ) | Not determined | 4 | Christie et al. (2000) |
| 4 | Jubuk Kaolin (A) | 8 | 31.2 | Abeysinghe and Fetherston (1999) |
| | Ockley-Wickepin Kaolin (A) (Narrogin district) | Not determined | 29 | Abeysinghe and Fetherston (1999) |
| | Kerrigan Kaolin (A) | Not determined | 80 | Abeysinghe and Fetherston (1999) |
| | Gabbin Kaolin (A) | Not determined | 27.6 | Abeysinghe and Fetherston (1999) |
| | Poochera (Carey Well) Kaolin (A) | Not determined | 30 | Ferris and Keeling (1993) |
| | Mount Hope Kaolin (A) | Not determined | 11 | Keeling et al. (1992) |
| | Northland halloysites (NZ) | Not determined | Not determined | Christie et al. (2000) |
| | Coromandel halloysites (NZ) | Not determined | Not determined | Christie et al. (2000) |
| | Central Volcanic District halloysites (NZ) | Not determined | Not determined | Christie et al. (2000) |
| | Fireclays (NZ) | Not determined | Not determined | Christie et al. (2000) |
| | Weathered Cretaceous or Tertiary clay deposits (NZ) | Not determined | Not determined | Harvey, personal communication |

Mt = million metric tons.
A = Australia.
NZ = New Zealand.

the alteration of volcanic ash contained in sedimentary deposits in the Orallo Formation of late Jurassic age. The largest developed resource is at Gurulmundi which contains substantial resources of a Category 3A, sodium bentonite suitable for use in drilling mud and civil engineering applications, as well as a foundry sand binder and pet litter adsorbent. More recently, mining operations were commenced on a large Category 3B deposit of sodium and magnesium bentonite at Arumpo near Pooncarie in southwestern New South Wales (Browns Creek Gold, 1993; Churchman et al., 1999). Another Category 3B clay is palygorskite (attapulgite) from Lake Nerramyne in Western Australia which is used mainly as an adsorbent for domestic pet litter and in controlling oil, water and chemical spills in engineering workshops and maintenance centres (Rakich, 1990).

In New Zealand, the Coalgate bentonite deposit in Canterbury, South Island may provisionally be classified as a Category 3A clay. This somewhat unusual iron-rich bentonite is of mid-Tertiary age, a lake deposit of altered basaltic ash (Carleson and Rodgers, 1975). It may have the potential to be a Category 2 clay, if its unique properties can be matched or modified to meet with the specific requirements of a high added-value market.

### 3.4. Category 4

Examples of Category 4 clays in Australia and New Zealand include numerous low grade resources. The clays are mined and used for the manufacture of bricks, pipes and other clay products. Category 4 clay deposits also include kaolins, mainly in Western Australia and South Australia, which are located in arid environments, remote from population centres and markets (Gaskin et al., 1979; Keeling, 1997, Abeysinghe and Fetherston, 1999).

Australian kaolin resources in Category 4 include numerous residual deposits in Western Australia (e.g., Greenbushes, Gabbin, Jubuk, Ockley-Wickepin, Mount Gibson, Kerrigan); South Australia (e.g., Poochera, Calca, Mount Hope, Birdwood); Victoria (Hallum, Bulla and Lal Lal) and the Scottsdale district of Tasmania. Sedimentary kaolins in Western Australia at Jarrahdale (Abeysinghe and Fetherston, 1999); South Australia at Golden Grove and McLaren Vale; Victoria at Axedale and Heyfield (McHaffie and Buckley, 1995), New South Wales at Gulgong, Coorabin and Merrygeon, and in Queensland at Kingaroy, Ravensbourne and Cape York are also included.

Australian smectite deposits include undeveloped saponite clay at Watheroo in Western Australia; Ca–Mg bentonite in the Cressfield-Scone district of New South Wales; Ca-bentonite seams in Middle Jurassic Walloon Coal Measures near Rosewood and deposits at Yarraman and Miles in Queensland (Carmichael, 1995). Undeveloped palygorskite resources are known in the Garford palaeochannel in South Australia (Keeling and Self, 1996) and at Peak Crossing near Ipswich, Queensland.

New Zealand Category 4 clays include the Parehaka bentonite on the East Coast of the North Island. It is currently mined and dry-processed for landfill liners, earth dams, water treatment and as an animal food supplement. There are also numerous small low-grade clay resources elsewhere, throughout the country. They are used for local production of bricks, pipes, pottery, and relatively low-grade refractories; minor amounts are used as mineral fillers. The coal measure clays in Northland, the Waikato, Nelson, West Coast, Canterbury, Otago, and Southland are classed as Category 4. Northland, the Central Volcanic District and Coromandel also host several small low grade deposits of halloysite or kaolinite associated with hydrothermal alteration or weathering of acid volcanic rocks.

## 4. The role of categorization in the assessment of industrial clay

In any assessment of an industrial clay resource, the explorer has to go through the various stages of resource evaluation from raw material testing to the assessment of product quality, market size, and market demand. All these data must then be integrated into a feasibility study recommending that the project should either proceed or be abandoned (Table 2, Fig. 2).

An early categorization of materials is a useful precursor to establishing development strategies and likely project costs. This can provide an early appreciation of the complexities of resource development because the different categories have different requirements with respect to the work programme and time needed to complete the feasibility study (Fig. 2).

### 4.1. Relationship between category and annual tonnage

In any mineral processing operation, the term ‘economy of scale’ is used to denote that significant economic advantages can be obtained by having larger production volumes and by shipping in larger vessels. Larger tonnage operations can operate with fewer man hours per ton while capital costs for larger machines are less than the multiples of smaller units. In order to compete on world markets, Category 1 producers must consider the economies of scale. In the kaolin industry in the 1970s for example, a 100,000 tons/year operation was considered to be a reasonably sized commercial operation. For current developments in Brazil, minimal plant sizes are 300,000 tons/year.

For Category 2 clays, the annual tonnage requirement is governed by market size rather than ‘benefits of scale’. Annual production from such processing operations typically fall between 10,000 and 100,000 tons/year. The size of Category 2 operations is therefore governed by market size or accessible market share. This is also often the case for Category 3 operations.

Table 2
Timetable of activities and investments

| Activity | Category 1 | Category 2 | Category 3 | Category 4 |
|---|---|---|---|---|
| *Stage I: Reconnaissance* | | | | |
| Geological reconnaissance, property surveys, testing, broad categorization of materials, market surveys and evaluation | | | | |
| Decision to proceed | 12 months | 9 months | 6 months | 3 months |
| *Stage II: Exploration (pre-feasibility)* | | | | |
| Property negotiation, drilling, testing, market surveys, precise material characterizations, process flow sheet development, resource calculations, economic studies and evaluation | | | | |
| Pre-feasibility study and decision to proceed | 18–24 months | 9 months | 9 months | 6 months |
| *Stage III: Delineation and feasibility* | | | | |
| Drilling, testing, market surveys, bulk samples, engineering studies, assessment of products in the marketplace, economic studies and evaluation | | | | |
| Feasibility study | 24 months | 12 months | 9 months | 3 months |
| *Stage IV: Decision to invest* | | | | |
| Total elapsed time since project initiation | 4–5 years | 2–2.5 years | 2 years | 1 year |
| Design, construction, and commissioning | 1–2 years | 1 year | 1 year | 1 year |
| Typical overall project time | 5–7 years | 3–4 years | 2–3 years | 1 year |

### *4.2. Relationship between category and resource confidence*

Based on the above criteria, the development of a Category 1 resource requires a very high level of confidence in the quality and quantity of the raw material. If a minimum resource life of 20 years is required at 300,000 tons/year, then the resource size must be sufficient to produce 6 million tons of product. For Categories 2 and 3 industrial clays, the tonnage requirements may be significantly less, which could significantly reduce the work required in resource definition.

### *4.3. Relationship between category and value*

Category 1 kaolin products command the largest tonnage and high added-value positions in the industry. Frequently, however, it is the Category 2 products that may command the highest value position, although their tonnages may be small. Category 3 kaolins command an intermediate value between Categories 1 and 4 kaolins. Asian markets are considered to have the best potential for Australian and New Zealand clays and Table 3 presents an analysis of imports and exports of kaolin and halloysite clays in Asian countries in 1994 (Harvey, 1996). These clays have been grouped into the four categories along with their tonnages and values. Similar data could be made available for bentonites and other clays.

### *4.4. Relationship between category and investment capital*

Category 1 projects require significant pre-investment or 'risk' capital. The level of confidence in the resource and markets has to be very high, as the level of investment may well exceed US$1 million. The pay-back time for such investments may be at least 5 years because of the lead time required to move from reconnaissance through commissioning (Fig. 2). The pre-investment capital requirements for Categories 2, 3 and 4 become progressively lower as you move to the lower category clays.

The investment capital requirements for large tonnage, high-complexity Category 1 kaolin projects, are

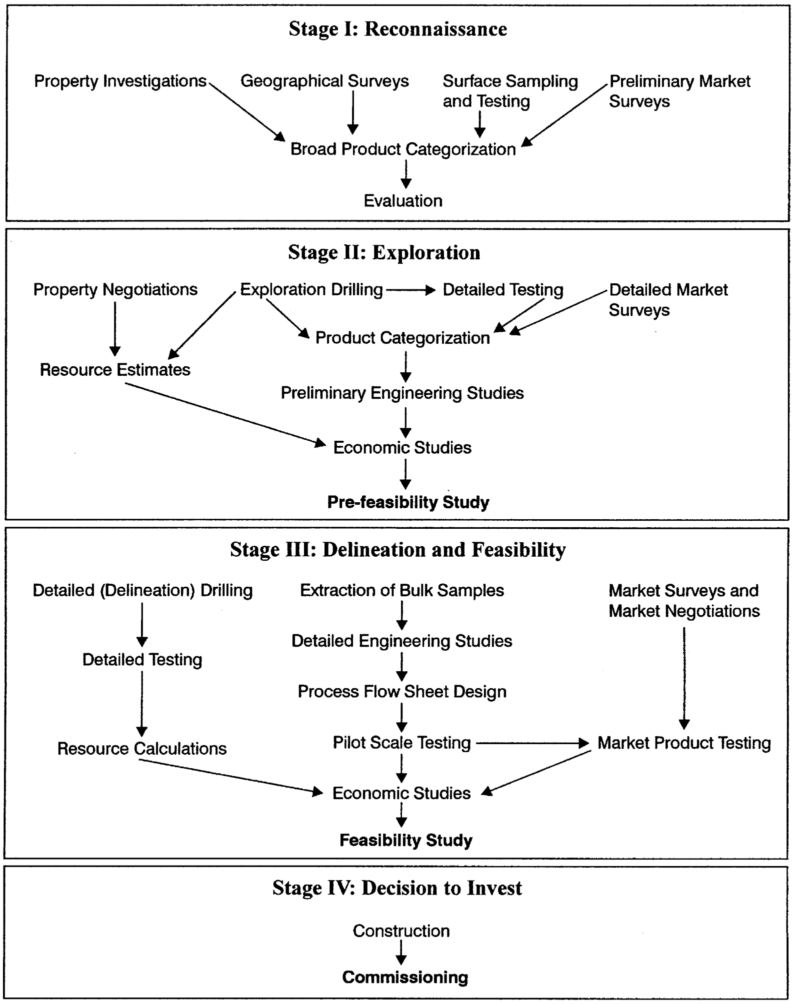


Fig. 2. Flowsheet of project development.

quoted to be as high as US$300 per processed ton (Harvey, 1995; Pleeth, 1997). For Category 2 clays, figures of US$100 per processed ton would be realistic, while for Category 3 clays, the investment level may be of the order of US$50 per processed ton.

## 5. Reducing risk and shortening timetables for Categories 1 and 2 developments

There are several means or procedures for minimizing risk and shortening the time necessary to establish Category 1 or Category 2 ventures.

• Associate, or form a joint venture, with established producers in the industry. In this way, the processing technology already acquired by the established producer can be brought to the project. In addition, the established producer may achieve early market entry by substituting the new product for an established product, or by adding the new product to the existing product inventory.

• Associate, or form a joint venture, with major market users of the product. Many of the market users may consider that if they have a stake in processing the raw material, they will have stronger negotiating capabilities with other raw material suppliers. This

Table 3
Imports and exports of categories of kaolinite and halloysite clay in the Asean Region (analyzed from 1994 U.N. data base)

| | Major sources of supply | Tonnage '000 mt | Major user | Industrial use | Tonnage '000 mt | Average value (CIF)/mt |
|---|---|---|---|---|---|---|
| Category 1 | US | 1200 | Japan | Paper | 841 | Ranging between US$165 and US$240 |
| | Brazil | 100 | Korea | Paper | 146 | |
| | Australia | 100 | Taiwan | Paper | 125 | |
| Category 2 | New Zealand | 20 | Japan | Ceramics | 9 | Ranging between US$500 and US$600 |
| | | | Korea | Ceramics | 6 | |
| | | | Taiwan | Ceramics | 4 | |
| Category 3, kaolin | China | 200[a] | Japan | Paper and Ceramics | 128[a] | Ranging between US$80 and US$160 |
| | Indonesia | 160 | | Refractories | | |
| | | | Taiwan | Refractories | 40 | |
| | | | Malaysia | Ceramics | 20 | |
| Category 4, kaolins and other clay | China (often re-exported via Hong Kong) | 1000 + [a] | Taiwan | Refractories | 800 + | Ranging between US$25 and US$70 |
| | | | Japan | Ceramics | 320 | |

[a] Tonnages estimated from compiled statistical data for which the various categories have not been separated, and only combined tonnage data are available (mt = metric ton; CIF = cost including freight).

also is a way to ensure early market entry for the product.

• Engage specialist consultants for resource evaluation, market surveys, and engineering. Behind every mineral product are experienced consultants who typically have worked extensively in the industry. It is critical for the mineral explorer or promoter to identify the best and most experienced consultant or team of consultants at the earliest possible stage of the project.

• Develop resources adjacent to proven resources already established in the marketplace. The pioneer developer of any new product in a new resource location will have to face real or imagined skepticism with respect to the ability of the new product to compete with established products. For example, in the kaolin markets, the paper companies are recognized to be very conservative purchasers. If the resource to be developed is adjacent to existing ones, the time required to develop market confidence may be significantly shorter than for operations developed in unproven resource locations.

## 6. Summary

If all these factors are taken into account, the following generalized outline can be considered as a guide to development of Australian and New Zealand clay resources.

### 6.1. Category 1 clays

Category 1 industrial clay operations require large proven resources of raw materials of consistently high quality raw materials. The profit potential for such clay products is high, but the risk capital required to identify, drill and evaluate the raw materials may also be very high. Category 1 clays require careful detailed drilling and testing to confirm their quality and uniformity. For example, exploration drilling at 300-m spacings is typically required. Production drilling in Georgia is usually on 30-m (100 ft) spacings (Harvey and Murray, 1997). The processing requirements or options for Category 1 clays are complex, requiring specialist engineering and chemical experience. The markets are highly sophisticated, strongly competitive, and a high level of technical expertise is needed to service these markets.

Any potential new developer of a Category 1 resource should certainly be aware of these constraints. For example, recent developments of Category 1 kaolin resources in Brazil (Pleeth, 1997) quote time intervals of at least 5 years to move from initial exploration through commissioning. The kaolin deposits in the Cape York area of Australia at Weipa and Skardon River have potential to be classed as Category 1. Other Australian deposits, particularly the residual kaolins in Western and South Australia, have yet to demonstrate that they can overcome challenges of location and market requirements to achieve this Category.

### *6.2. Category 2 clays*

Category 2 industrial clays supply much smaller niche markets and from a much smaller resources base. Processing requirements are typically highly sophisticated and the level of technical support required in the marketplace is inevitably high. Risk capital is therefore moderately high. The gestation period from exploration through commissioning is likely to be significantly shorter than for Category 1 projects, but nevertheless is likely to take between 2 and 3 years.

The New Zealand Northland halloysite is a good example of a Category 2 development. The Australian Williamstown kaolin/sillimanite deposits may meet the requirements of Category 2 clays should additional resources be discovered. It seems likely that other unique clay resources will be found in the diverse and extensive geological settings of Australia and New Zealand. However, no other such deposits have so far been proven.

### *6.3. Category 3 clays*

Category 3 industrial clays have lower technical requirements and less rigid product specifications than either Category 1 or Category 2 clays. They typically supply local markets and in many cases evolve from former Category 4 clay operations. The resource requirements are less rigid and the clays can be produced with a lower level of technology. However, their profit potential is typically much less than that for Category 1 or Category 2 clays. The large granite masses within Australia combined with a wide range of climates and geological settings offer excellent potential for both Categories 3A and B resources of kaolin. However, the geographic isolation (from markets) of many of these resources currently moves them into Category 4. The Australian bentonite deposits at Miles and Arumpo and the palygorskite resources at Lake Nerramyne are included in Category 3B. Further development of these resources will largely depend on market directions.

### *6.4. Category 4 clays*

The Category 4 clays are used industrially with little or no processing and generally have a low profit potential. Such deposits are too numerous to detail and do not warrant a detailed discussion.

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