Photograph 9. Stockpile of raw kaolin, Caroma Industries ceramics plant, Sydney. This material came from kaolin deposits in the Oaklands-Coorabin area, southern New South Wales. The whiteness, plasticity and chemical stability of kaolin allow its use as a filler, extender, ceramic raw material, and pigment in coated films for paper manufacture. Kaolin is also an important raw material to refractories, and to catalyst, cement and fibreglass, industries. (Photographer D. Barnes)

Potential and Outlook

New South Wales has considerable potential for the development of known resources of kaolin and the identification of new deposits (Figure 13).

Although New South Wales accounts for only a minor proportion of total Australian production, there are widespread deposits, mainly within the eastern highlands. Although no resources of kaolin suitable for paper coating have yet been identified, the state has substantial resources suitable for ceramic, refractory and filler applications.

The majority of known deposits are primary (residual) or secondary (transported) deposits of Tertiary age. Residual deposits have developed on a variety of lithologies, including granite, slate and volcanic rocks. The highest quality kaolin occurs in residual deposits developed on granite and granite-derived transported deposits.

The major current sources of high-grade white kaolin in New South Wales are transported deposits associated with the Gulgong Granite, and large sedimentary deposits in the Oaklands–Coorabin area, near Deniliquin.

Deposits with potential for development that are known to contain substantial resources occur at Tichbourne, near Parkes; Elsmore, near Inverell; and the Oaklands–Coorabin area.

Extensive deposits of flint clay occur within Jurassic and Permian sedimentary rocks in the Dunedoo–Merrygoen area and in the upper Hunter Valley. These deposits have been quarried at a number of localities for refractory use. Few of the major known kaolin deposits have been assessed in detail and there has been little systematic exploration. There are several areas with established potential for large high-grade deposits that include:

- Glen Innes–Inverell–Emmaville
- Gulgong
- Goulburn–Marulan–Braidwood
- Cooma–Adaminaby–Bombala
- Coorabin–Oaklands.

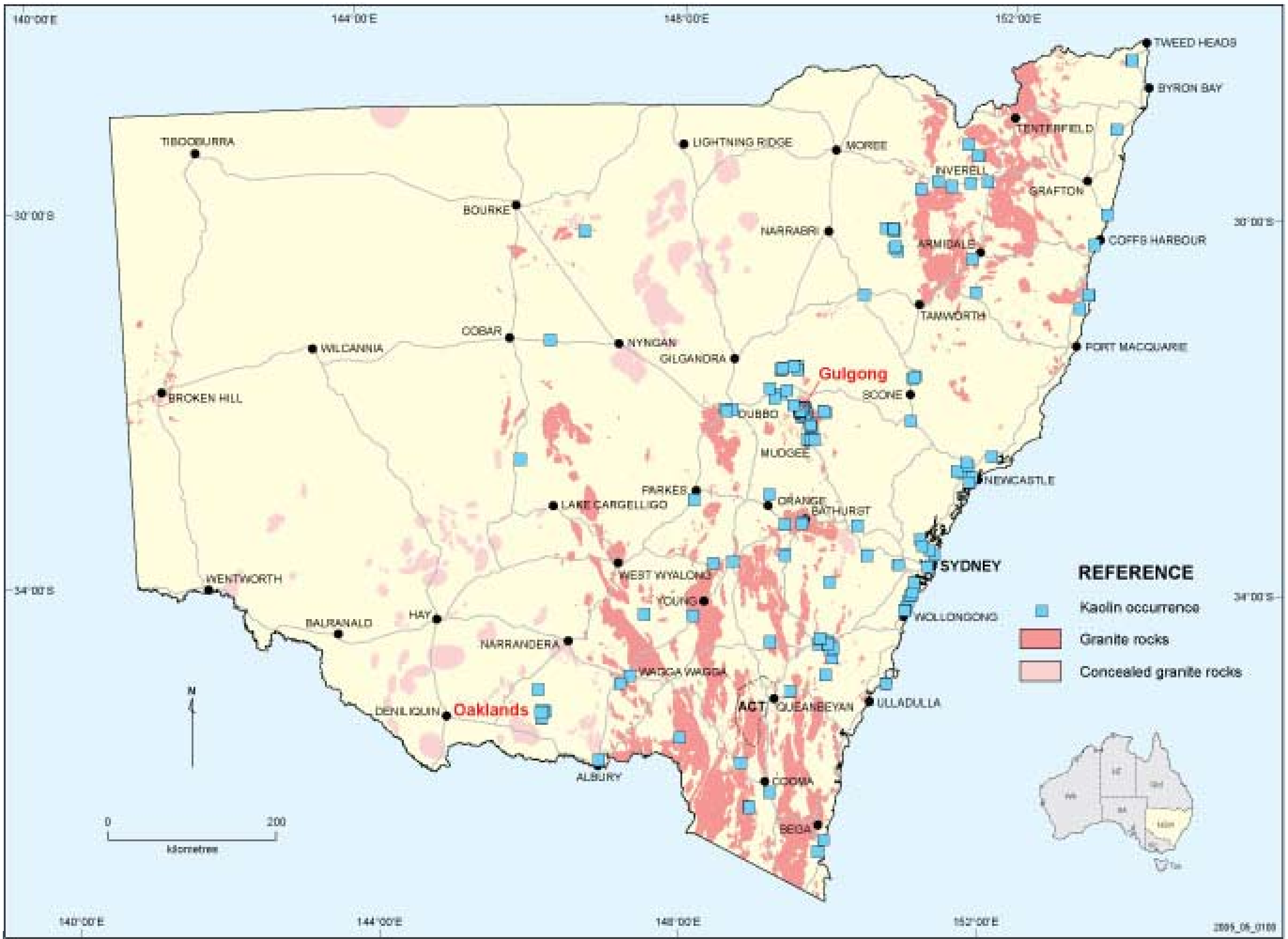

Figure 13. Kaolin occurrences and potentially prospective granitic rocks

In addition, there is mainly untested potential for residual and transported deposits associated with deeply weathered basement rocks, particularly granites, on the 'Western Slopes and Plains' geographic region. One area with obvious potential is southeast of Bourke where a large sedimentary deposit was identified at Gongolgon in the 1980s.

Enormous deposits of deeply weathered friable sandstone on the Newnes Plateau, in the western Blue Mountains, and north and south of Sydney, have the potential to yield high-quality ceramic grade kaolin as a by-product of sand extraction. The kaolin is in the matrix of the sandstone and must be removed during processing. Recovery of the kaolin is dependent on the economic feasibility of beneficiation.

The relatively small size of domestic markets and competition from large deposits mined in Victoria and Queensland have acted as disincentives to kaolin exploration and development in New South Wales. The development of new ceramic manufacturing plants, such as the ceramic tile plant recently constructed at Rutherford, near Maitland, by National Ceramic Industries Australia, should provide a boost to exploration and production in New South Wales. This plant is already providing significant opportunities for the use of structural clay obtained from tuffaceous rocks during coal-mining operations at Newcastle and towards Mudgee.

Nature and Occurrence

Kaolin is a white, soft, plastic clay composed mainly of kaolinite, $Al_4(OH)_8[Si_4O_{10}]$, and other related clay minerals such as nacrite and dickite (Baker & Uren 1982). It forms in response to anhydrous aluminium silicate alteration in feldspar-rich rocks by weathering or hydrothermal processes. The physical properties of kaolin vary considerably depending on the origin of individual deposits. Impurities that can affect properties — such as whiteness; abrasiveness; particle size, shape and distribution; viscosity and rheology — are important in determining the suitability of kaolin for specific applications.

Many kaolin deposits have been significantly upgraded by post-depositional weathering and diagenesis that have removed much of the original impurities — such as carbonaceous material and iron minerals — and have allowed extensive recrystallisation of the kaolinite to take place.

World production of kaolin in 2004 was 41 Mt (Virta 2005). Kaolin is produced by more than 50 countries. World trade was dominated by such producers as the USA (8.8 Mt), Commonwealth of Independant States (5.7 Mt), Czech Republic (4.1 Mt) and the Republic of Korea (2.5 Mt). Australia accounts for less than 1% of world production.

The main exporters of refined (filler-grade) kaolin for high-quality markets, including paper, plastics and paints, are the USA, Great Britain, Brazil, and Germany. Major suppliers of low-to medium-quality kaolin used in applications such as refractories and ceramics include Colombia, South Korea, Uzbekistan and Ukraine. Brazil is in the process of developing very large deposits of high-quality kaolin and production has increased rapidly over the past decade, largely to supply the European market. China has numerous deposits of kaolin, and has the potential to become a leading supplier.

Deposit Types

Kaolin deposits are commonly classified into two types (Harben & Kužvart 1996).

Primary (residual) deposits
Formed by in-situ hydrothermal alteration and/or leaching and weathering of such feldspar-rich rocks as granite, syenite or gneiss.

Secondary (transported) deposits
These are composed of detrital clay derived from residual deposits formed by sedimentary processes.

Commercial concentrations of kaolin can occur in the following forms.

Ball clay
A fine-grained, highly plastic kaolinite mixed with quartz, mica, illite, smectite, chlorite and colloidal carbonaceous matter.

Flint clay
A smooth, microcrystalline hard-slaking rock composed mainly of kaolinite that becomes plastic when ground in water.

Fire (or refractory) clay
A siliceous or aluminous clay composed of a disordered variety of refractory kaolinite capable of withstanding high temperatures without deforming.

Halloysite
Similar to kaolinite but with more hydroxyls and composed of long, slender, tube-like crystals.

Primary kaolin tends to be well-ordered, with a high degree of crystallinity, forming a dense texture of semi-plastic clay. In Cornwall (Great Britain), and in Japan, kaolin deposits of hydrothermal origin formed by alteration of permeable granites. In Australia and Guyana, kaolinisation of Late Cretaceous and Tertiary age associated with hot, humid conditions formed thick deposits of high-purity white kaolin, commonly underlying bauxitic laterites.

Secondary kaolin generally shows a disordered structure of low crystallinity giving it free slaking, plastic properties, rendering it suitable to applications requiring high degrees of dispersion.

In the upper coastal plain of Georgia and South Carolina, USA, extensive high-purity kaolin deposits of deltaic origin occur in rocks of Late Cretaceous and Early Tertiary age that were derived from weathered gneisses and granites. In Brazil, very large deposits of kaolin derived from granitic rocks of the Guyana Shield were deposited in a lacustrine to deltaic setting of Tertiary age. These deposits subsequently underwent intense lateritic weathering to form very pure, extensively recrystallised deposits over 20 m thick.

Main Australian Deposits

Most of the known deposits of high-grade kaolin in Australia formed during the Tertiary as either residual or transported deposits (Baker & Uren 1982). Australia currently produces about 260 000 tpa of kaolin, primarily to supply domestic markets. Most of the production (over 200 000 tpa) comes from residual and transported deposits in the Ballarat and Bendigo areas of central Victoria (McHaffie & Buckley 1995).

Large, high-quality residual deposits associated with the bauxite deposits at Weipa (Schaap 1990), on the western coast of Cape York, in Queensland, were formerly a major source of kaolin. They produced over 100 000 tpa, primarily paper-coating clay for export to Japan and southeast Asia. The kaolin occurs within the pallid zone of lateritic bauxite deposits developed on kaolinitic and arkosic sedimentary rocks of the Carpentaria Basin. The kaolin was mined by Comalco in conjunction with mining of the overlying bauxite. In 1996, kaolin production ceased because the production rate was no longer economically viable. A similar deposit at Skardon River, north of Weipa, developed by Minerals Corporation Ltd, began production in 2005. The company proposes to produce up to several hundred thousand tonnes of kaolin yearly from this deposit.

New South Wales Occurrences

New South Wales has widespread deposits of kaolin, mainly in the eastern highlands and southern New South Wales. The major current sources of high-quality white kaolin are the deposits at Gulgong and in the Oaklands–Coorabin area in southern New South Wales.

In 2003, approximately 21 000 tonnes of kaolin were produced in New South Wales, but annual production has been as much as 40 000 tonnes in recent years. The kaolin is used mainly in various ceramic, refractory and building-related applications, such as paint, building board and adhesives.

There are over 250 recorded kaolin occurrences in New South Wales (Ray et al. 2003). Residual deposits have developed on granites, slates and volcanic rocks. Transported deposits were formed by the re-deposition of kaolin in Tertiary drainage systems, the highest grade deposits being derived from kaolinised granites.

Transported deposits of kaolin and, to a lesser extent, primary deposits derived from, and developed on, the Gulgong Granite have been mined for many years for various uses — including refractories, fillers and ceramics. Production has come mainly from secondary deposits that occur along major palaeo-drainage systems.

Lenses of kaolinitic clay in excess of several metres thick, that occur within Tertiary sediments in the Oaklands–Coorabin area, southern New South Wales, have been mined for use in ceramic (vitreous china), brickmaking and industrial (tile) applications. There, large quantities of kaolin occur within an upper and lower horizon of kaolin separated by medium- to coarse-grained kaolinitic quartz sandstones. Identified resources are about 45 Mt, and potential resources could easily exceed several hundred million tonnes given the large area over which the deposits have been identified. Other sources of kaolin, mainly lower-grade material used in refractories, include Swan Bay (near Newcastle), Barraba (ball clay) and Marulan.

Extensive deposits of flint clay (pelletal claystone and clay sandstone) which occur within Jurassic rocks (in the Merrygoen area) and Permian coal measure sequences (in the upper Hunter Valley) have been utilised for many years in refractory applications. Until reserves were depleted several years ago, an unusual deposit of flint clay that has been naturally calcined by a burning coal seam was mined for refractory use at Burning Mountain (Wingen), in the upper Hunter Valley.

At Elsmore, near Inverell, in northern New South Wales, a deposit of high-purity kaolin with reserves of more than two million tonnes has been identified near the Elsmore tin mine. The deposit occurs within granite (Elsmore Granite) that has been hydrothermally altered to quartz–kaolin rock adjacent to areas of intense greisenisation (Brown & Stroud 1997).

The area east of Bourke appears to have considerable potential for transported and residual kaolin deposits associated with deeply weathered Silurian granites, but has been subject to only limited exploration to date. A variably outcropping, but extensive, kaolin-rich unit of inferred Tertiary clays, unconsolidated to poorly consolidated sands and gravels to the west of Gongolgon was prospected in the early 1980s and early 1990s (Byrnes 1993). The sequence, which consists of interbedded hard pure kaolin and softer sandy kaolin (Byrnes 1993), locally exceeds 14 m in thickness but averages 4 m. Limited sample testing indicated that the material was suitable for refractory and general ceramic uses but the deposit's remoteness from potential markets has been a significant constraint to its development.

Other areas with known deposits and potential for further discoveries include the following (Baker & Uren 1982):

- Glen Innes–Inverell–Emmaville–Warialda
- Goulburn–Marulan–Braidwood
- Cooma–Adaminaby–Bombala

Recent geological mapping suggests that palaeo-drainage systems draining extensive granites west of Goulburn, may be prospective for secondary kaolin deposits.

Laboratory tests on tailings from the Newnes Plateau have shown that clay matrix in the sandstone can be beneficiated to yield high-quality kaolin suitable for use in whiteware ceramics.

Applications

Kaolin is an extremely versatile mineral that is primarily used as: filler material and coating pigment in paper; in ceramic applications (Photograph 9), such as whiteware; and in alumina-based refractories.

The paper industry is by far the largest consumer of kaolin, using more than 10 Mt per annum worldwide. In paper manufacture, kaolin is used in filling and coating, and represents 45% to 60% of all minerals used by the paper industry. The importance of kaolin in paper manufacture is declining to some extent owing to technological advances in paper production and the increased use of less-costly ground calcium carbonate.

Kaolin is also used as filler material in paint, rubber, plastics, pharmaceuticals, cosmetics, polishes, insecticides, fertilisers, and many other products. Kaolin reduces the proportion of more-expensive ingredients, increases the opacity of the product or dilutes the concentration of active ingredients to safer or more useful amounts.

Large amounts of unprocessed kaolinitic clays of lower quality are also used in the manufacture of structural products such as bricks, pavers and roofing tiles.

Specifications for kaolin vary significantly depending on the intended use. Kaolin used for paper manufacture needs to be fluid, that is, have a low viscosity; whereas clay used for ceramics needs to be plastic, that is, have a high viscosity (plasticity increases with montmorillonite content).

The most important parameters for kaolin in the ceramic industry are particle size distribution, which affects strength and casting properties; shrinkage; and fired whiteness. Good plasticity and strength are important factors in the manufacture of tableware and porcelain clays. Significant factors in the sanitary ware industry include the viscosity of the kaolinite and its rheological properties.

There are many substitutes for kaolin, some of which may offer superior performance in particular applications. Sillimanite, kyanite, andalusite, bauxite and alumina can substitute for kaolin in refractory bricks. These materials, however, are more expensive than kaolin.

Economic Factors

Kaolin production is sensitive to such factors as the availability of suitable deposits with good access to markets, high investment costs, the highly competitive market, and access to technical expertise combined with research and development financing (Harben & Virta 1999, 2000). Kaolin remains competitive in most sectors of the industry, provided production and transport costs are successfully managed.

The successful use of kaolin is related to its relatively low unit value, compared to many of the substitute materials. Kaolin should continue to be the dominant paper coating pigment, although the challenge by carbonate rocks and talc will clearly continue (Harben & Virta 2000). Advances in ceramic manufacturing technology, as well as improvements in other whitewear manufacturing techniques, are placing increased demands on kaolin producers to pay more attention to their clay's particle size distribution, packing density and reaction rates.

In the paper manufacturing industry, there has been a significant increase in the use of calcium carbonate because of its tendency to have a higher brightness than kaolin and its superior response to ink application, particularly coloured ink.

Future growth in demand for filler and coating materials for the paper industry should be in Asia and Latin America. Although the traditional production sites in the USA and Great Britain will continue to be major sources of high-grade kaolin, Brazil will challenge market dominance. Australia, China, the Czech Republic and Ukraine have favourable locations relative to large kaolin markets and the potential for upgrading their markets (Minerals Gazette 2001).

References

Baker C.J. & Uren R.E. 1982. Kaolin in New South Wales. *Geological Survey of New South Wales, Mineral Resources* **44**.

Brown R.E. & Stroud W.J. 1997. *Inverell 1:250 000 Metallogenic Map SH/56-5: metallogenic study and Mineral Deposit Data Sheets.* Geological Survey of New South Wales, Sydney.

Byrnes J.G. 1993. *Bourke 1:250 000 Metallogenic Map SH/55-10: metallogenic study and Mineral Deposit Data Sheets.* Geological Survey of New South Wales, Sydney.

Harben P.W. & Kužvart M. 1996. *Industrial minerals: a global geology.* Industrial Minerals Information Ltd, London.

Harben P. & Virta B. 1999. High grade kaolin fillers. Production review. *Industrial Minerals* **386**, 25–37.

Harben P. & Virta R.L. 2000. High grade kaolin fillers. Trade and distribution. *Industrial Minerals* **388**, 34–37.

McHaffie I.W. & Buckley R.W. 1995. Industrial minerals and rocks of Victoria. *Geological Survey of Victoria, Report* **102**.

Minerals Gazette 2001. World price of kaolin on the way up. *Minerals Gazette* April 2001, p 16.

Pecover S.R. 1986. Construction and industrial sand resources of the Newnes Plateau. Geological Survey of New South Wales, Report GS**1986/214** (unpubl.).

Ray H.N., MacRae G.P., Cain L.J. & Malloch K.R. 2003. New South Wales Industrial Minerals Database, 2nd edition. Geological Survey of New South Wales, Sydney, CD-ROM.

Schaap A. D. 1990 Weipa kaolin and bauxite deposits. *In:* Hughes F.E. ed. Geology of the mineral deposits of Australia and Papua New Guinea, pp. 1669–1673. *The Australasian Institute of Mining and Metallurgy, Monograph* **14**, vol. 2.

Virta R.L. 2005. Clays. *In:* United States Geological Survey. compiler. *Mineral Commodity Summaries 2005,* pp. 48–49. United States Department of the Interior.