Revised stratigraphy for the Earaheedy Group: implications for the tectonic evolution and mineral potential of the Earaheedy Basin

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Abstract

The Palaeoproterozoic Earaheedy Basin, which contains the Earaheedy Group, is part of the Capricorn Orogen. The basin is thought to post-date the Capricorn Orogeny (c. 1800 Ma), and was probably deformed during the second phase of the Yapungku Orogeny (1760 Ma). Revisions to Earaheedy Group stratigraphy include the introduction of the Sweetwaters Well Member of the Yelma Formation for a stromatolitic carbonate unit in the southwestern and western parts of the basin, the amalgamation of the Wandiwarra Formation and Princess Ranges Quartzite into the Chiall Formation, the introduction of the Karri Karri Member for thinly laminated shale at the base of the Chiall Formation in the north and southwest, and the recognition that the Windidda Formation is a correlative of the upper Frere Formation.

The sedimentary features in the Earaheedy Group indicate deposition in a shallow-marine to coastal environment. We suggest that the Earaheedy Group, as exposed, represents the southern portion of a passive continental margin on the northeastern edge of the Yilgarn Craton. Mineralization is related to this passive-margin environment, and subsequent deformation, associated with southwesterly directed compression. Mineral deposits include iron ore in the Frere Formation, lead–zinc sulfides and lead carbonate in the Sweetwaters Well Member, and structurally controlled gold. The tectonic setting of the Earaheedy Basin suggests that stratabound copper deposits may be present.

KEYWORDS: Earaheedy Basin, Capricorn Orogen, stratabound deposits, iron ore, copper, lead, zinc, sulphides, tectonics, models

Introduction

The Palaeoproterozoic Earaheedy Basin (Bunting, 1986; Pirajno et al., 1999), which contains the Earaheedy Group (Fig. 1), lies at the eastern end of the Capricorn Orogen (Tyler et al., 1998). The basement to the exposed Earaheedy Basin is the Archaean Yilgarn Craton, and the early Palaeoproterozoic Yerrida Basin to the west. The Earaheedy Basin was probably much larger than its present-day exposure, extending farther to the southwest and the north, where it is concealed by the overlying Bangemall and Officer Basins. The preserved exposure of the Earaheedy Basin forms an easterly plunging open syncline. Compressive movements from the northeast created a zone of deformation along the exposed northern margin of the Earaheedy Basin, which is named the Stanley Fold Belt.

Regional stratigraphic relationships indicate that the Earaheedy Basin is younger than the Yerrida Basin (about 2200 Ma; Woodhead and Hergt, 1997) and older than the Bangemall Basin (1650 Ma; Nelson, 1995). The basin appears to be unaffected by, and is thus probably younger than, the 1800 Ma Capricorn Orogeny, which records the collision of the Pilbara and Yilgarn Cratons (Tyler and Thorne, 1990). Alternatively, it may simply have lain east of the area affected by the orogeny, as parts of the Yerrida Basin (which is unequivocally older than the Capricorn Orogeny) are also unaffected. Poor age constraints hinder more accurate placement of the Earaheedy Basin within the regional framework. Isotopic ages for Earaheedy Group sedimentary rocks and mineralization in the basin cluster around 1800–1700 Ma. Deformation in the Stanley Fold Belt is tentatively attributed to the second phase of the Yapungku Orogeny at 1760 Ma (Smithies and Bagas, 1997), which was probably caused by the collision of the North and West Australian Cratons. If this is correct, then 1760 Ma provides a minimum age for the Earaheedy Basin. Based on stromatolite taxa, Grey (1994, p. 192) suggested that the age of the Earaheedy Group might be between 1.9 and 1.8 Ga.

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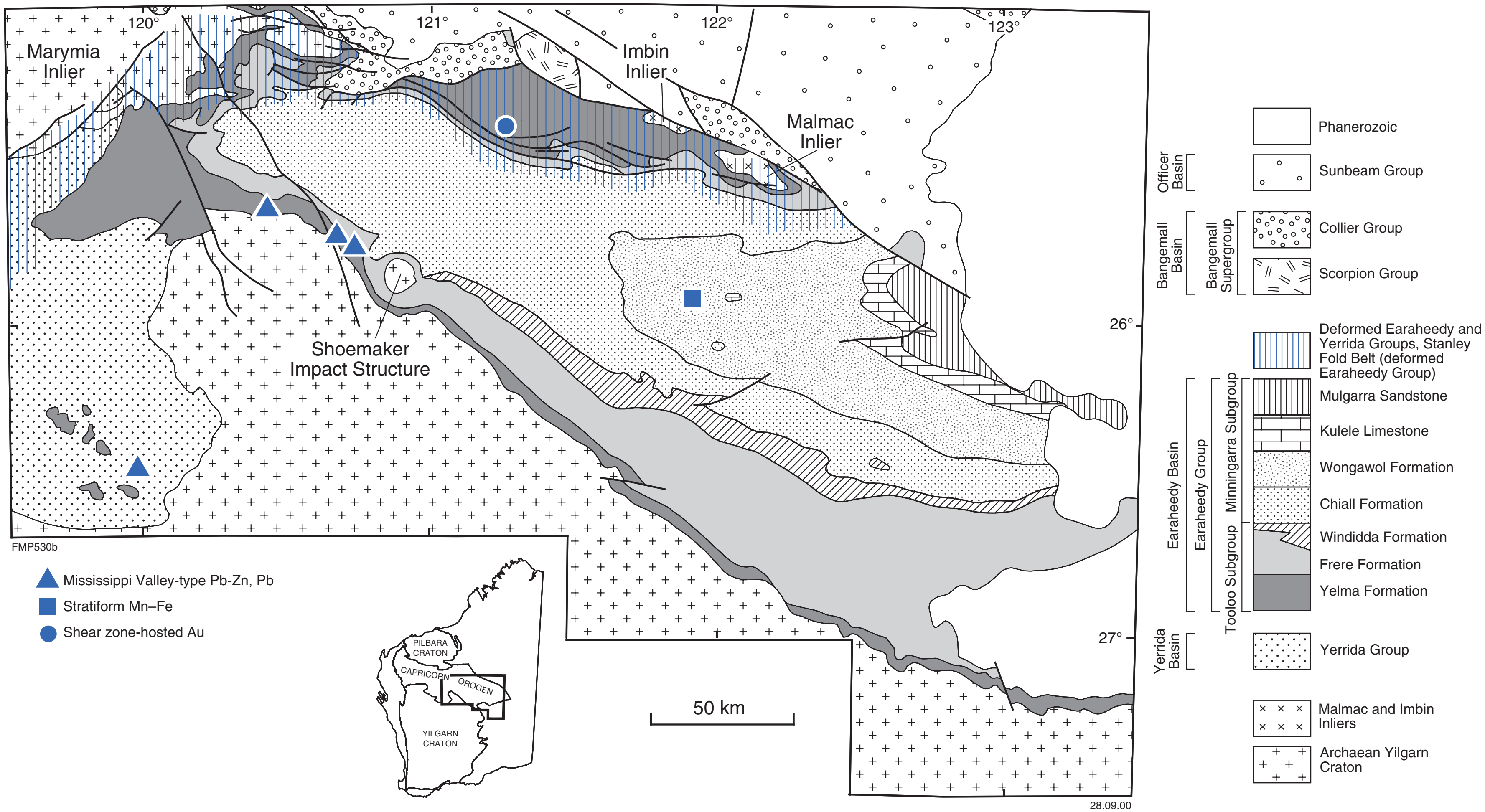

Figure 1. Simplified geological map of the Earaheedy Basin (modified from Bunting (1986) and including data from recent mapping)

Stratigraphy

The Earaheedy Group (Fig. 2) is a 5 km-thick package of shallow-marine clastic and chemical sedimentary rocks divided into two subgroups (Hall et al., 1977). The Tooloo Subgroup consists of (from base to top) the Yelma Formation, Frere Formation, and Windidda Formation. The overlying Minningarra Subgroup consists of (from base to top) the Chiall Formation, Wongawol Formation, Kulele Limestone, and Mulgarra Sandstone.

Yelma Formation

The Yelma Formation contains shale, sandstone, and carbonate deposited in shallow-marine and locally fluvial environments. The formation is quite variable laterally and vertically in thickness and composition. The thickness ranges from 3 m in the southeastern part of KINGSTON*, to 150 m in the type area in the western part of KINGSTON (Bunting, 1986), to at least 500 m in a drillhole in the northwestern part of NABBERU. Bunting (1986) estimated a thickness of 1500 m in the western part of STANLEY, but we interpret this as structural thickening. Sandstones in the southeast are trough cross-bedded, with local asymmetric ripples and mudcracks. Stellate pseudomorphs may be after evaporite. A 100 m-thick stromatolitic carbonate facies in the southwestern part of the basin is named the Sweetwaters Well Member (Hocking et al., 2000). Stromatolites in metre-scale upward-shallowing cycles include *Asperia digitata* Grey 1984 (Grey, 1994; restricted, quiet-water environment, possibly supratidal pond), *Pilbaria deverella* Grey 1984 (moderately high energy, lagoonal environment), *Ephyaltes edingunnensis* Grey 1984 (deeper quiet-water environment), and *Murgurra nabberuensis* Grey 1984 (patch reef, moderate energy environment). Both the stromatolites and cycles are similar to those in the Duck Creek Dolomite (upper Wyloo Group; Grey, 1994). Tepee structures, crystal-mush horizons, and flat-pebble carbonate conglomerate are recognized in drillcore.

* Capitalized sheets refer to standard 1:250 000 map sheets.

The Yelma Formation was deposited in a fluvial to possibly coastal setting in the south, and a shallow-marine to coastal environment in the north. Carbonates of the Sweetwaters Well Member formed in a saline lagoonal environment. Widespread shale (with minor sandstone) at the top of the Yelma Formation was deposited during a regional marine transgression.

Frere Formation

The Frere Formation records the onset of iron-oxide precipitation within the basin and consists of up to three major granular iron-formation intervals, separated by up to three major shale and siltstone bands, and minor carbonate. Granular iron-formation horizons consist of jasperoidal granular iron-oxide beds, typically 50 to 200 mm in thickness, and intraclastic breccia interbedded with shale and siltstone. Individual granular iron-formation beds consist of chert, iron oxides, peloids (microplaty hematite), and jasper (crypto-crystalline silica with finely disseminated hematite) in a cherty, chalcedonic or jasperoidal cement. Hematite is replaced by magnetite in iron formation deformed in the Stanley Fold Belt. Shale and siltstone units contain quartz, iron-rich chlorite, and disseminated euhedral magnetite. Along the southern basin margin, where deformation is minimal, siltstone rather than shale is present. These are parallel laminated, with minor cross-lamination. Individual lamellae are 1 to 10 mm in thickness. Laminar granular iron-formation, previously interpreted as banded iron-formation, is mylonitized granular iron-formation and iron-rich shale.

The granular iron-formation beds probably formed in the shallow waters of a continental shelf. Ferruginous peloids accreted in wave- and current-agitated iron-rich waters (Beukes and Klein, 1992), and were deposited after some reworking by mechanical processes, with variable terrigenous contamination. Cross-bedding is locally recognized in granular iron-formation units, and bedding structures commonly indicate moderate-energy conditions with intermittent still-water periods. Interbedded shale and siltstone horizons represent subwavebase deposits in the north to possibly lagoonal deposits in the southeast.

Windidda Formation

The Windidda Formation consists of shale and siltstone, locally stromatolitic carbonate, minor jasperoidal beds, and granular iron-formation and is present southeast of the Shoemaker Impact Structure. The Windidda Formation represents a carbonate shelf with coastal lagoons in the southeastern part of the basin.

Granular iron-formation persists until the top of the Windidda Formation, and chert and limestone intervals are present throughout the Frere Formation. In addition, three major granular iron-formation intervals can be differentiated in the Frere Formation in the western part of the Earaheedy Basin, but only two in the southeastern part. The Windidda Formation is therefore reinterpreted as a correlative of the upper Frere Formation southeast of the Shoemaker Impact Structure (Hocking et al., 2000), rather than a unit that only overlies the Frere Formation (Fig. 2).

Chiall Formation

The Chiall Formation combines, as members, the former 'Wandiwarra Formation' and 'Princess Ranges Quartzite' (Hocking et al., 2000). The formation consists of shale, siltstone, and mudstone intercalated with thick sandstone beds and intraclastic breccia, and represents a change from combined chemical and clastic sedimentation to dominantly clastic deposition. The base of the formation in the south is a breccia of poorly sorted, angular carbonate clasts in a ferruginized glauconitic sandstone matrix, which led Bunting (1986) to interpret the boundary as a disconformity. This is now interpreted as a submarine hardground, recording the rapid drowning, cementation, and partial reworking of the Windidda Formation carbonate platform. Thinly laminated shale in the northern and southwestern parts of the Earaheedy Basin (where the Windidda Formation is absent), previously assigned to the 'Wandiwarra Formation', is now referred to as the Karri Karri

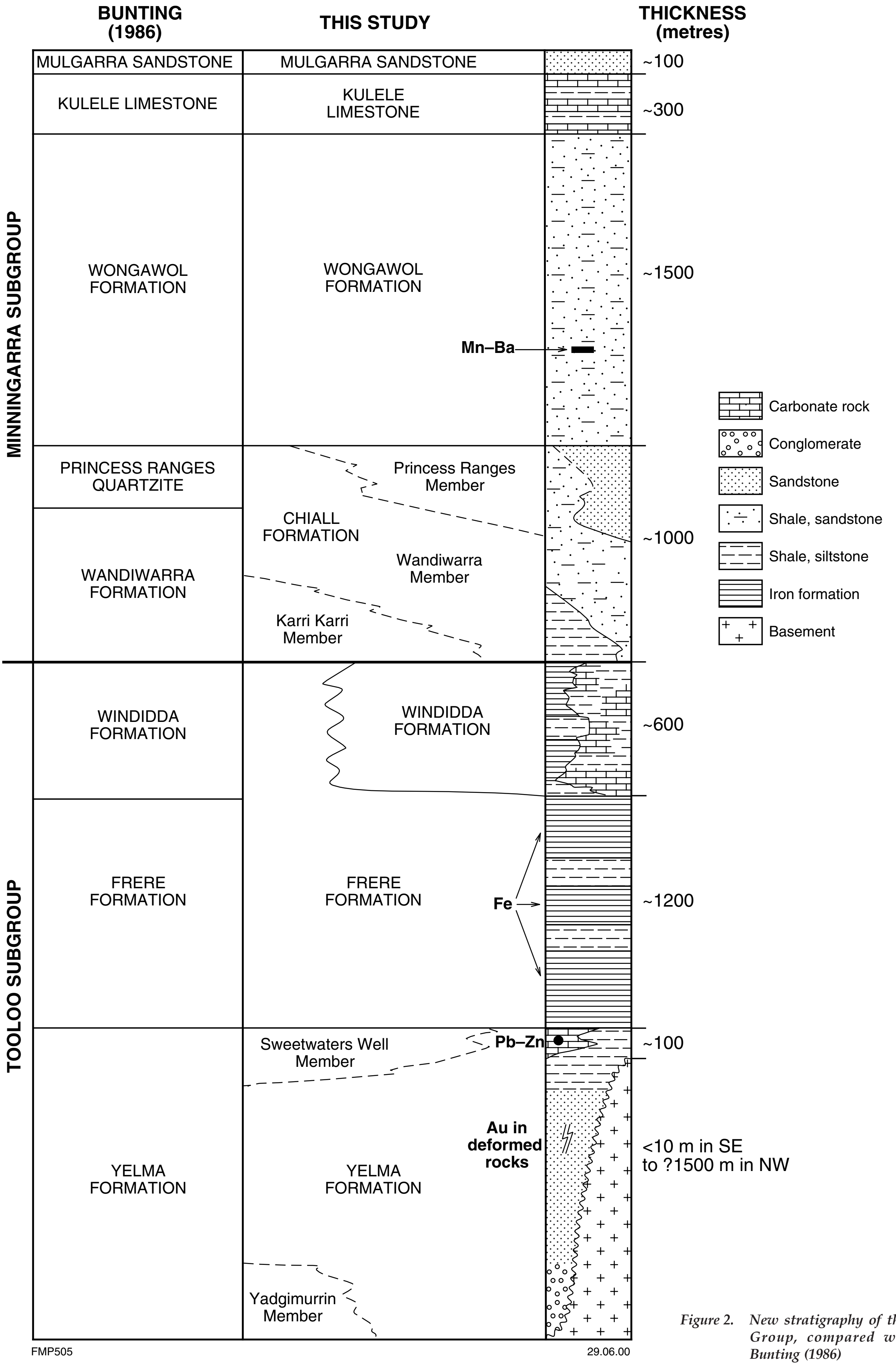

Figure 2. New stratigraphy of the Earaheedy Group, compared with that of Bunting (1986)

Member (Fig. 2). The shale is interbedded with thin, fine- to medium-grained sandstone beds in the upper part of the formation. The shale and siltstone are very similar to shale and siltstone of the Frere Formation. Initially thought to be a distal facies of the Windidda Formation, the Karri Karri Member was recently recognized as a basal, distal part of the Chiall Formation (Hocking et al., 2000). Deposition of the Karri Karri Member was probably below fair-weather wavebase, based on the presence of hummocky cross-stratification, graded bedding, and mass-flow deposits. Asymmetric ripples and cross-bedding are also present. In the southeast and the upper part of the Chiall Formation, symmetric and asymmetric ripples, interference ripples, rills, washouts, and trough cross-beds indicate a shallow-water upper shoreface to foreshore setting. In the southeast, a facies consisting of shale, mudstone, siltstone to very fine grained sandstone, and calcareous mudstone is present. Wrinkle marks, symmetrical ripples, and rills within it indicate intermittent emergence.

These structures, together with palaeocurrent data, indicate a tidal environment, with periodic localized lagoonal environments in the southeast deepening northwards to a subwavebase marine shelf.

Wongawol Formation

The Wongawol Formation consists of shale, siltstone to very fine grained sandstone, intraclastic breccia, and carbonate–glauconite breccia. Bunting (1986) suggested that the formation was 1500 m thick, but low-angle faulting and folding may have exaggerated the true thickness. Asymmetrical and symmetrical ripples, rills, wrinkle marks, washouts, and mudcracks in the siltstone and very fine grained sandstone indicate a very shallow, locally emergent environment, possibly lagoonal, with periods of minimal sedimentation. Contorted bedding is common, and detached pillows of sandstone within siltstone (load structures) are also present.

Kulele Limestone and Mulgarra Sandstone

The Kulele Limestone is a cyclic platform succession consisting of carbonate units separated by shale and sandstone (up to 300 m thick). Carbonate units are stromatolitic, oolitic, and pisolitic. Distinctive stromatolites, *Earaheedia wongawolensis* Grey 1984, consist of elongate domes, large individual domes up to 3 m high and 4 m wide, and minor columns. Compared to the Wongawol Formation, the Kulele Limestone records a slight deepening of the basin, accompanied by a drop in terrigenous influx. Metre-scale shallowing-upward cycles through most of the unit record regular minor fluctuations in sea level in a subtidal to possibly intertidal setting.

The Mulgarra Sandstone consists of sandstone, shale, and minor carbonate, with a maximum thickness of 100 m. The formation may reflect the final stage of terrigenous influx in the basin.

Mineralization

In the Earaheedy Basin, Mississippi Valley-type lead–zinc–copper sulfide deposits are present in the Sweetwaters Well Member of the Yelma Formation (Fig. 1). This mineralization is near Sweetwaters Well, where galena is hosted in the spaces between columns of *Asperia digitata*, which probably acted as local conduits for mineralizing fluids (Grey, 1984). West of the Shoemaker Impact Structure, sulfide mineralization was intersected in several drillholes. Here, the mineralized stromatolitic dolomite extends along strike for about 13 km and consists of sphalerite, galena, pyrite, and chalcopyrite, largely as fracture fills, vug fills, or carbonate replacements. Petrographic and fluid inclusion studies suggest that the Shoemaker meteorite impact generated high-temperature (>300°C) fluids (Seccombe and Jiang, 1994), which may have caused the redistribution of part of the sulfide mineralization in impact-induced fractures.

The large (>200 Mt) Magellan lead deposit is hosted by outliers of the Sweetwaters Well Member resting unconformably on the Yerrida Group to the southwest near the town of Wiluna. The Magellan mineralization consists of cerussite, plattnerite, and anglesite (Pirajno and Preston, 1998).

Minor stratiform manganese and iron oxides within the shale units of the Wongawal Formation (Pirajno and Adamides, 2000) contain anomalous abundances of copper, barium, and lead, thus enhancing the prospectivity of the Earaheedy Basin for stratabound copper of the Kupferschiefer type. Gold mineralization in the Stanley Fold Belt (the presently exposed deformed northern margin of the Earaheedy Group) is associated with mylonite and quartz veins.

Depositional model

Poor age constraints hinder our understanding of the tectonic evolution and development of the Earaheedy Basin. Any model for the evolution of the basin must account for influx of iron during the deposition of the Frere Formation, the allochemical nature of the jasperoidal and iron-oxide clasts, the coastal to shallow-marine environment for the Earaheedy Group, and the lack of evidence for contemporaneous volcanism or deformation. A proposed model for the geodynamic evolution of the Earaheedy Basin is presented in Figure 3.

The exposed Earaheedy Group is characterized throughout by deposition in a shallow-marine to coastal environment, with a shoreline to the south and southeast, and deepening towards the north. The lack of change from coastal bathymetry suggests that there was no major tectonic activity, either as abrupt hinterland uplift or basin subsidence. We envisage that the Earaheedy Basin was part of a passive continental margin (Fig. 3a) along the northeastern Yilgarn Craton. The Earaheedy Group represents the southern coastal to nearshore portion of the continental margin, where deposition occurred in response to subsidence, sediment loading, and compaction. Deposition was strongly influenced by water chemistry, sediment supply, and minor sea-level fluctuations. Sea-level fluctuations are envisaged to have been both eustatic and tectonic, with short-term eustatic changes in a greenhouse climate (Read et al., 1995) producing metre-scale cyclicity in carbonates, and longer term tectonism responsible for increases in sand deposition by

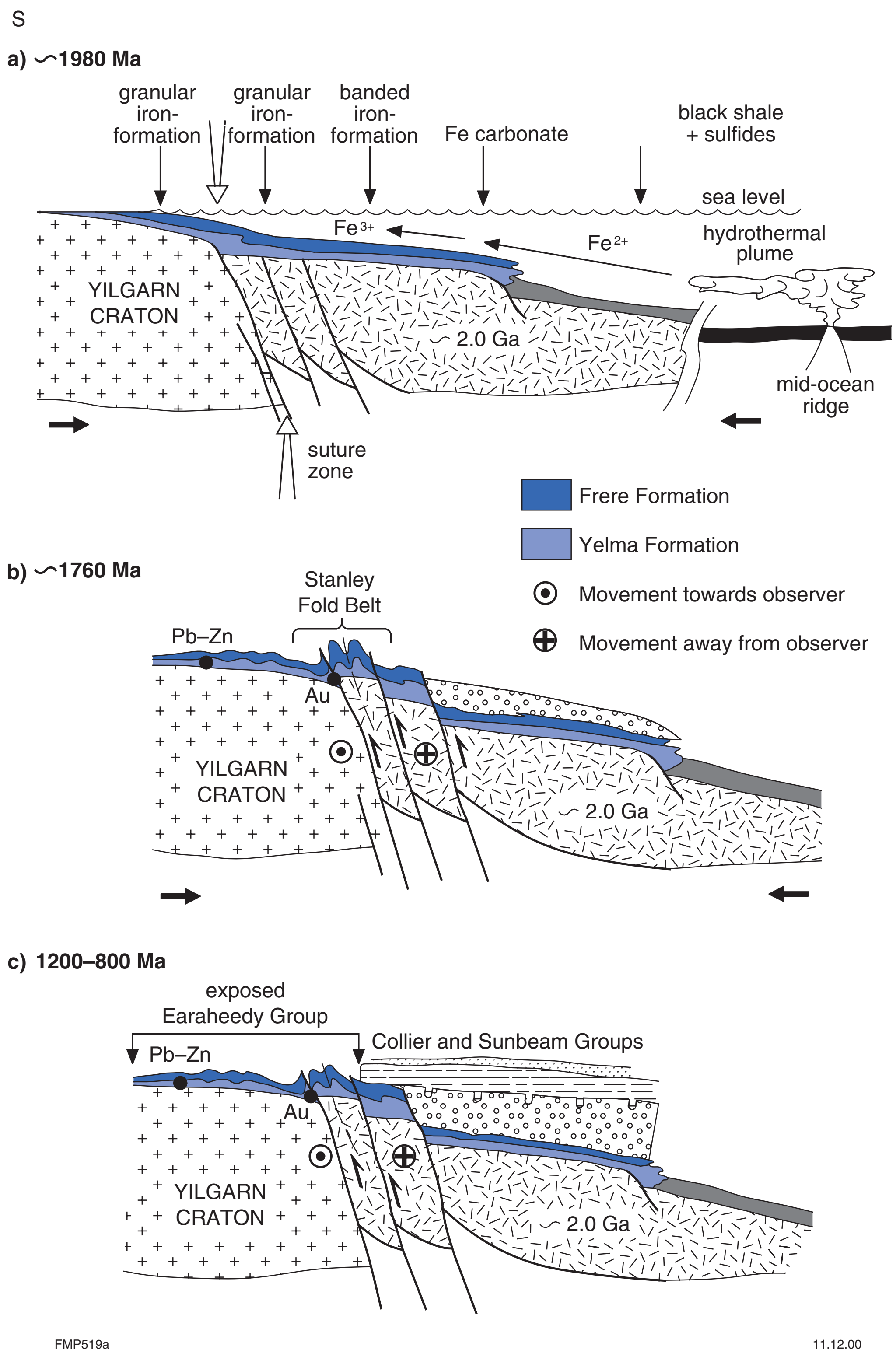

Figure 3. Schematic illustration (not to scale) showing the depositional and tectonic model for the Earaheedy Basin; note that only the Yelma and Frere Formations are shown, for the sake of clarity: a) at about 1980 Ma, iron formation is deposited on a passive continental margin (northeastern Yilgarn Craton), with the iron sourced from a spreading centre; b) at about 1760 Ma, strike-slip movements form the Stanley Fold Belt, resulting in the formation of Mississippi Valley-type lead–zinc and mesothermal gold lodes; c) between 1200 and 800 Ma, deposition of the Collier and Sunbeam Groups conceals parts of the passive continental margin; the exposed portion is the present-day Earaheedy Basin

either hinterland rejuvenation or basin subsidence. We propose that the quiet low-energy conditions typifying most of the sediment fill of the basin and the suggestion of saline lagoonal environments within the Earaheedy Group are consistent with deposition on an arid coastline.

The northward-deepening model for the basin is consistent with hypotheses that granular iron-formation is the shallow-water facies equivalent of deeper water, banded iron-formation (Beukes and Klein, 1992; Isley, 1995). The ultimate source of the iron, and perhaps of other metals (lead, zinc, and manganese), is interpreted to have been from a mid-ocean ridge probably located well to the north and east of the presently exposed margin of the Pilbara Craton (Fig. 3a). The lead–zinc sulfide occurrences in the Sweetwaters Well Member, west of the Shoemaker Impact Structure, and the Magellan lead carbonate and oxide deposit were probably formed during flow of basinal fluids through sandstone aquifers. These fluids originated by dewatering of the sediments, initially through compaction, and subsequently during tectonic transport to the southwest. The structurally controlled veins in the Stanley Fold Belt are also related to the deformation of the Earaheedy Group at this time (Fig. 3b). High-temperature fluids may have been generated during a thermal event related to the Shoemaker meteorite impact. The Earaheedy Group is now partly concealed by rocks of the Collier Group (Fig. 3c).

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