AGSO Journal of Australian Geology & Geophysics, 17(4), 247–251

Sediment-hosted magnesite deposits

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EXPLORATION MODEL

Examples

Kunwarara/Yaamba (40–70 km north of Rockhampton), Marlborough and Herbert Creek (100 km north of Rockhampton), Thuddungra (near Young, New South Wales)

Target

- Large to very large, up to 1000 Mt.
- Magnesite content over 5%.
- Magnesite ($MgCO_3$) dominant; accessory dolomite ($CaMg(CO_3)_2$).

Mining and treatment

- Tabular form, thin overburden.
- 1–26 m thick.
- Variations in vertical and lateral grade and magnesite content complicate assessement and mining.
- Conventional open-cut truck and shovel mining.
- Beneficiation by crushing, screening, scrubbing and heavy media separation.
- CaO contamination from dolomite.
- May be largely beneath water table.

Figure 1. Typical orebody cross-section, Kunwarara.

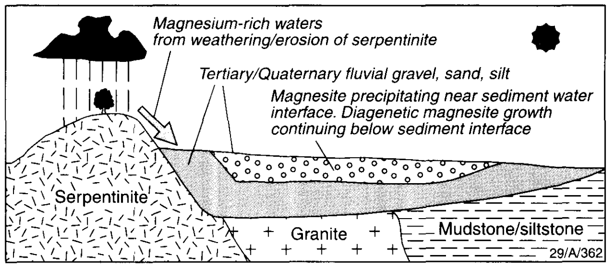

Figure 2. Model of formation of sediment-hosted deposit.

Regional geological criteria

- Tertiary–Quaternary terrestrial environment.
- Adjacent to Paleozoic ultramafic complexes.
- Contained in silty to gravelly fluvial sedimentary sequence.
- Other related mineralisation present in area: vein magnesite in ultramafics; minor magnesite in weathering profiles of diverse rock types adjacent to ultramafics.

Local geological criteria

- Age uncertain, but overlies Eocene oil shales in part of Yaamba deposit.
- Located in present-day topographically low areas.
- No structural deformation present.
- Sinuous deposit outline reflects Tertiary fluvial channels.
- Tertiary sediment package 2–3 km across, 10s of km long and 10–40 m thick.
- Overlain by black clay overburden.
- No surface exposure.

Mineralisation features

- Stratabound within upper parts of fluvial sequence.
- Chemical deposit.
- Magnesite occurs as concretionary nodules up to 60 cm diameter.
- Dolomite generally smaller nodules.
- Magnesite nodules have siliceous outer skin.
- Magnesite cryptocrystalline (1–10 microns).
- Magnesite nodules range from hard, dense 'bone' to softer porous chalky magnesite.
- Fluvial sedimentary features of host rocks disturbed by nodule growth.
- Host rocks include mudstone, siltstone, sandstone (dominant) and conglomerate.
- Dolomite nodules formed by replacement of clay cement in host sandstone.

Alteration

- Upper parts of ore body may be silicified.

Deposit geochemical criteria

- MgO up to 98.5% (LOI free).
- Main contaminants SiO_2, CaO.
- Minor contaminants Fe_2O_3, Al_2O_3, MnO.

Geophysical criteria

- No anomalous geophysical characteristics.

Fluid chemistry and source

- Magnesium sourced from weathering of adjacent ultramafic rocks during Tertiary.
- Precipitation of magnesite from Mg bicarbonate-rich waters triggered by mechanisms such as mixing with high-alkalinity groundwater or concentration through evaporation.
- Nodule formation initiated during deposition of fluvial sequence.

Comments on genesis

- Characteristics of host sediments and association with present topography indicate fluvial origin for the sedimentary sequence.
- Magnesite is a syndepositional chemical deposit within the sedimentary sequence with nodule growth continuing after deposition due to diagenetic processes.
- Earlier models suggested lacustrine origin (Schmid 1987), but exposures during mining indicate a higher energy fluvial regime.

Introduction

In Australia, the majority of past magnesite ($MgCO_3$) mines worked localised vein deposits found in ultramafic complexes, and only limited production was achieved. Numerous small deposits of this type of magnesite occur in Queensland (Jones 1995). In New South Wales, relatively small-scale production occurs at the partly sediment-hosted magnesite deposit at Thuddungra (Anon 1993). However, most of Australia's production now comes from deposits in central Queensland.

In 1985, Queensland Metals Corporation discovered a very large magnesite deposit beneath flat black soil plains at Kunwarara, north of Rockhampton in Queensland. Located near a significant ultramafic complex, it is a large sediment-hosted mineral deposit. Mining has been in progress since 1991 on part of the Kunwarara deposit. The magnesite is processed into various grades of magnesia (MgO) for use in the refractory industry (Milburn & Wilcock 1994).

Other deposits of this type in the same region occur at Yaamba, Herbert Creek and Marlborough (Burban 1990).

Regional geological setting

The magnesite deposits are found in Late Tertiary (post Eocene) to Quaternary sediments deposited in a fluvial environment, and are associated with Paleozoic ultramafic complexes. The ultramafic complexes are the source of the Mg required for deposit formation. In the central Queensland deposits, the ultramafics are part of the Marlborough terrane, a component of the northern New England Fold Belt. The rocks are part of an ophiolitic assemblage that separates the Carboniferous Yarrol terrane from the Devonian–Carboniferous Wandilla terrane. The exact mode of formation of these basement rocks is still a matter of debate (Leitch et al. 1994). Serpentinites are a common component of the ultramafic assemblage.

During the late Tertiary and Quaternary, a sinuous fluvial system developed adjacent to the ultramafic complex and the resulting sedimentary sequence has formed the host for the magnesite deposits. Three semi-continuous deposits have been recognised, stretching from Yaamba (near the present-day Fitzroy River) through Kunwarara to Herbert Creek (adjacent to Broad Sound), a distance of approximately 60 km.

Deposit geology

Sediment-hosted magnesite deposits can be very large. The Kunwarara deposit has a measured resource of 1200 Mt with greater than 5 wt% magnesite content (Queensland Metals Corporation 1995).

The magnesite has been derived from the weathering and erosion of the adjacent ultramafic complex during the Tertiary and Quaternary. The ultramafic complex is, in some places, immediately adjacent to or underlying the magnesite deposit. At most, the deposits are within 10 km of the ultramafics. The ultramafics are characterised by hilly landforms rising 40–200 m above the surrounding plains. They also host lateritic Ni–Co deposits, one of which was mined by QNI over a 2 year period, ending in 1995. The ultramafic rocks have provided the source of Mg-rich fluids which have been transported into the palaeofluvial system where the deposits are now found. The magnesite deposits are located in topographically low areas, and there is no outcrop.

The Tertiary–Quaternary fluvial sequence is up to 40 m thick. It generally fines upwards from gravel and coarse unconsolidated sand at the base, through finer grained weakly cemented sandstones, to siltstone and mudstone. The magnesite orebodies are found in the upper half of the sedimentary sequence, within the weakly cemented sandstone and siltstone. The sediments are overlain by 1–4 m of black clay, which has been deposited by periodic sheet-flood events, which continue today.

No fossils have been found in the sediments, so the only age indication comes from the fact that they overlie Eocene oil shales near Yaamba and may be partly overlapped by Holocene alluvial sand deposits at Kunwarara.

Earlier depositional models for the host sediments indicated a lacustrine depositional environment (Schmid 1987, Queensland Metals Corporation 1992). However, exposures in pit walls during mining at Kunwarara and data from extensive exploration drilling have shown higher energy sedimentary features than would be expected in a purely lacustrine environment. These include gravel bars, erosionally based sandy channel deposits, and clay-filled abandoned channels. In addition, the sinuous nature of the deposits indicates that a more likely depositional environment is a low to moderate energy fluvial system.

The host sediments are only weakly cemented, but form a competent rock mass which causes few geotechnical problems during mining. The magnesite is found in the upper parts of the sedimentary sequence and is 1–26 m thick. Ore thickness at the Kunwarara mine has averaged 12 m over the 5 years of mining operations. Magnesite content in the deposit varies from 5 to 90 wt% (Queensland Metals Corporation 1995). Test work during mining operations at Kunwarara has shown an average magnesite content of around 35 wt%.

The magnesite is cryptocrystalline and pure white. Scanning electron microscope (SEM) studies show crystal sizes of 1–10 microns. Inclusions include amorphous silica, clays, and Fe and Mn oxides. The magnesite occurs as distinctive concretionary nodules and as a stockwork of veins and sheets. The nodules range in size from a few millimetres up to 60 cm. Concentric growth rings are not normally visible, but in a rare nodule type where Fe content is higher, the rings become evident. The nodules have a conchoidal fracture.

Magnesite texture ranges from hard, pure, porcellanous 'bone' type through to softer, less dense, porous and chalky types. Bone magnesite most commonly forms the most distinctive nodules. The porous and chalky types are more common as veins and sheets. All nodules have a skin of amorphous silica, which forms a rough crusty surface. In bone magnesite, the interior of the nodules can be up to 98.5% MgO (LOI free). In the more porous types, amorphous silica penetrates deeply into the nodules along cracks and around pores, leading to lower MgO content.

In the upper parts of the orebody, additional silicification has occurred and the nodules may show deep desiccation cracks and higher levels of silica. Larger bone nodules often have an egg-sized smaller nodule inside, separated completely from surrounding deeply cracked bone magnesite. This is believed to indicate at least two growth stages.

Lime occurs in solid solution in magnesite. It ranges from around 1% CaO to 2.5% CaO (LOI free) in different parts of the deposits. The more significant source of lime is from the mineral dolomite ($CaMg(CO_3)_2$) which ranges in abundance from nil to 100% of the carbonate assemblage. Dolomite often occurs as separate nodules, although intergrowths with magnesite are locally common. Dolomite nodules are generally smaller and more irregularly shaped than magnesite nodules. They also differ in that they are characterised by inclusions of quartz grains, and have higher amounts of Fe and Mn oxides. As a result, dolomite has higher silica values than magnesite (around 10% SiO_2 LOI free) and higher Al_2O_3, Fe_2O_3 and MnO. Dolomite is generally more abundant in the lower parts of the ore zone and may form a pure dolomite layer (within host rocks) at the base of the deposit.

Variations in the host rock are related to variations in quality of magnesite. At Kunwarara, bone magnesite is more abundant in a red-brown fine-grained sandstone, whereas the porous types of magnesite are more common in the grey siltstone facies. It would appear that this distribution is related to higher permeability in sandstone allowing greater circulation of Mg rich fluids.

Deposit formation

The close spatial association of the magnesite deposits with a large ultramafic complex gives an obvious pointer to the source of the Mg. No studies of Mg dissolution from the Marlborough terrane serpentinites have been undertaken, but studies overseas give valuable pointers as to the likely mechanisms operating for this class of deposit (e.g. Zachmann & Johannes 1989). Weathering of the ultramafic complex during the late Tertiary–Quaternary has mobilised Mg in groundwaters.

Cryptocrystalline magnesite formation has been linked with selective dissolution of Mg from serpentinite under the influence of waters rich in atmospheric and biogenic CO_2. Hydrated Mg carbonates precipitate in suitable environments, given an appropriate trigger mechanism, such as mixing with high-pH waters or by concentration through cyclic evaporation. The hydrated Mg carbonates are transformed to magnesite by diagenetic processes (Zachmann & Johannes 1989).

A modern-day analogy for this type of deposit, albeit in a lacustrine environment, has been documented at Salda Lake in Turkey (Schmid 1987). The lake is flanked by serpentinite hills, which shed Mg-rich waters and particulate matter into the lake. Magnesite is currently being deposited around the lake shore and occurs in rubbly dunes up to 10 m high. Cryptocrystalline nodules and lumps of Mg carbonate and hydroxide are forming at the mud–water interface under the influence of seasonally varying water levels. Field evidence shows that magnesite crystallisation can occur very rapidly, given an adequate source of Mg (Schmid 1987). Chemically precipitated nodules from Salda Lake are very similar to Kunwarara nodules.

In the case of the central Queensland deposits, the magnesite precipitated in situ very soon after deposition of the host sediments. Evidence for this is shown in mine pit exposures—channels have eroded nodule aggregates and formed pebbly channel-floor deposits. In-situ precipitation continued above such minor hiatuses. It would appear that nodules and veins continued to develop for some time after sediment deposition. The original sedimentary structures are still visible in pit exposures, but are heavily disrupted and distorted by the growth of nodules and penetration by veins. These processes are diagenetic. The nodules of magnesite do not incorporate any of the host sediments. Field observations show that they displace the host sediments.

Conversely, dolomite appears to be at least partly replacive. Field observations show gradations from fine sandstone to dolomite, and SEM studies show abundant quartz grains in dolomite, indicating that dolomite has replaced the clay cement in sandstone.

Magnesite nodule precipitation (in situ) is very common in the vicinity of ultramafic complexes. In the central Queensland region, magnesite nodules have been observed in numerous locations in the weathering profiles above diverse rock types within a few kilometres of serpentinite bodies. This indicates that magnesite will readily precipitate out of solution, given a suitable trigger mechanism.

Within the serpentinites, veins of magnesite are locally very common. This type of magnesite is related to weathering of serpentinite and deposition of magnesite through interaction of weathering products with descending meteoric waters loaded with atmospheric and biogenic CO_2 (Zachmann & Johannes 1989).

Exploration techniques

A requirement for the formation of sediment-hosted magnesite deposits is the local presence of an ultramafic complex containing serpentinite. With such a body available, weathering will release abundant Mg into the environment. Magnesite will readily precipitate where the conditions for deposit formation, discussed above, are satisfied. However, for an economically viable deposit to be developed, the magnesite needs to precipitate in an accumulating sedimentary sequence with good permeability. The presence of magnesite at shallow depths in soil profiles, as well as vein magnesite in serpentinite bodies, is a good indication that conditions are suitable for magnesite accumulation.

Late Tertiary–Quaternary terrestrial sedimentary sequences, such as those hosting the central Queensland deposits, are located in topographically low areas with no outcrop, (i.e. in shallow sedimentary basins). The preferred exploration method for initial discovery commences with an examination of geomorphological features. Air photos and satellite imagery are useful at this stage. Target areas are of low topographic relief and water bore records may be a source of subsurface data.

The most cost-effective technique for exploration in a target area is open-hole rotary drilling. Experience with the central Queensland deposits indicates that a 400 m spaced drill pattern gives the minimum necessary data for initial evaluation. In areas proved up for mining, drill spacing is gradually closed to a 25 x 25 m grid.

Drill-hole sampling provides data only on the presence of magnesite and gross chemistry. Magnesite yield data are also necessary and can only be obtained using bulk sampling techniques. In central Queensland, bulk samples up to 500 t have been routinely gathered and 1 m diameter Caldweld drilling has also been used to collect bulk samples.

Conclusion

Sediment-hosted cryptocrystalline magnesite deposits have become a source of magnesite of world-scale importance since the discovery of the Kunwarara deposit in 1985. The mode of formation of these deposits is broadly understood, although the reasons for some localised, but practically important features, such as dolomite distribution within the ore bodies, require further study.

Magnesite deposits will only form where an ultramafic complex with common serpentinite is present to provide a source of Mg. Tertiary–Quaternary weathering of the ultramafics produces Mg-rich groundwaters that may precipitate economically important deposits in permeable Tertiary–Quaternary terrestrial sedimentary sequences.

Acknowledgments

The author thanks the management of Queensland Magnesia (Operations) Pty Ltd, and Queensland Metals Corporation Limited for permission to publish this paper.

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Received 1 February 1996; accepted 25 September 1996