COBAR SUPERBASIN SYSTEM METALLOGENESIS

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Abstract

The term Cobar Superbasin System refers to a regional, complex tectono-stratigraphic terrain in the Central Subprovince of the Lachlan Orogen marked by Late Silurian-Early Devonian sedimentation of the Cobar Supergroup.

The Cobar Superbasin System developed as four deep-water troughs surrounded by shallow-water flanking shelfs. The northern portion (Cobar Basin) is characterised by siliciclastic sediments locally intruded with felsic volcanics. The southern portion (Mt Hope and Rast Troughs) is dominated with volcanics of bimodal character and volcaniclastic rocks intercalated with sediments. During the Early Devonian, an array of scattered carbonate reefs (or probably a carbonate ramp) existed along the eastern margin of the Cobar Superbasin System. As rifting persisted, carbonate reefs (ramp) broke-down and collapsed in the deep-water parts of the superbasin system.

The Cobar Superbasin System developed during Silurian-Devonian time (Glen, 1995) and was (half-) inverted by combined thick and thin-skinned tectonic style (Glen, 1990). The region underwent deformations during Late Devonian Tabberaberran Orogeny and Middle Carboniferous Kanimblan Orogeny (Scheibner, 1989; Glen 1992). The Cobar Basin opened as a haft-graben, by transtensional NE-SW extension and closed by NW transpression. The overall structural style of the Cobar Basin is NW-SE folding overprinted by NE-SW folding and eastwards oblique left-lateral thrusting. In general, the basin development was influenced by placement of Silurian granite batholiths, which acted as structural weakness and/or tectonic butters.

The Cobar Superbasin System metallogenic work in conjunction with basin architecture, facies analysis and structural history attempted to find answers to the metal sources, mechanism of fluid-flow and mineral deposition in a dynamic environment of basin evolution. Metallogenesis is characterised with formation of initial mineral deposits (early mineralisation stage), their subsequent modification and formation of syn-tectonic deposits (late mineralisation stage). Early mineralisation stage is characterised with syn-rift phase of basin development accompanied with extensional tectonic environment, whilst later mineralisation formed in the inversion phase under compression.

In the early mineralisation stage, the intrusion related epithermal, the VMS and the Irish type deposits were formed. These deposits are hosted in the syn-rift sedimentary sequence, where intense lithofacies distribution and basement architecture controls their occurrences. They formed in the zones of growth faults, intersections of growth faults and transform/transfer faults and intersection of major transform/transfer faults. The later mineralisation stage formed Cobar style deposits, quartz vein hosted deposits and Mississippi Valley Type deposits. The reverse lateral inversion tectonic environment controls morphology of these deposits. Deposits are localised in the structurally favourable sites: at the deflected segments of strike slip faults (CSA); at the intersection of reactivated growth and transfer/transform faults (Elura); at the end of major strike-slip faults (as results of differential displacement – Peak and Perseverance); at the overlap zones of en-echelon strike-slip faults (Cobar Goldfields; Rayner, 1969); and at the junction of major faults (McKinnons Tank).

The Cobar Superbasin System represents a mineralisation continuum, where the deposits formed during the syn-rift phase underwent structural overprinting and green-schist grade metamorphism during the basin inversion phase.

Introduction

The Cobar Superbasin System forms the richest polymetallic 'basin' in the Lachlan Orogen. It contains a metal inventory of 198t Au; 4,597t Ag; 2.2Mt Cu; 4.8Mt Zn and 2.9Mt Pb. About 70% of these resources have been mined since initial discovery in 1870. In the district, three polymetallic underground mines are operating.

After the discovery of the Elura deposit in 1974, a modern approach was introduced to metallogenic studies. Such modern approach generated controversial interpretations of ore genesis.

Syngenetic, sediment-hosted, genetic models were introduced by Brooke (1975); Gilligan and Suppel (1978); Sangster (1979), Schmidt (1980) and Marshall et al., (1981). These models also involved the possibility of mechanical remobilisation close to the original place of deposition. Syn-deformational, structurally controlled models were advocated based on the study of fault relationships between the major deposits and quartz vein microstructures (Glen, 1978; Schmidt 1980, 1990). DeRoo (1989); Lawrie (1990); and Glen (1987, 1995) interpreted a syn-deformational, structurally controlled model for the Elura zinc-lead deposit. Similar, syn-deformational models were proposed to the CSA copper-zinc-lead deposit by Brill (1989) and to the Peak gold deposit by Hinman and Scott (1990), and Perkins et al., (1994). However, some authors proposed a polymodal genesis for the Cobar deposits (Marshall and Gilligan, 1987; 1993), based on overlapping concepts of remobilisation and syn-tectonic formation. Secombe and Brill (1989); Seccombe (1990); Jiang (1996), Foster (1997) and Jiang et al., (2000) provided detailed studies on fluid inclusion, stable isotopes, lead isotopes of the individual deposits in the Cobar Basin. During the 1990's, Marshall and Gilligan (1987; 1993), Glen (1987, 1995) and Stegman (2001) made the most significant contributions in a complex approach to the understanding of metallogenesis.

In the metallogenic studies, the high quality 1:100 000 NSW Geological Survey geology maps of the Cobar region (Pogson, 1982; MacRae, 1987; Glen, 1988; Glen 1994) played a crucial role. In addition, under the NSW government project Discovery 2000 the Geological Survey of New South Wales in collaboration with numerous of mineral exploration companies acquired high-quality geophysical coverage: airborne magnetic on 400m spaced lines, radiometrics and ground gravity with 1x2km grid. These data helped to create a structural-geological framework on which this metallogenetic work is based.

In this paper, author undertook a complex approach to the metallogenesis involving basin evolution processes and tectonostratigraphic placement of mineral deposits. In addition, the paper correlates basement architecture, lithofacies distribution and deformation styles which controls deposit occurrences

Structural History

Structural history of the Cobar Superbasin System is associated with processes of basin evolution: basin formation (extensional tectonic) and basin inversion (compressional tectonic).

The Cobar Basin formed by subsidence along NNW-trending normal listric faults (e.g. Jackermaroo Fault, Woorara Fault, Coonara Fault and Rookery Fault), which developed perpendicular to the main extensional direction. The pre-existing weaknesses and heterogeneities in the basement rocks, such as granite batholiths governed the occurrences and orientations of the listric faults. The variations in the spacing, orientation, geometry and the detachment depth of the listric faults were accommodated by NW- and NE-trending strike-slip and/or dip-slip sub-vertical transform/transfer faults. The Buckwaroon Fault, Plug Tank Fault, Amphitheatre Fault and Wagga - Nymagee Structure developed as a conjugate set of

NW- and NE-trending extensional faults (Figure 1). Cobar Basin formed as a haft graben with greater block down-throw on the eastern margins.

The basin inversion phase commenced with development of N-S cleavage associated with open folding and low-angle thrusting (Glen, 1990), and the selective reactivation of normal gently dipping listric faults along the eastern trough margins. The reactivated faults penetrated into basin sediments and formed blind reverse fault systems and leading imbricate fan structures. The irregular reactivation of listric (syn-sedimentary) faults caused the development of tear faults and rotation of structural blocks. The tear faults formed NE- and SW-trending en–echelon array of left-lateral, with and south block-down movement in the northern part and vice versa in the southern part. Tight folds and decollement faults advanced eastwards with deformation culminating in reverse lock-up thrust faults at the eastern margins. Tectonic barriers such as basement horsts of Silurian granites caused clockwise rotation of local stress axes (σ1' rotated from E-W to WNW-trend) and left-lateral movement along basin bounding faults. This short description of structural history supports Glen's (1990) interpteratation implying that Cobar Basin was (half-) inverted by combined thick and thin-skinned tectonic style.

Cobar Superbasin System Lithofacies

Facies analysis includes study and interpretation of textures, sedimentary structures, fossils and lithological associations of sedimentary rocks on the scale of an outcrop, drillhole or small segment of a basin (Miall, 1990). The Cobar Superbasin System comprises deep-water troughs, flanking and intra-basinal shelves delineated by major structures and abrupt lithofacies changes (Figure 1). The major tectono-stratigraphic units characterised with sedimentary environments and constrained by distinct lithofacies are:

- Flanking shelfs on the deep-water troughs margins (Kopyje Shelf and Winduck Shelf);
- Intrabasinal shelves (Wiltagoona Shelf and Walters Range Shelf); and
- Deep-water troughs (siliciclastic Cobar Basin, volcanic-volcaniclastic-siliciclastic Mt Hope and Rast Troughs).

Basin evolution commenced in latest Silurian to Early Devonian, with formation of the shallow-water shelf to the east (Kopyje Shelf with late Silurian fossils) and deeper water Rast and Mt Hope troughs to the west. Basin subsidence progressed northwards, followed by transgressive facies. Sedimentation started with upward finning outwash-fan facies of conglomerates, arkoses and greywacke (Glen, 1990, 1994; MacRae, 1987; Trigg, 1987). A high-rate of basement subsidence in the Rast and Mt Hope Trough was followed by a high-thermal gradient that produced bimodal volcanism (Scheibner, 1987). Volcanism ranges from rhyolite, rhyo-dacite, dacite to basaltic composition and occurs as submarine intrusions. The initial volcanism of the Mt Kennan Group volcanism was I-type, followed later S-type volcanism of the Mt Halfway Volcanics. Tectonically, the Mt Hope and Rast Troughs were separated by Walter Ranges Shelf, which was characterised as an area of stable shallow-water sedimentation.

Clastic sediments

In the syn-rift phase of basin-formation, sedimentation commenced with shallow-water sequences (lower sequence of the Nurri Group, Mouramba Group) that pass rapidly up section into turbidites such as the Chesney Formation) and turbidites of the lower Amphitheatre (e.g. lower sequence of the CSA Siltstone). In the Cobar Basin, deep-water turbidites comprise the Nurri Group, lower Amphitheatre Group and upper Amphitheatre Group. The relationship between different lithofacies suggests that fans from the east were progressively abandoned by a marine transgression. In general, the thin-bedded, fine-grained turbidite sequences of mudstone, siltstone and fine-grained sandstone intervals (marked by C and D Bouma sequences) with distinct sedimentary structures and fossiliferous assemblages indicate a basin plain with distal submarine fans at the variable depth (Glen, 1994).

The progressive rifting and extension is exemplified by facies relations around the Elura Mine, where carbonate facies of the Kopyje Shelf are overlain by turbidites of the CSA siltstone. At Elura the following facies can be identified from bottom to top:

- Mud mouth shallow-water carbonates reef;
- Proximal back-reef facies with domination of carbonate components;
- Distal back/fore reef facies with domination of siliciclastic components;
- Open outer shelf bellow storm base; and
- Fine-grained turbidites.

These relations are interpreted to reflect drowning of the carbonate shelf during renewed extension along part of the northern margin of the Cobar Basin.

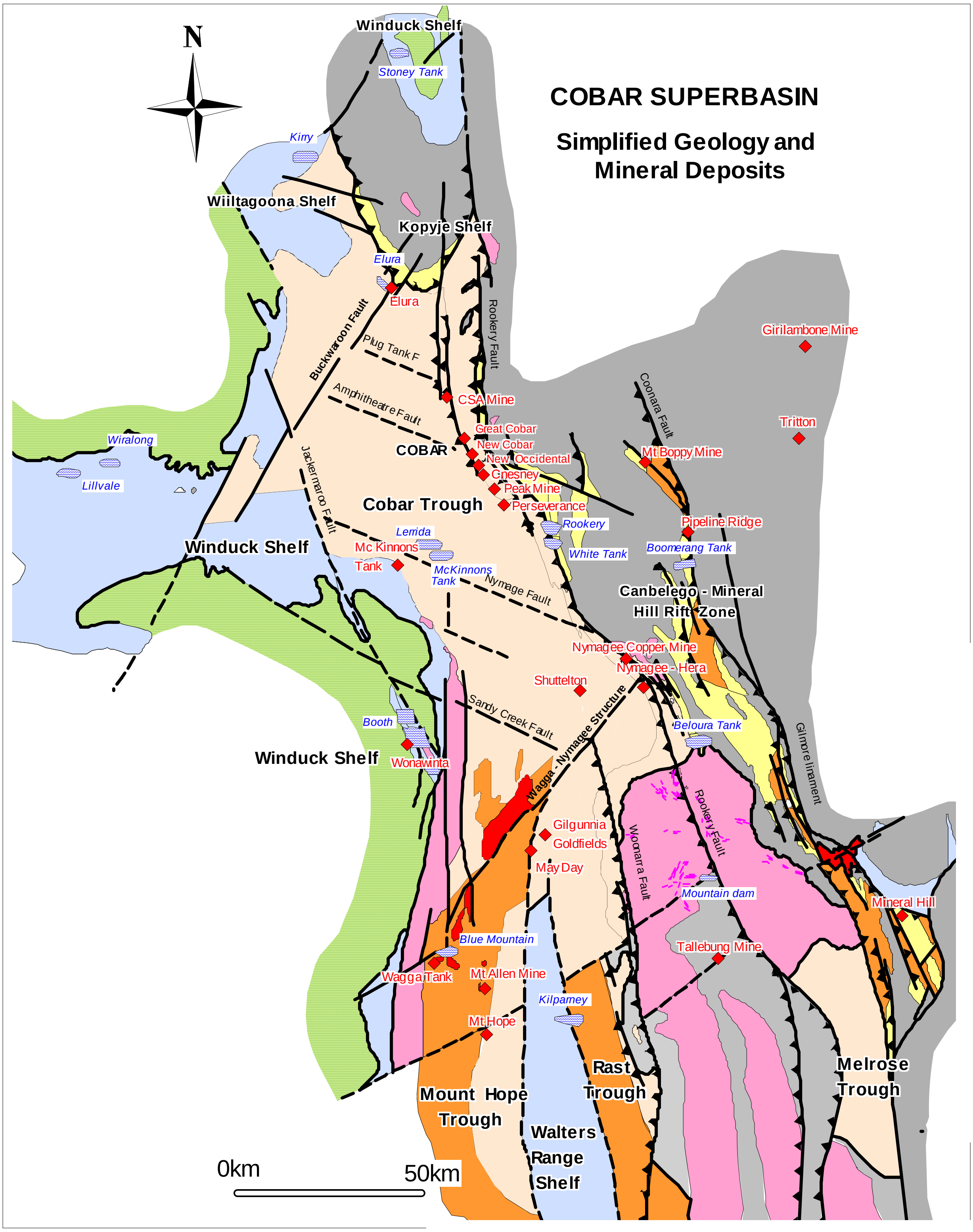
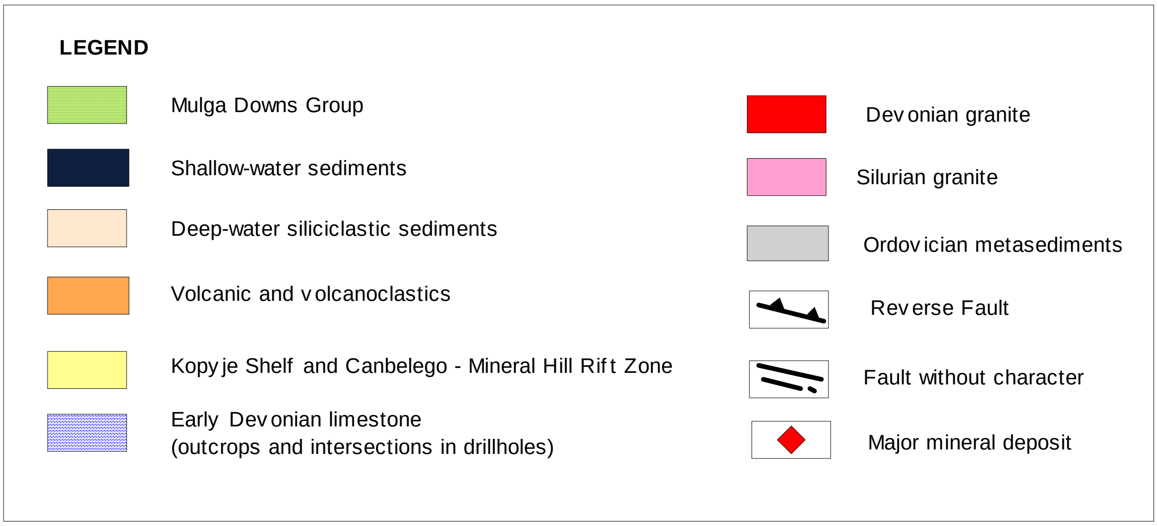


Figure 1. Simplified geology map of the Cobar Superbasin System. Map shows locations of the Early Devonian limestone and major mineral deposits. In addition, the major tectonostratigraphic units are marked.



Sag-phase deposition in the Cobar Superbasin System is reflected by reversion to thin-bedded turbidites in the Cobar Basin and silty turbidites of the Broken Range Formation in the Mt Hope Trough. Sag phase deposition extended over granite and Ordovician basement west of the basin where it is deposited as the Winduck Group and between the Mt Hope and Rast troughs where it is deposited as the Walters Range Group. A hiatus marked by disconformity and paraconformity separates the Winduck Group from coarse-grained sandstone, conglomerate and shale of the fluviatile Munga Downs Group which probability ranges in age from late Early to Mid Devonian up into Late Devonian, possible with an internal break.

Limestone

Until recently, rare and small limestone outcrops did not attract the interest of geologists who worked in the Cobar region. Following the discovery of the mineralised limestone reef beneath Elura the importance of limestone was recognised in basin evolution and basin metallogenesis deposit (Carolan, 1999; Coller, 1999; David, 2000; David et al., 2001).

Limestone was deposited in the places with insufficiency of terrestrial material and along the growth faults. It occurs in a discontinuous N-S trend along the deep-water trough margins (eastern and northern) and on the Winduck Shelf (Figure 1). Limestone was deposited in the areas of a steady basin subsidence and insufficiency of terrestrial material. The sedimentation vanished with increased subsidence rate and increased input of terrestrial material. The shallow-water fossil assemblages (conodonts, brachiopods, molluscs, bryozoans, crinoids, corals and ostracods) (Pickett, 1979; Felton, 1981; Sharp, 1992; Carolan, 1999; Talent et al., 2002) in limestone indicate the existence of uniform sedimentary environment in the Lockhovian. The uniform limestone lithofacies implies an existence of an array of patchy reefs or carbonate ramp along the growth faults, now preserved below the turbidites along the basin margin. Advanced rifting probably break-up carbonate reefs/ramp and caused collapse of large limestone blocks - olistolithe in the deep-water troughs such as Lerida Limestone (Glen, 1987).

The limestone marks the position of major growth faults and the top of basement-tilted blocks. During basin extension and inversion, limestone reefs acted as rigid buttresses (tectonic barriers) creating dilatation sites. In terms of basin metallogenesis, limestone played an important role as a fluid conduit for fluid focussing as a chemical reactant and as a host rock for mineralisation (Elura and Wonawinta).

Early Devonian Porphyritic Intrusions and Volcanics

An advanced basin extension and subsequent decrease in crustal thickness produced regions of abnormally high heat flow, which may have led to igneous activity (c.f. McKeinzie, 1974). These regions occupy zones of listric faults with a high heat-flow rate at the eastern trough margins and deflected deep-seated strike-slip transform faults. In addition, there is a close spatial relationship between occurrences of volcanic rocks and mineralisation in the Cobar Superbasin System.

In the northern siliciclastic–rich Cobar Basin, Early Devonian volcanic rocks occur sporadically as small porphyritic dyke-like bodies (Arrowa, Ferricartup), whilst in the south they are a significant constituent of the basin sequence. The occurrences of bi-modal (I- and S-type) rhyolite/dacite volcanic rocks in the Mt Hope Trough are associated with Early Devonian S-type (Gilgunnia Granite and Boolabone Granite) and I-type (Mt Allen and Coan Granite) granitoids (Scheibner, 1987). These rocks are highly anomalous in Cu, Pb and Zn and were probably one of the sources for metals accumulated in the mineral deposits in the basin. In the Rast Trough, I-type the Shepherd Hill Volcanics interfinger with and overlie the Crossleys Tank Formation turbidites of Cobar Supergroup.

Early Devonian volcanic rocks are rare in the siliciclastic portion of the basin and are associated with major structures: growth faults and transform/transfer faults high terrain subsidence rate and high sedimentation rate. They occur at the following locations:

- Arrowa and Ferricartup, - quartz-feldspar porphyritic dykes in the northern trough
- Elura Tuff, (Schmidt, 1980; Maetz, 1985 and this study) - several tuff beds up to 0.5m thick with mafic composition;
- Mopone Tuff, (Maetz, 1985) - several tuff beds up to 0.3m thick with felsic composition;
- Peak - CSA Tuff (Robertson, 1974) – sub-aerial felsic tuff unit up to 35m thick occurs between Peak and CSA;
- Peak Rhyolite (Stegman, 1998) - flow banded rhyolite extrusion is emplaced coeval with basin sediments at the Peak Gold Mine;
- Queen Bee Porphyry (Kelso, 1982) – feldspar porphyry at Queen Bee deposit ; and
- Other small occurrences are: McKinnons Porphyry (Glen, 1987a; at McKinnons Mine), Shuttelton Rhyolite (MacRae, 1987), Nymagee-Hera Rhyolite (David, 2001), and Nymagee Porphyry (Pogson, 1983).

The whole rock composition of the Early Devonian volcanics infers a magma derived from partial melting of a pre-existing volcanic arc or sediments derived from a volcanic arc provenance. The porphyry intrusions belong to the high-K calc-alkaline series. High Cu and Zn are due to presence of sulphide, which may have been introduced later by hydrothermal alteration. These volcanic rocks may also be one of the sources of metals for Cobar-style mineralisation deposits, but there is not enough evidence to support this hypothesis.

Basement Architecture

The Cobar Superbasin System basement architecture illustrates the final output of results derived from geophysical modelling, lithofacies analysis and structural analysis. The basement architecture is interpreted as a half graben basin with greater block down-throw on the eastern margin then on the western margins. The deepest part of the basin is located in the central part, along the eastern margin, between two subparallel transform/transfer structures: the Buckwaroon Fault and the Nymagee-Wagga Structure (Figure 1).

In relation to the basement architecture, the mineral deposits are located in the:

- In proximity to major marginal faults (growth faults; hangingwall) with the maximum block down-throw (the intermediate size Au-rich (Cu) deposits: Cobar Goldfields, Peak, Queen Bee);
- In proximity to the intersection of growth faults with transform/transfer faults (the largest base metal deposits (+Au); CSA, Elura in the siliciclastics and small

polymetallic deposits; Nymagee-Hera and Wagga Tank in the volcaniclastic and volcanic rocks) and

- In proximity of major transform/transfer faults (small size polymetallic deposits: McKinnons Tank, Mt Hope and May Day).

The metal bearing fluids were focused by growth faults and associated transform/transfer faults into tectonic (blind faults, overlapping and deflected strike-slip faults) and stratigraphic traps (carbonates and sediments enriched in carbonaceous component) forming mineral deposits. The reactivation of the basement structures during basin formation created current morphology of mineralisation in the basin.

Cobar Superbasin System Mineral Deposits

A spectrum of mineralisation styles occurs in the Cobar Superbasin System. These mineralisation styles are characterised by differed tectonostratigraphic settings, volcanic activity, host lithology and amount of deformations (Figure 2). The mineralisation styles are shortly described bellow in the order of abundance.

1) Cobar-Style mineralisation includes syn-tectonic, remobilised structurally controlled deposits dominated by Cu-Au mineralisation (Glen, 1987; Lawrie and Hinman, 1998; Stegman, 2001). The mineralisation is controlled by right-stepping deflections within the Rookery Imbricate fan accompanied by reverse oblique left-lateral movement. This group contains major mineral deposit (e.g. CSA deposit, New Cobar, Peak, Great Cobar, New Occidental and Chesney, Nymagee –Hera).

2) Carbonate and sediment hosted base metal mineralisation occurs in the reef limestone open-platform and silciclastics turbidites at the margin of the deep-water troughs (Elura) and shelf limestone (Wonawinta). This mineralisation is characterised with dominant Zn-Pb-Ag metal associations and replacement/cavity fill mineralisation textures. The most important deposits are Irish Type (Elura) and MVT (Wonawinta).

3) Metamorphosed VMS mineralisation (Sangster, 1979) is characterised by recrystallised and mechanically remobilised, discontinuous transposed en-echelon sulphide lenses. The mineralisation is localised in high-strain zones in proximity to the Early Devonian volcanics and porphyritic intrusive. Base metal associations, locally with high-grade gold, dominate the mineralisation. In this group, belong following deposits and occurrences: Pipeline Ridge, Shuttleton, Queen Bee and May Day.

4) The epithermal gold mineralisation is hosted by quartz and sulphide stockwork veins, e.g. McKinnons Tank deposit (Brywater, 1996: Foster, 1997) and Mt Boppy (Corbett, personal communication).

5) Intrusion-related mineralisation (Tenant Creek Style) occurs at Mt Allen (Au, Fe) and Double Peak (Au, Cu) in the Mt Hope Trough. Mineralisation is characterised with gold-bearing haematite-magnetite lenses and haematite-magnetite-quartz-pyrite stockwork veins in chloritic siltstone. In addition, mineralisation and alteration are strongly associated with anomalous Ag, Bi and W (Suppel, 1979) and the I-type Mt Allen Granite.

6) The gold-bearing quartz-vein mineralisation is hosted by Early Devonian turbidites (Gilligan and Suppel, 1978; Suppel and Gilligan, 1993). The vein geometry is controlled by their position in relation to fold axial plane and deflection along the fault jogs.

7) Porphyry-style mineralisation occurs in the central basin adjacent to Sandy Creek Fault - 20km north of Gilgunnia (Skirka, 2002). Mineralisation is hosted by coarse-grained quartz-feldspar-chlorite-sericite granite.

8) Skarn mineralisation occurs on the eastern margins of the Walter Range Shelf. A magnetite skarn occurs at the contact between limestone and dacite porphyry (Aberfoyle Exploration, 1980).

Genetic Model of Cobar Superbasin System Mineral Deposits

The deposits in Cobar Superbasin System display some of the common features such as tectonostratigraphic settings, host rocks, strain domains and mineralogical paragenesis. In addition, they have similar fluid chemistry, and metal and sulphur sources (Secombe, 1994; Jiang 1996; Foster, 1997; Jiang et al., 2000; Gilles and Marshall, 2003).

The major mineral deposits are located on the unstable eastern basin margins in the zone of growth faults. Exception is the MWT deposit Wonawinta, which is located on the stable Winduck Shelf. The lithostratigraphic settings of mineral deposits in the Cobar Basin show that all the major deposits (Peak, Chesney, New Occidental, Great Cobar, New Cobar, CSA, Elura, Nymagee-Hera, ect.) are hosted in the syn-rift sedimentary sequences associated with high rates of sedimentation and local volcanic activity. The sag sequence hosts only small quartz veins hosted Au-deposits (Gilgunnia Goldfields) and mineral occurrences. The high strain domain at the eastern basin margins host major Cobar Style deposits; the medium strain domain hosts VMS and epithermal deposit and low strain domain hosts MVT Wonawinta deposit (Figure 2). Mineralogical paragenesis is characterised with an early Cu-Au mineralisation, which is overprinted by later Pb-Zn mineralisation (Robertson, 1974; Gilligan and Suppel, 1978; 1986; Brill, 1991; Scott and Philips, 1990; Hinman, 1991; Perkins et al., 1994; Lawrie and Hinman, 1998; Jiang, 1996; Stegman, 2001).

Genesis of mineral deposits comprises initial deposit formation and their subsequent modification. Ones the sulphides are deposited, they are subject to diagenesis, regional metamorphism, deformation and supergene alteration. The genetic model for mineral deposits in the Cobar Superbasin System is an integral part of the basin evolution. The metallogenic event is a mineralisation continuum, which progressed northwards subsequently with lithofacies migration. This event can be divided in two phases:

1. The early mineralisation Basin syn-rift metallogenic phase (including sag phase) characterised by:
    a) VMS deposits;
    b) Intrusion related deposits;
    c) Epithermal gold deposits (porphyry style);
    d) Sediment and carbonate hosted Pb-Zn (Irish Type); and
    e) Skarn deposits.
2. The late mineralisation the Basin inversion metallogenic phase characterised by:
    a) Cobar Style deposits (syn-deformational or remobilised from the early mineralisation);
    b) Quartz-vein hosted Au deposits; and
    c) MVT deposits.

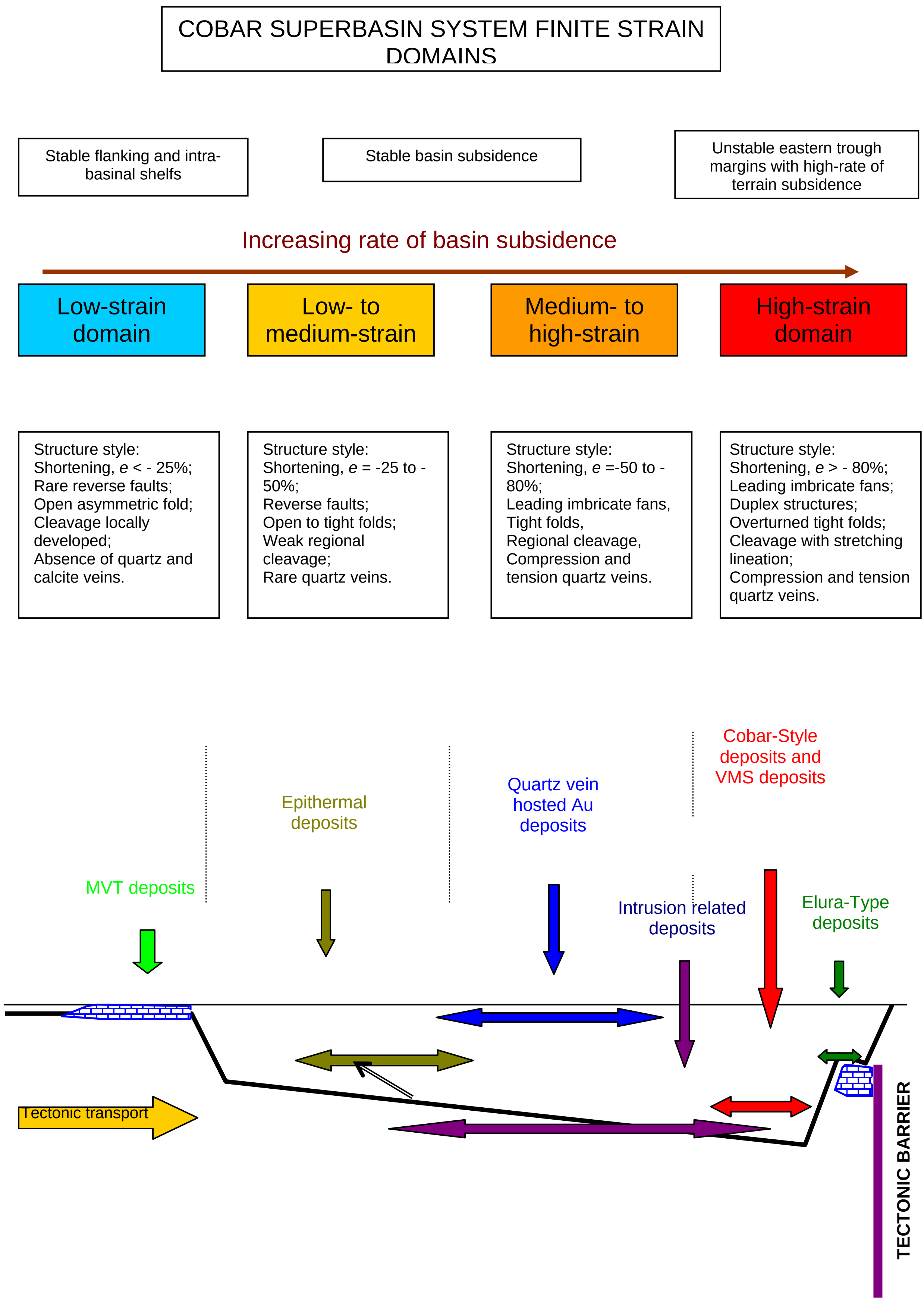
In the Superbasin System, syn-rift metallogenic phase early mineralisation formed deposits on the eastern margins characterised by growth-faults, rapid subsidence, elevated geothermal gradient and felsic to intermediate volcanism. The deposits formed proximal to intersections between transfer/transform faults and basin marginal growth-faults. The deposits formed in this phase were similar to epithermal intrusion related, sediment hosted VMS and Irish-Type.

The late mineralisation Basin inversion metallogenic phase is characterised by modification of an early syn-rift mineralisation, formation of the Cobar Style mineralisation (CSA, New Cobar, New Occidental and Peak), quartz-vein hosted Au deposits (Gilgunnia Goldfield) and MVT deposits (Wonawinta). The quartz vein hosted Au-mineralisation is controlled by the inversion tectonic, whilst MVT mineralisation is controlled with the lithofacies of the host rock lithology (Booth Limestone).

The Cobar Style mineralisation is characterised with a subsequent modification including metamorphism and remobilisation and syn-deformational ore formation processes. The formation of new deposits and remobilisation of pre-deformational deposits are overlapping concepts (Marshall and Gilligan, 1993). In addition, these processes can produce similar types of geometric relationship, ore textures, fluid chemistry, and metal and sulphur sources.

This make hard to distinct genetic nature of the Cobar Style mineralisation. In the absence of the clear distinguishable genetic characteristics between syn-deformational and remobilisation model, they are probably polygenetic.

The late mineralisation is characterised with subsequent modification and metamorphism of pre-deformational deposits associated with formation of new deposits (syn-tectonic ore emplacement).



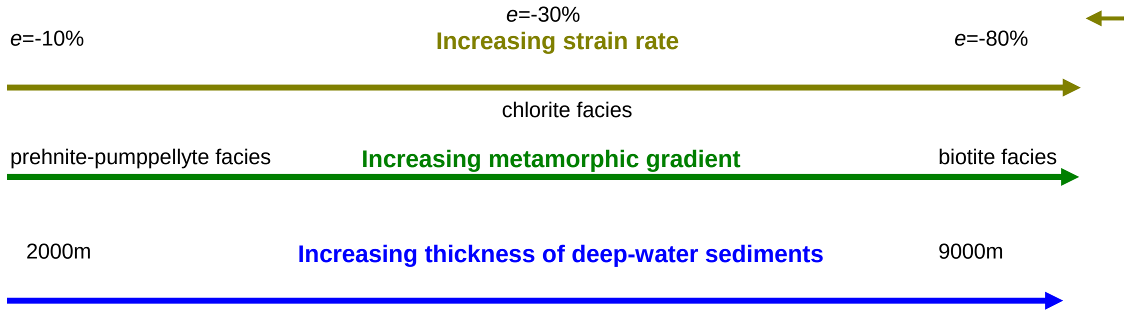


Figure 2. Distribution of major mineral deposits in relation to strain domains and tectonostratigraphic settings.

Conclusion

The Cobar Superbasin System represents a complex metallogenic system containing mineral deposits formed in a mineralisation continuum from the rift phase through the sag phase to the inversion phase of the basin evolution. The initially formed deposits subsequently underwent deformation tectonic transposition and metamorphism, as well as mechanical and chemical remobilisation.

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