Mineral Resources
Tasmania

Tasmania

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Zeolites in Tasmania

by R. S. Bottrill and J. L. Everard

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Abstract

The zeolites are a 'supergroup' of aluminosilicate minerals, and natural deposits are of diverse style and may be of considerable economic significance. Nineteen different species are known to occur in Tasmania (including Macquarie Island), and the major occurrences are briefly described. The host rocks are mostly Tertiary basaltic rocks, but also include dolerite, mudstone, sandstone, granite, quartz veins, skarns and other rock types. Styles include veins, replacement, pore filling, breccia fill and vesicle fill. Economic deposits are not currently known in Tasmania, but there are numerous small occurrences, some of which are relatively rich and of moderate size, giving indications of some potential for economic mineralisation. Very little exploration for zeolites has, however, been undertaken in this State.

INTRODUCTION

Zeolites are a diverse 'supergroup' of minerals, all being crystalline hydrated aluminosilicates of the alkali and alkaline earth metals, particularly Ca, Na and K. They less commonly contain Ba, Li, Cs, Sr and Mg. Some 94 species are known, some of the more important including clinoptilolite, chabazite, mordenite, phillipsite, laumontite, stilbite, heulandite, analcime, natrolite and thomsonite. They are all characterised by a 3D aluminosilicate framework but have variable polyhedral groups and, importantly, relatively large channels and cavities between these polyhedra. These cavities and channels can contain cations (e.g. metal ions), water and other molecules, and give the zeolites some of their most important properties, in regards to their use as molecular sieves, catalysts, ion exchange materials, etc.

USES

The zeolites have some unusual and important characteristics, including capacity for ion-exchange and molecular sieving which make many varieties of considerable economic significance. Uses include adsorption (e.g. removal of ammonia, heavy metals, radio isotopes, etc.), purification (particularly waste water, sewage, hydrocarbons, air and gases), drying, kidney dialysis, hydrogen production (from water), detergent production, animal feeds, fertilisers, aquaculture, hydrocarbon conversion (e.g. conversion of methane to petroleum), isomerisation, redox reactions, hydrogenation and dehydro- genation, organic catalysis (e.g. shape-selective reforming), solar energy storage, and many more (Mumpton, 1977; Clifton, 1987).

Synthetic zeolites are very important in many of these applications, especially where high purity is required (particularly the chemical, oil, detergent and other manufacturing industries). Natural zeolites are, however, used in many applications (Rustamov *et al*., 1988; Clifton, 1987), for example:

- clinoptilolite to remove NH^{4+} in tertiary sewage treatment;
- mine waste management;
- agriculture (soil conditioner, fertiliser carriers and in animal feeds);
- aquaculture;
- pet litter;
- mordenite for removal of organochlorides from industrial effluent; and
- phillipsite to remove Cs and Sr from radioactive materials.

Natural zeolites may require some chemical modification prior to use.

ECONOMIC FACTORS

Natural zeolite deposits may be economic, especially if the beds are several metres thick and relatively massive (i.e. >70% zeolites). The thickness of mineable zeolite deposits can range up to several tens of metres, whilst the thickness of the strata containing the zeolitic tuffs commonly ranges from 100's to 1000's of metres. Areal extent is commonly 100's to 1000's of square kilometres (Green River Basin, USA: Hay and Sheppard, 1977). The economics of mining are affected by the thickness of overburden, and the distance to transport links and processing plants.

The hardness and attrition resistance of zeolitic tuff (mostly affected by the abundance of opal, cristobalite, tridymite and quartz) are important in processing and end use. The crystal size of the zeolite (usually fine grained) can affect the adsorption of gases and the extent and rapidity of cation exchange. The Si/Al ratio and exchangeable cation ratios of the zeolites affect certain uses. Cation exchange capacity and adsorption capacity for various gases are important. Colour (due to iron staining) and the abundance of non-zeolitic minerals may limit some uses.

GEOLOGICAL OCCURRENCES

Zeolite deposits may occur in:

1. saline, alkaline lakes;
2. saline, alkaline soils;
3. tuffaceous sea-floor sediments;
4. open hydrological systems; and
5. hydrothermal veins and zones.

The major known economic deposits in the United States are of types 1, 2 and 4 (Clifton, 1987).

Saline, alkaline deposits form in closed hydrological systems in arid to semi-arid environments and contain some of the purest zeolite deposits (>90%, Hay, 1977; Clifton, 1987; Surdam, 1977). Saline lakes forming in closed basins may have a pH of up to 9.5, promoting dissolution of aluminosilicates (Hay, 1977). Deposits in the USA formed mostly from rhyolitic tuffs, but a wide variety of materials (including clays and quartz) may be altered to zeolites under these conditions (Hay, 1978). Analcime, clinoptilolite, phillipsite, erionite, chabazite and mordenite occur in these lakes.

Deposits in alkaline soils are related to the above style, but are limited by depth of the water table, and are commonly analcime rich (Clifton, 1987; Surdam, 1977). They can contain up to 40% zeolites.

Zeolites are very widespread in marine sediments (Iijima, 1978; Iijima and Utada, 1966; Lisitzina and Butuzova, 1982) and form by the alteration of tephra under low temperatures and moderate pH (~7–8, Clifton, 1987). Clinoptilolite is usually dominant in areas of rapid sedimentation, siliceous tephra and older sediments, while phillipsite commonly dominates in areas of slower sedimentation, basaltic tephra and younger sediments (Hay, 1977). Phillipsite may alter to clinoptilolite (Clifton, 1987). Associated zeolites include analcime, chabazite, erionite, laumontite, gmelinite, natrolite and thomsonite (Iijima and Utada, 1966). Deposits may contain up to 80% zeolites.

Economic deposits of zeolites in open system deposits (dominated by clinoptilolite, chabazite, mordenite, phillipsite, laumontite, stilbite, heulandite, analcime and natrolite) crystallise in relatively thick, generally non-marine vitric tephra sequences (Clifton, 1987; Hay and Sheppard, 1977). Deposits may be very extensive, thick and rich (up to 90% zeolite), and commonly show a more or less vertical zonation of zeolites and associated silicate minerals that reflects the chemical modification of meteoric water as it flowed through the tephra sequence (Hay and Iijima, 1968; Hay and Sheppard, 1977).

Zeolites may precipitate from alkaline to weakly acidic hydrothermal systems, such as in Wairaki, New Zealand and the Kuroko deposits of Japan (Iijima, 1980). Zeolites are also locally common as interstitial and vesicle fillings in hydrothermally altered basaltic rocks (e.g. Iceland; Walker, 1960; Kristmannsdóttir and Tómasson, 1978). The deposits are commonly zoned and include wairakite, laumontite and mordenite zones (Japan; Iijima, 1980) or laumontite, scolecite and heulandite zones (e.g. India; Sukheswala *et al.*, 1974). These deposits do not appear to be of economic significance, although submarine hydrothermal activity may be responsible for some of the zeolite deposits in marine sediments (Clifton, 1987).

Zeolites may also occur in several other situations, including as a primary magmatic mineral (analcime in some basalts; Iijima, 1980), during burial diagenesis (e.g. the Green Tuff sequence, Japan; Iijima, 1980), in contact metamorphic zones (Utada, 1991), and in sediments in calderas (Utada, 1991) and impact craters (Iijima, 1980). With the exception of caldera deposits, these mineralisation styles generally do not appear to be of any great economic significance (Utada, 1991).

Host rock types include igneous, metamorphic and sedimentary rocks, and vary from monomineralic, wholly zeolite-bearing lithologies to rocks with occasional zeolitic geodes, veins or inclusions. Igneous hosts include volcanic ashes, lavas and tuffs (having a broad compositional range, including rhyolite, dacite, trachyte, phonolite, and basalt to basanite) and less commonly various hypabyssal and plutonic rocks. The silicic tuffs were commonly deposited as non-welded permeable ash flows. Sedimentary host rock types include fluviatile mudstone, siltstone, sandstone, conglomerate and diatomite. Metamorphic hosts (for hydrothermal deposits) are rarer, but include hornfels, amphibolite, schist and gneiss.

Zeolites form stratabound, stratiform or lens-shaped, zoned, massive, fine-grained deposits that may be cross-cutting to the bedding. They are similar to bedded diatomite and bentonite. Most deposits are non-marine (fluviatile and lacustrine), but some are shallow marine and some thick zeolitised tuffaceous deposits were subaerially deposited. Some rare redeposited zeolite deposits are known (Djourova and Milakovska-Vergilova, 1996).

Typical regional depositional environments may contain thick sequences of zeolitised vitric tuffs affected by very low to low grade metamorphism (<300°C, <3 kb). The deposits are often zoned: the low temperature zeolites in the upper part of the deposit (e.g. mordenite, clinoptilolite and phillipsite) are commonly replaced at depth (~1–3 km, ~60–150°C) by analcime, heulandite, stilbite and mesolite; at greater depths (~3–11 km, ~90–300°C) by laumontite, thomsonite and wairakite; and finally potassium feldspar and/or albite (Iijima, 1980). Eventually conversion of zeolitic tuff to an assemblage of alkali feldspar and quartz (Sheppard and Gude, 1968) or prehnite-pumpellyite-epidote (Cho *et al.*, 1985) can occur.

Most zeolite deposits form by the flow of water through permeable rocks and sediments. Mineralisation controls include the amount of fluid flow, the composition, size, grain size and permeability of host rocks, plus, depending upon the particular style of deposit, the climate, fluid temperatures and compositions and burial depth. The pressure and temperature variations may result in a vertical or near-vertical zonation of zeolites and other authigenic minerals. Composition of the vitric material may have dictated which zeolite species precipitated; clinoptilolite and mordenite are common in silicic tuffs, but chabazite and phillipsite are common in mafic or trachytic tuffs.

The age range is usually Mesozoic to Holocene; most deposits in the USA are Cainozoic, but many are Mesozoic. Worldwide, several deposits are Palaeozoic but sedimentary zeolites in Proterozoic rocks are rare (Iijima and Utada, 1966; Iijima, 1980). A Late Carboniferous deposit is known in NSW (Flood, 1991). In general the zeolites crystallise in a post-depositional environment over periods ranging from thousands to millions of years.

Associated deposits include pumice, perlite, bentonite, diatomaceous earth, oil shale and coal.

TASMANIAN OCCURRENCES

Naturally occurring members of the zeolite group are widespread in Tasmania, particularly as secondary minerals in Jurassic dolerite and Tertiary basalt. They have also been reported from Devonian mineralised systems, Permian hornfels, Upper Triassic volcaniclastic lithic sandstone, Cretaceous alkaline rocks and Tertiary conglomerate. Nineteen different species have been recorded. The following is a description of general occurrences, classified by the age of host rocks. The major occurrences are shown on Figures 1 and 2.

Devonian

Laumontite and stilbite occur in Late Devonian tin-tungsten-bismuth–bearing quartz veins in calc-silicate hornfels and skarns at the Shepherd and Murphy mine at Moina (Anon, 1970; Polden, 1983). Stilbite also occurs in veins in Devonian granite in the King Island Scheelite mine. Analcime has been reported from Devonian granitic pegmatite in the Blue Tier area (Reid and Henderson, 1928). None of these occurrences are economically significant.

Permo-Triassic

Laumontite has been reported from Triassic sandstone near Wayatinah (Anon, 1970) and York Plains. At the latter locality it occurs as a pore-filling cement and as a replacement of plagioclase and lithic fragments in late Triassic volcaniclastic lithic sandstone (Eggert, 1983). Similar occurrences occur in stratigraphically equivalent rocks in Antarctica (Vavra *et al*., 1980).

Laumontite also occurs in veins, breccias and fossil infills in hornfelsed fossiliferous Permian mudstone in various areas, including:

- Variety Bay, Bruny Island (Bottrill, 1995);
- Proctors Road, Mt Nelson;
- Fossil Cove, Blackmans Bay; and
- Tabors Road, Margate.

The mudstones in these locations are all altered and hornfelsed by underlying and intruding Jurassic dolerite, and contain quartz, feldspars, clinopyroxene, grossular, wollastonite, prehnite and vesuvianite. Opalisation is locally associated.

Stilbite veins and breccia infills occur in hornfelsed fossiliferous Permian mudstone at Mt Mary, Cygnet, and are closely associated with alkaline intrusive rocks. Similar veins cut dolerite and syenite in the same area.

The pore-filling and replacement-style occurrences may be economically significant styles, but no indication of zeolite concentration is known.

Jurassic

Jurassic dolerite (174.5 ± 8 Ma, Banks *in* Burrett and Martin, 1989, p. 375) dominates the geology of eastern and central Tasmania, forming dykes and sills, often hundreds of metres thick, mainly in the essentially flat-lying Late Carboniferous to Late Triassic Parmeener Supergroup rocks. In western and far northeastern Tasmania dolerite is restricted to remnant outliers capping mountains, or as rare intrusions in the pre-Carboniferous basement. The chilled margin composition, a quartz-normative tholeiite, is virtually constant throughout Tasmania, but *in situ* differentiation by crystal fractionation, locally producing granophyre, is ubiquitous (e.g. McDougall, 1962). The dolerite near Cape Town in South Africa and the similar Ferrar dolerites of Antarctica were originally contiguous, and the entire phase of magmatism is thought to be related to the break-up of Gondwanaland.

Zeolites in the Jurassic dolerite are common as volumetrically minor secondary minerals lining joints and fractures, and in alteration zones. The minerals recorded, most from many localities, are chabazite, stilbite, stellerite, heulandite, scolecite and laumontite (Anon., 1970). Stellerite is a zeolite closely related to stilbite. Leonhardite, also reported, is a variety of laumontite. Zeolitisation appears to have been at least partly earlier than early Palaeocene faulting. Sutherland (1977) interpreted the assemblage laumontite + prehnite as implying higher temperatures and greater depths of burial (1600–2200 m) than the assemblage chabazite + stilbite ± scolecite (800–1600 m). As there is little or no correlation with stratigraphic level of the host dolerite, he suggested that the former assemblage may be older, suggesting a Jurassic surface possibly capped by comagmatic Jurassic lavas, whilst the latter assemblage may be late Cretaceous, by which time the amount of overburden had been decreased by erosion.

Some significant locations include:

- Giblin Street quarry, Hobart;
- Bashen quarry, Waddamana;
- McCarthys quarry, Longley;
- Lonnavale (Sorrell, 1995*a*; Bottrill, in prep.);
- Bruny Island (Bottrill, 1995).

Associate minerals include calcite, prehnite, pumpellyite, quartz, pyrite, apophyllite, smectite, bitumen and native copper.

Chabazite, heulandite, clinoptilolite, stellerite and laumontite also occur in mid-Mesozoic basalt near Catamaran and Lune River, in the extreme south of Tasmania. Associates include chalcedony, smectite and crystalline hematite. The basalt appears to be comagmatic with the dolerite, and represents the only known related extrusive rocks in Tasmania (Hergt *in* Burrett and Martin, 1989). The zeolites occur mostly in veins and breccias, plus stellerite and clinoptilolite partly replace some felsic xenoliths (M. R. Banks, pers. comm.) and stilbite occurs in vughs in chalcedonic amygdules (agates).

None of these occurrences, although locally very pure and coarse grained, are economically significant.

Cretaceous

Analcime also occurs with cancrinite and hauyne in small intrusions of sanidine-phyric syenite of Cretaceous (c. 99 Ma) age near Cygnet, south of Hobart (e.g. Ford, 1983). Stellerite occurs in veins in some similar porphyries at Mt Mary, Cygnet.

These occurrences are not economically significant.

Tertiary

Tertiary volcanic rocks in Tasmania range in age from Palaeocene (58.5 0.7 Ma) to Miocene (8.5 1 Ma), with about half the available radiometric dates falling in the interval 22–31 Ma (Sutherland, 1989). These volcanic rocks comprise lavas and subordinate pyroclastics and are entirely basaltic, ranging from tholeiites to alkali olivine basalts and basanites, with generally less voluminous strongly undersaturated types such as olivine nephelinites and melilitites. They occur widely throughout Tasmania, but are most extensively developed in the northwest and are absent in the southwest. Many eruptions were aquagene, and zeolitisation is concentrated near volcanic centres (Sutherland, 1980). Some dolerite or gabbro occurs in volcanic vents.

Zeolite minerals are common as amygdaloidal fillings in the basalts, often associated with calcite, aragonite and smectites (montmorillonite, nontronite, stevensite and saponite). They also occur in related aquagene pyroclastic rocks, as at Gads Hill near Lorinna in northwestern Tasmania. There are well documented reports in the literature of chabazite, phillipsite, analcime, natrolite, gonnardite, thomsonite, heulandite, stilbite, tetranatrolite, levyne, gmelinite, gismondine and herschelite (see individual descriptions below). Other associated secondary minerals include calcite, vaterite, aragonite, siderite, pyrite, chalcedony, opal, smectite, apophyllite, tacharanite, tobermorite, gyrolite and thaumasite. A summary of some described localities follows.

- At The Nut at Stanley, in the far northwest, analcime appears to occur both as a primary interstitial phase and a deuteric alteration product of feldspar in a prominent feeder of an undersaturated teschenite (alkali gabbro) (Cromer, 1972). Nearby agglomerate is rich in phillipsite, natrolite and analcime. Zeolite concentrations are probably not high in the feeder, but may be >20% in the agglomerate.
- Chabazite, with minor phillipsite, levyne and analcime, occurs abundantly in Tertiary aquagene basaltic pyroclastic rocks (pillow lavas, hyaloclastite, tuff and tuffaceous siltstone) at Gads Hill near Lorinna (Andersen, 1984). Zones of up to 20% zeolite may be present (Askins, 1980).
- Chabazite, phillipsite, heulandite, thomsonite, gonnardite, herschelite and analcime are locally abundant in Tertiary basaltic sequences, including basalt, tuff and pyroclastic rocks, in the Guildford area (Everard, 1989). Zeolite concentrations are locally greater than 10%.
- Relatively large crystals of chabazite and phillipsite occur in vesicular Tertiary basaltic agglomerates near the Hellyer River bridge, Guildford (Sorrell, 1995*a*). Zeolite concentrations are probably less than 5%.
- Natrolite and analcime, with minor thomsonite, calcite and gmelinite, are abundant in a vesicular Tertiary basaltic pyroclastic dome underlying flood basalt at Weldborough in northeast Tasmania (Bottrill, 1992). Zones estimated at up to 25% zeolite are present.
- Natrolite, analcime, thomsonite and chabazite are abundant in Tertiary basaltic rocks at Table Cape, near Wynyard (Sorrell, 1995*b*). Zeolite concentrations are probably less than 5%.
- Natrolite, mesolite, herschelite, phillipsite, thomsonite, gmelinite, chabazite and analcime are locally abundant in Tertiary basaltic tuff and

agglomerate in the Redpa–Marrawah area of far northwest Tasmania (Heron, 1988; Poltock, 1980; Polden, 1983). Concentrations have not been determined.

- Abundant zeolite cement is common in Tertiary deposits of dolerite conglomerate and sandstone in the Tamar area and in some nearby sub-basalt Tertiary sandstone (S. Forsyth, pers. Comm.). Concentrations and types have not been determined.
- Zeolites are locally abundant in amygdules and veins in weakly metamorphosed Tertiary ocean-floor basalt on Macquarie Island. Phillipsite occurs with calcite and smectites in samples subjected only to sea-floor weathering. Thomsonite, mesolite, phillipsite, wairakite, natrolite, analcime, laumontite, heulandite and levyne have been reported with calcite, smectites, chlorite and illite in zeolite facies assemblages. Laumontite and wairakite occur in rocks transitional to the lower greenschist facies (Griffin, 1982; B. D. Goscombe and J. L Everard, unpublished data).

Some of these occurrences may be economically significant, although only Gads Hill has received any real exploration attention.

The distribution of zeolites in some areas can be used for distinguishing burial depths and hydrothermal zoning (Iijima, 1980; Sukheswala *et al.*, 1974; Kristmannsdóttir and Tómasson, 1976), but there is no clear zoning in the Tasmanian basalts. One of the most common zeolite assemblages in the basalts (chabazite and phillipsite) is typical of relatively low temperature (<70°C) and burial, whilst the rarer stilbite is usually indicative of higher temperatures (~70–120ºC) and deeper burial (Kristmannsdóttir and Tómasson, 1976). Geothermal gradients may be locally very high, making inferral of temperatures of formation and depths of burial unreliable (Kristmannsdóttir and Tómasson, 1976).

EXPLORATION FOR ZEOLITES IN TASMANIA

Zeolites have been explored for on two Exploration Licences (ELs) in Tasmania.

The Commonwealth Aluminium Corporation Ltd (Comalco) explored EL7/74, in the Sheffield area, for various commodities, including zeolites. The zeolite occurrences in Tertiary basalt and agglomerate at Gads Hill (see above) were tested by diamond drilling, geological mapping and metallurgical beneficiation (Askins, 1980). This work indicated that the zeolites (mostly chabazite) reach concentrations of up to 25% over about 20 m, and can be upgraded by gravity concentration and magnetic separation to purities of up to 98% (Askins, 1980).

Comalco took out EL24/79, in the Redpa–Marrawah area in far northwest Tasmania (see above), specifically to search for zeolites. The zeolite occurrences, in Tertiary basalt and agglomerate were only examined by brief reconnaissance geological mapping, and only minor (unquantified) zeolites were noted (Poltock, 1980).

Both ELs were dropped because of a company reorganisation, rather than perceived geological or resource potential limitation.

RESOURCE POTENTIAL

Natural zeolites have not been exploited economically anywhere in Tasmania, and large, rich deposits have not been recognised to date. The major known economic deposits of the United States were formed in saline, alkaline environments, settings rarely present in the Mesozoic and Cainozoic in Tasmania.

It is, however, interesting to note the occurrence of potentially economic zeolite deposits in Late Carboniferous lacustrine to fluvioglacial rocks at Werris Creek, New South Wales (Flood, 1991). There are obvious comparisons with the geological setting for Parmeener Supergroup (Late Carboniferous– Triassic) lacustrine to fluvioglacial sequences in Tasmania, especially as felsic tuffs are known in some areas (Bacon and Everard, 1981). The Werris Creek deposit is considered by Flood (1991) to be of the alkaline lake style, although there is no evidence given for an alkaline, arid environment. The potential for this style in Tasmania may be quite significant.

Abundant zeolite cement is common in Tertiary deposits of dolerite conglomerate and sandstone in the Tamar area and in some nearby sub-basalt Tertiary sandstone (S. Forsyth, pers. comm.). The style (open hydrological system?) and distribution of this mineralisation is poorly known, but it could have economic potential.

Disseminated laumontite occurs in significant (but unquantified amounts) in Permo-Triassic volcaniclastic lithic sandstone near Wayatinah (Anon, 1970) and York Plains (Eggert, 1983). This may be due to normal burial diagenesis and low-grade metamorphism, as in zeolitised volcanic-rich Triassic sandstone in Antarctica (Vavra *et al.*, 1980); the economic potential is unknown.

Zeolite deposits in hydrothermal veins and zones, and in magmatic deposits, are known in Tasmania, but are of no economic importance.

No sea-floor deposits are known, but there may be potential in some Tertiary, Cretaceous and Permo-Triassic volcanogenic sediments.

Deposits of open hydrological systems in post-Carboniferous rocks appear to have the highest economic potential for zeolites in Tasmania. Deposits at Gads Hill, near Lorinna, have proven grades of up to 25% zeolite over 20 m, upgradable by beneficiation to ~98 % zeolite. There are probably many more deposits of this type in Tasmania, and the zeolitised conglomerates also need assessment.

MINERAL OCCURRENCES

Mineral descriptions are based on the *Catalogue of the Minerals of Tasmania* (Anon, 1970, updated mainly with unpublished work by the authors). Major occurrences are shown on Figures 1 and 2.

Analcime (Analcite) $NaAlSi_2O_6.H_2O$

Analcime is the only common isometric member of the zeolite group, but is considered by some mineralogists to be closer to the feldspathoids in structure. It is often found as a late-stage mineral in vesicles in the Tertiary basaltic rocks of the State. Such occurrences have been reported from Redpa–Marrawah (Heron, 1980), Table Cape (Sorrell, 1995*b*), Weldborough Pass (Bottrill, 1992), Guildford (Everard, 1989), Mt Cameron West, the Tamar Valley and the Railton–Moriarty area. At The Doughboys, near Cape Grim, crystals to several centimetres occur with natrolite in vesicular basalt. An interesting occurrence has been noted at Bonney's quarry, South Burnie, where radiating acicular natrolite crystals are tipped with analcime which makes up to a third of the total 2 mm length of the crystals (Sutherland, 1965).

Analcime appears to occur both as a primary interstitial phase and a deuteric alteration product of feldspar in a prominent feeder of undersaturated teschenite (an alkali gabbro) at The Nut at Stanley, in the far northwest (Cromer, 1972). It also occurs in the groundmass of Tertiary alkali olivine basalt at Marys Island (Robbins Island) and Reid Rocks in Bass Strait (Everard *et al*., in prep.). In an unusual occurrence, analcime has been reported from granite pegmatite in the Blue Tier area (Reid and Henderson, 1928). It was also reported from Port Cygnet, in syenitic intrusive porphyry dykes with cancrinite and hauyne (Ford, 1983).

Analcime is abundant in vesicles, veins, and as a replacement of plagioclase in Tertiary basalt on Macquarie Island, with phillipsite, natrolite and thomsonite (Griffin, 1982; B. D. Goscombe pers. comm.). It typically occurs at the rims of amygdules, and is therefore one of the first zeolites to form.

Chabazite $(Ca,Na_2,K_2)Al_2Si_4O_{12}.6H_2O$

This is a trigonal member of the zeolite group which usually occurs as white translucent to transparent rhombohedral crystals which approximate to cubes, but are commonly twinned. Herschelite is a sodium analogue, sometimes described incorrectly as a variety of chabazite. Twinning of chabazite crystals gives rise to complex hexagonal forms which have been given the varietal name of 'phacolite'.

Chabazite is widespread in the basaltic rocks of the State. Crystals up to 15 mm in diameter have been recorded from Tertiary basalt at Bell Mount near Moina. Smaller crystals occur in basalt at many localities including near the railway bridge over the Hellyer River (10 mm crystals with phillipsite: Sorrell, 1995*a*), at Table Cape (Sorrell, 1995*b*), Gads Hill at Lorinna (Andersen, 1984; Askins, 1980), near Deloraine, Maggs Mountain, Lefroy, Guildford (Everard, 1989), Springfield, Inspection Head, near Craigburn, Liawenee Canal, Sheffield, Ridgely, Goodwood and Catamaran. Examples of 'phacolite' have been found in basalt near Waratah, the Hellyer River, Table Cape, Middlesex, Sheffield, Lefroy and Springfield.

Chabazite also occurs as good large crystals (<10 mm) along joint planes and in breccia zones in Jurassic dolerite at the Giblin Street quarry in Hobart, where it is associated with stilbite and calcite. There are similar dolerite breccia-hosted occurrences at Lonnavale (with calcite, stilbite, stellerite, pyrite, laumontite and bituminous hydrocarbons; Sorrell, 1995*a*; Bottrill, in prep.), at Longley (with prehnite, calcite, laumontite, pyrite and stilbite), and Bruny Island (Bottrill, 1995). Dolerite east of Deloraine, on Ben Lomond and elsewhere also carries the mineral.

Clinoptilolite $(Ca,Na_2,K_2)_{2\text{-}3}Al_5Si_{13}O_{36}.12H_2O$

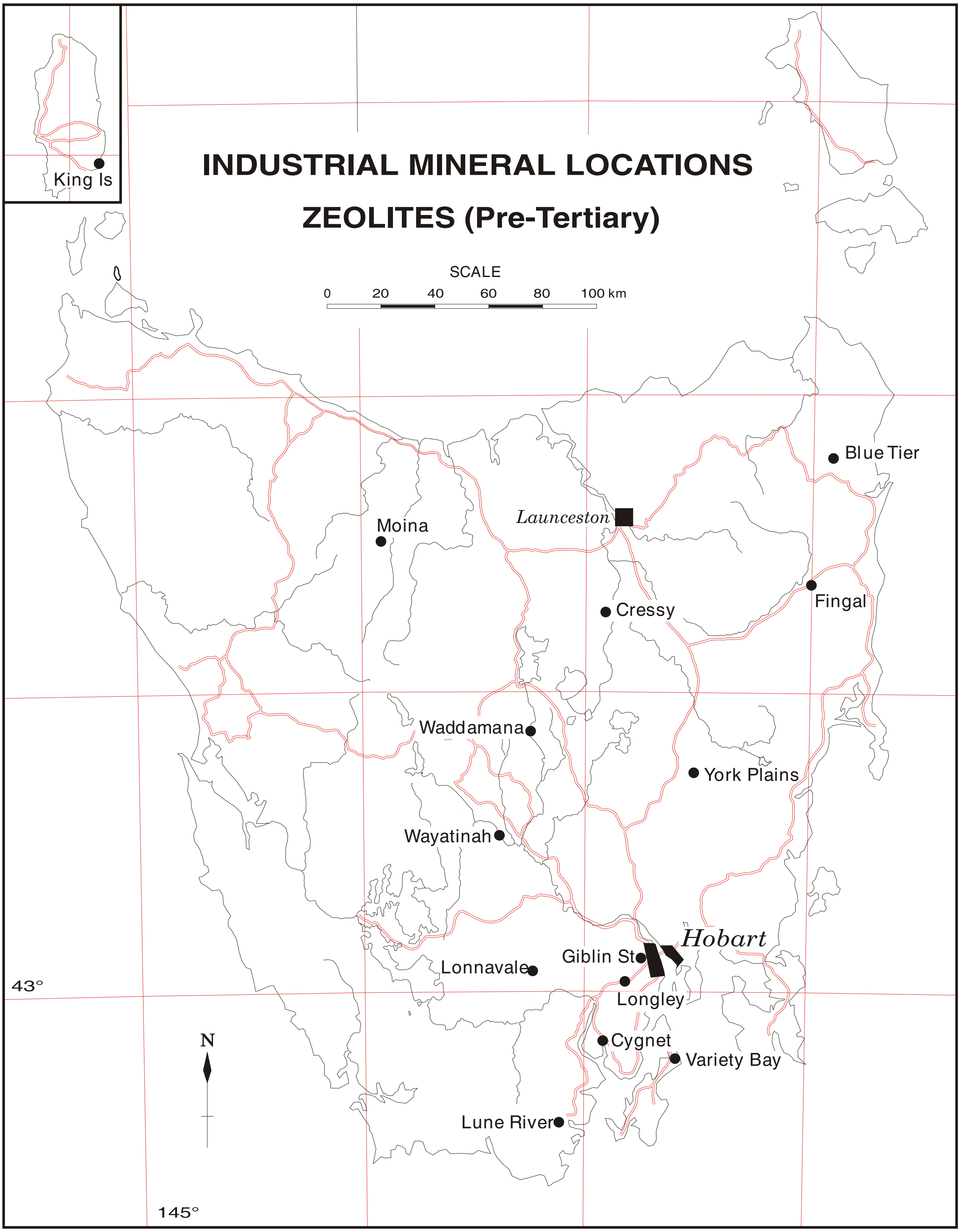
This heulandite-like mineral is uncommon in Tasmania but has been identified (by XRD) as pinkish bladed crystals with stellerite, heulandite and hematite in breccia zones and altered feldspathic xenoliths in Jurassic basalt at Lune River.

Gismondine $Ca_2Al_4Si_4O_{16}.9H_2O$

This uncommon mineral has been identified (by XRD) in vesicular basaltic agglomerate at Weldborough Pass, as rare intergrowths with natrolite and analcime.

Gmelinite $(Na_2Ca)Al_2Si_4O_{12}.6H_2O$

This zeolite is closely related to chabazite. It usually crystallises with hexagonal or rhombohedral habit and was reported by Petterd (1903) to occur in quantity in a vugh in Tertiary basalt at Bell Mount. Fine pink crystals to about 10 mm occur in vesicular basalt at Weldborough Pass, with analcime and natrolite, and fine colourless to white crystals occur intergrown with herschelite in vesicular basalt near Redpa (Heron, 1980). A few small white crystals occur with analcime and phillipsite in Tertiary basalt collected by K. F. Lancaster from Cape Grim (letter from Director of Mines, 14 May 1980).



INDUSTRIAL MINERAL LOCATIONS
ZEOLITES (Pre-Tertiary)
SCALE
0
20
40
60
80
100 km
King Is
Blue Tier
Launceston
Moina
Fingal
Cressy
Waddamana
York Plains
Wayatinah
Hobart
Giblin St
Lonnavale
Longley
43°
N
Cygnet
Variety Bay
Lune River
145°

Figure 1

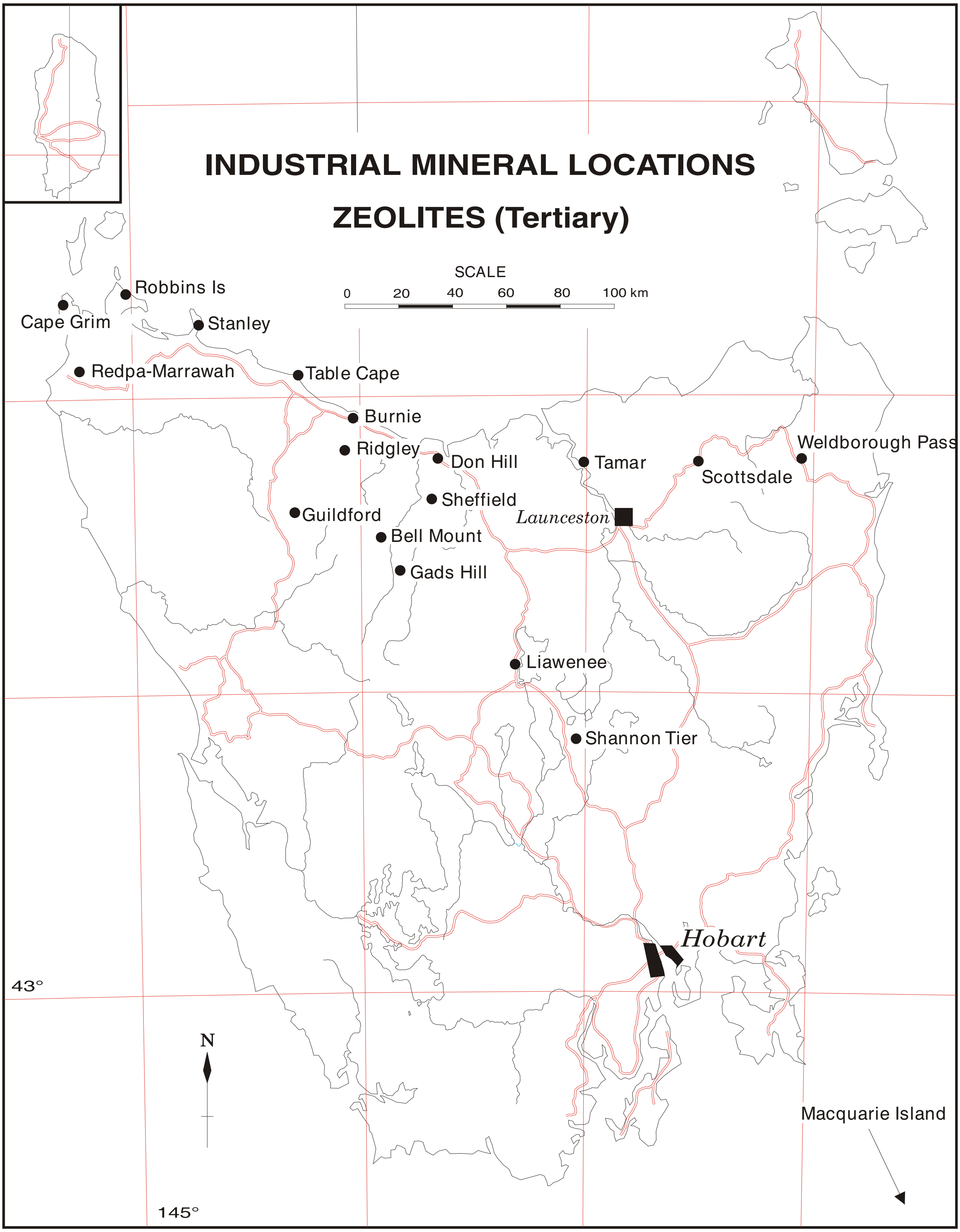

INDUSTRIAL MINERAL LOCATIONS
ZEOLITES (Tertiary)
SCALE
0
20
40
60
80
100 km
Robbins Is
Cape Grim
Stanley
Redpa-Marrawah
Table Cape
Burnie
Ridgley
Don Hill
Tamar
Weldborough Pass
Scottsdale
Sheffield
Guildford
Launceston
Bell Mount
Gads Hill
Liawenee
Shannon Tier
Hobart
43°
N
Macquarie Island
145°

Figure 2

Gonnardite $Na_2CaAl_5Si_5O_{20}.6H_2O$

This comparatively rare fibrous zeolite has been identified in nephelinite three kilometres southwest of Scottsdale, where the mineral is overgrown by natrolite. It also occurs in vesicular Tertiary basalt at various locations, including with natrolite and thomsonite near Stanley, intergrown with natrolite at Don Hill (Carney and Carney, in prep.), and in drillholes near Guildford, with chabazite and calcite (Everard, 1989). A mineral occurring in faults and joints within Jurassic dolerite, described as gonnardite (Sutherland, 1964), has since been recognised as scolecite (Anon, 1970).

Herschelite $(Na,Ca,K)Al_2Si_4O_{12}.6H_2O$

This white, hexagonal tabular to prismatic mineral, a sodium analogue of chabazite, occurs in vesicles in Tertiary Basalt in a quarry three kilomtres southwest of Redpa, in part intergrown with gmelinite (Heron, 1980; Sutherland and Corbett, 1967). It also occurs in basalt at Gads Hill (Askins, 1980) and near Guildford (Everard, 1989).

Heulandite $(Ca,Na_2,K_2)\ 2\text{-}3Al_5Si_{13}O_{36}.12H_2O$

This stilbite-like mineral is moderately abundant in joints and small veins in dolerite, and has been recorded from near Swansea, near Lonnavale (with chabazite, calcite, pyrite and bitumen; Bottrill, in prep.), with calcite and pyrite at Black Bobs, and with native copper in a drillhole at Variety Bay, Bruny Island (Bottrill, 1995).

It is relatively uncommon in vesicular Tertiary basalt in Tasmania, but is found in such rocks near Waratah and Guildford (Everard, 1989). It also occurs as orange-red crystals with clinoptilolite and hematite in Jurassic basalt at Lune River. Barium-bearing, bright red heulandite (<1.6% BaO) occurs in carbonaceous Triassic mudstone in a diamond-drill hole near Fingal (Green, 1980).

Heulandite is a rare zeolite on Macquarie Island, where it occurs as white bladed crystals up to 7 mm long, associated with natrolite, in veins in basalt (Griffin, 1982).

Laumontite $CaAl_2Si_4O_{12}.4H_2O$

This unstable monoclinic zeolite is relatively common, with the partially dehydrated variety known as leonhardite occuring at most localities. It has been recorded from joints and breccias in dolerite at Great Lake, Bronte, Wayatinah, Lutana, Lonnavale, Lower Longley and New Town. Laumontite makes up the matrix of Triassic sandstone at Wayatinah and has also been found near Cressy (Eggert, 1983). It replaces fossils in hornfelsed limey mudstone in the Proctors Road quarry on Mt Nelson, and occurs in brecciated hornfelsed limey mudstone at Variety Bay on Bruny Island. The mineral has been recorded from the Hampshire silver mine. A specimen from the Shepherd and Murphy tin-tungsten-bismuth mine at Moina contained a trace of mercury, which was possibly present as cinnabar (R. A. A. Johnston, 1917, *in litt.*). Laumontite has also been found in Jurassic basalt at Lune River.

Laumontite occurs in veins up to 20 mm wide in Tertiary ocean-floor basalt on Macquarie Island. It is not associated with other zeolites, and occurs in higher grade assemblages transitional to lower greenschist facies (Griffin, 1982).

Levyne $(Ca_{2.5},Na)Al_6Si_{12}O_{36}.6H_2O$

This moderately rare zeolite was described as white hexagonal plates to 25 mm in vesicles in Tertiary basaltic agglomerate at Gads Hill, near Moina (Andersen, 1984). It also occurs, with mesolite and thomsonite, in amygdules in Tertiary ocean-floor basalt on Macquarie Island (J. L. Everard, unpublished data).

Mesolite $Na_2Ca_2(Al_6Si_9O_{30}).8H_2O$

This fibrous zeolite has been recorded from the Bell Mount area, near Moina (Polden, 1983). It is also abundant in vesicles and veins in Tertiary basalt on Macquarie Island, with thomsonite, natrolite and analcime (Griffin, 1982, B. D. Goscombe, pers. comm.).

Mordenite $K_{2.8}Na_{1.5}Ca_2(Al_9Si_{39}O_{96}).29H_2O$

Fibrous radiating aggregates occur in Tertiary basalt on Macquarie Island, with quartz and laumontite (B. D. Goscombe, pers. comm.).

Natrolite $Na_2(Al_2Si_3O_{10}).2H_2O$

This fibrous zeolite is relatively abundant in vesicular Tertiary basalt in Tasmania and on Macquarie Island. It forms a bristly overgrowth on gonnardite in nephelinite three kilometres southwest of Scottsdale and occurs as large radiating spherules in basalt around Marrawah and Redpa, in the Tamar Valley, and at Breadalbane. At Bonney's quarry, South Burnie, radiating groups of composite crystals of acicular natrolite tipped with analcime average 2 mm in length. Groups several centimetres in diameter occur near Cape Grim. Good natrolite specimens occur with analcime, thomsonite and gmelinite in a Tertiary basaltic pyroclastic dome underlying flood basalt at Weldborough (Bottrill, 1992 and in prep.), and with analcime, thomsonite and chabazite in Tertiary basaltic rocks at Table Cape, near Wynyard (Sorrell, 1995*b*).

Natrolite is abundant in veins and amygdules in Tertiary basalt on Macquarie Island, with phillipsite, thomsonite and analcime (Griffin, 1982, B. D. Goscombe pers. comm.).

Phillipsite $(Ca,Na,K)_3Al_3Si_5O_{16}.6H_2O$

This is a common white monoclinic zeolite which usually crystallises as glassy, prismatic twin crystals. It is found in many Tertiary basaltic rocks in the northeast and northwest of the State. Small complex twins and radiating aggregates of unusual stalactitic or coralline form have been reported from nephelinite, three kilometres southwest of Scottsdale. Cruciform twins have been noted at Maggs Mountain and in the vicinity of Gads Hill (Andersen, 1984). It occurs as a fine-grained alteration product in and about felsic (anorthoclase) xenoliths in Tertiary basalt at Weldborough Pass (average composition $(Ca_{0.6}Na_{0.2}K_{0.4})_{1.2}Al_{3.0}Si_{5.2}O_{16}.6H_2O$, Bottrill, unpub. data). Phillipsite occurs in good crystals to ~3 mm, with chabazite in vesicular basalt at the Hellyer River bridge on the Ridgely–Waratah Road (Sorrell, 1995*a*), and in drillholes near Guildford, with chabazite and calcite (Everard, 1989). It also occurs with analcime, smectite and possibly nepheline in the groundmass of a Tertiary alkali-olivine basalt at Marys Island, near Guyton Point on Robbins Island (Everard *et al.*, in prep.). Radiating clusters of phillipsite, together with clear trapezohedral analcime and platy to prismatic apophyllite, occur in amygdaloidal Tertiary volcanic rocks from Cape Grim. The phillipsite is in places altered to the rare mineral thaumasite (letter from the Director of Mines to K. F. Lancaster, 14 May 1980). It is also recorded from Springfield, Ridgely, Sheffield and Bell Mount.

Phillipsite is abundant in vesicles and veins in Tertiary basalt on Macquarie Island, with thomsonite, natrolite and analcime (Griffin, 1982; B. D. Goscombe, pers. comm.). It occurs in basalt subjected to both sea-floor weathering and zeolite-facies alteration.

Scolecite $CaAl_2Si_3O_{10}.3H_2O$

This white fibrous zeolite was originally recorded as prismatic crystals, acicular tufts and aggregates with fibrous radiating structure, from dolerite in the vicinity of Launceston. It has since been identified in dolerite south of Hillwood on the eastern side of the River Tamar. A mineral occurring in faults and joints within Jurassic dolerite near Glenorchy, described as gonnardite (Sutherland, 1964), has since been recognised as scolecite (Anon., 1970). Scolecite also occurs as veinlets in Jurassic dolerite near Gordon, with stellerite and laumontite.

Stellerite $(Ca,Na_2,K_2)\ Al_2Si_7O_{18}.7H_2O$

This mineral, closely related to stilbite, occurs with clinoptilolite in an altered feldspathic xenolith in Jurassic basalt at Lune River. It also occurs as druses in small veinlets at the same locality, and in veins with some small crystals in dolerite at Gordon and Regatta Point, near Cygnet. It occurs in brecciated syenitic intrusive rocks at Mt Mary near Cygnet, and also occurs with calcite, pyrite and chabazite in altered dolerite breccia in quarries near Lonnavale and Lower Longley.

Stilbite $(Ca,Na_2,K_2)\ Al_2Si_7O_{18}.7H_2O$

This zeolite occurs as veins in joints in Jurassic dolerite, typically as sheaf-like aggregates of numerous small colourless crystals up to 2 mm in length. It has been recorded in this form on Tasman Island, in the vicinity of Collinsvale and, abundantly, from the Giblin Street quarry at Lenah Valley (Sutherland, 1964). Small but fine white to colourless crystals (<2 mm) occur in breccia veins in dolerite in quarries at Leslie Vale, Lonnavale and Lower Longley, and in cavities in chalcedonic nodules in Jurassic basalt at Lune River.

Stilbite is rarer in Tasmanian basalt, but is recorded as yellow-brown divergent masses in amygdaloidal Tertiary basalt at Bell Mount (Sutherland, 1965). It also occurs with calcite in 'basalt seam material' and 'vesicular material' from the Central Plateau (letter from the Director of Mines to K. F. Lancaster, 20 May 1980), and in pale brown, well-formed crystals to 20 mm in fractures in granite in the King Island Scheelite mine.

Tetranatrolite $Na_2(Al_2Si_3O_{10}).2H_2O$

This mineral, closely related to natrolite, occurs in crystals up to about 20 mm in amygdules in flood basalts in the Weldborough Pass, usually intergrown with thomsonite.

Thomsonite $NaCa_2[(Al,Si)_5O_{10}]_2.6H_2O$

This fibrous bladed zeolite occurs as translucent, pearly spherulitic linings in vesicles in Tertiary basalt near Craigburn, East Tamar. The mineral was originally reported from Sheffield, the Hampshire silver mine, Hampshire Hills and from Shannon Tier, although some of the Shannon Tier zeolite has been found to be natrolite. It was described as pearly white globular aggregates of platy crystals coating vesicles at Gads Hill (Andersen, 1984). At Weldborough Pass it occurs as bladed crystals intergrown with natrolite, and is associated with analcime, chabazite and gmelenite in vesicular basaltic agglomerate. Good specimens occur with analcime, natrolite and chabazite in Tertiary basaltic rocks at Table Cape (Sorrell, 1995*b*).

Thomsonite is the most abundant zeolite species in Tertiary ocean-floor basalts on Macquarie Island, where it occurs as clear coarse interlocking bladed crystals, associated with phillipsite, natrolite, mesolite and analcime, principally in amygdules. It appears to be the last of these phases to form (Griffin, 1982, B. D. Goscombe, pers. comm.).

Wairakite $CaAl_2Si_4O_{12}.2H_2O$

This uncommon, relatively high temperature zeolite occurs in veins in Tertiary basalt on Macquarie Island, with natrolite (Griffin, 1982; B. D. Goscombe, pers. comm.). It is distinguished from analcime by its multiple twinning.

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