THE WAGGON CREEK FORMATION—AN EARLY CARBONIFEROUS SUBMARINE FAN DEPOSIT IN THE BONAPARTE GULF BASIN

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ABSTRACT

The Waggon Creek Formation is a submarine fan deposit in which two facies associations are recognized and related to deposition in separate areas of the fan. The lower coarse-grained association (40 m thick) consists of conglomerate, pebbly sandstone, and sandstone, deposited in an upper fan channel environment; and the upper fine-grained association (80 m thick) consists of sandstone and shale, deposited in the suprafan lobe area of the mid fan. The valley in which the formation now occurs may be an exhumed submarine erosion channel associated with the fan. Turbidity currents deposited most sediments. However, coarser deposits lack Bouma sequences and their texture, fabric and internal structures reflect differing sites of deposition within the channel. Minor depositional processes include debris flows in the coarse-grained facies association, and modification of turbidites by fluidization in the fine-grained facies association. Distinctive conglomerate clasts include Cambrian sandstone and dolomite transported several kilometres and laminated dolomite locally derived from the underlying Cockatoo Formation.

INTRODUCTION

In the southern Bonapart Gulf Basin, Veevers and Roberts (1966; 1968) mapped a unit of pebbly sandstone and conglomerate, which they named the Waggon Creek Breccia. They considered the unit to be unconformably overlain by sandstone tentatively correlated with the Point Spring Sandstone. Mapping in 1980 and 1981 by the Geological Survey of Western Australia has suggested that the lower conglomeratic unit and the upper sandstone unit are part of the same formation, here renamed the Waggon Creek Formation.

STRATIGRAPHY

The Waggon Creek Formation is a unit of conglomerate, pebbly sandstone, sandstone and shale occurring in the valley between the Ningbing Range and the Pretlove Hills (Fig 1). The type section of the Waggon Creek Formation (Section C) is 86 m thick, the lower 40 m of which corresponds with Veevers and Roberts (1966) type section for the Waggon Creek Breccia (their thickness is stated as 56 m). Section B (120 m) thick is here designated as a reference section (Fig. 1).

The formation consists of a lower coarse-grained facies association of conglomerate and pebbly sandstone, which corresponds to Veevers and Roberts' 'Waggon Creek Breccia' and an upper fine-grained facies association of sandstone with minor shale, mapped by them as ?Point Spring Sandstone. The two facies associations are here included in an enlarged Waggon Creek Formation because:

1. there is no field evidence for any discontinuity between them;
2. there is lithological unity throughout the formation; and
3. the fine-grained facies association bears little resemblance to the typical Point Spring Sandstone, which outcrops 20 km to the east.

The Waggon Creek Formation is at least 120 m thick. It unconformably overlies sandstone with very thick dolomite beds of the Hargreaves Member of the Cockatoo Formation. The top of the unit is nowhere exposed.

Part of the formation occupies a channel cut into the Hargreaves Member. In the westernmost exposure (Fig. 1) the channel is about 150 m wide and a few tens of metres deep; 2 km to the east it widens to about 700 m, but the base is not exposed.

Brachipods and bivalves in the formation suggest a mid-Visean (Veevers and Roberts, 1966) to late-Visean (Veevers and Roberts, 1968) age. Early Carboniferous shale (Jones, 1958) is present in boreholes in the valley (Fig. 1), but its precise stratigraphic relationship with the Waggon Creek Formation is not known. The shale may correlate with mid-Visean shale (A. J. Mory pers. comm. 1982) beneath Burvill Beds 14 km to the northeast, and with the Milligans Beds in the eastern part of the basin. Consequently, the Waggon Creek Formation may correlate wth part of the Milligans Beds (Fig. 2).

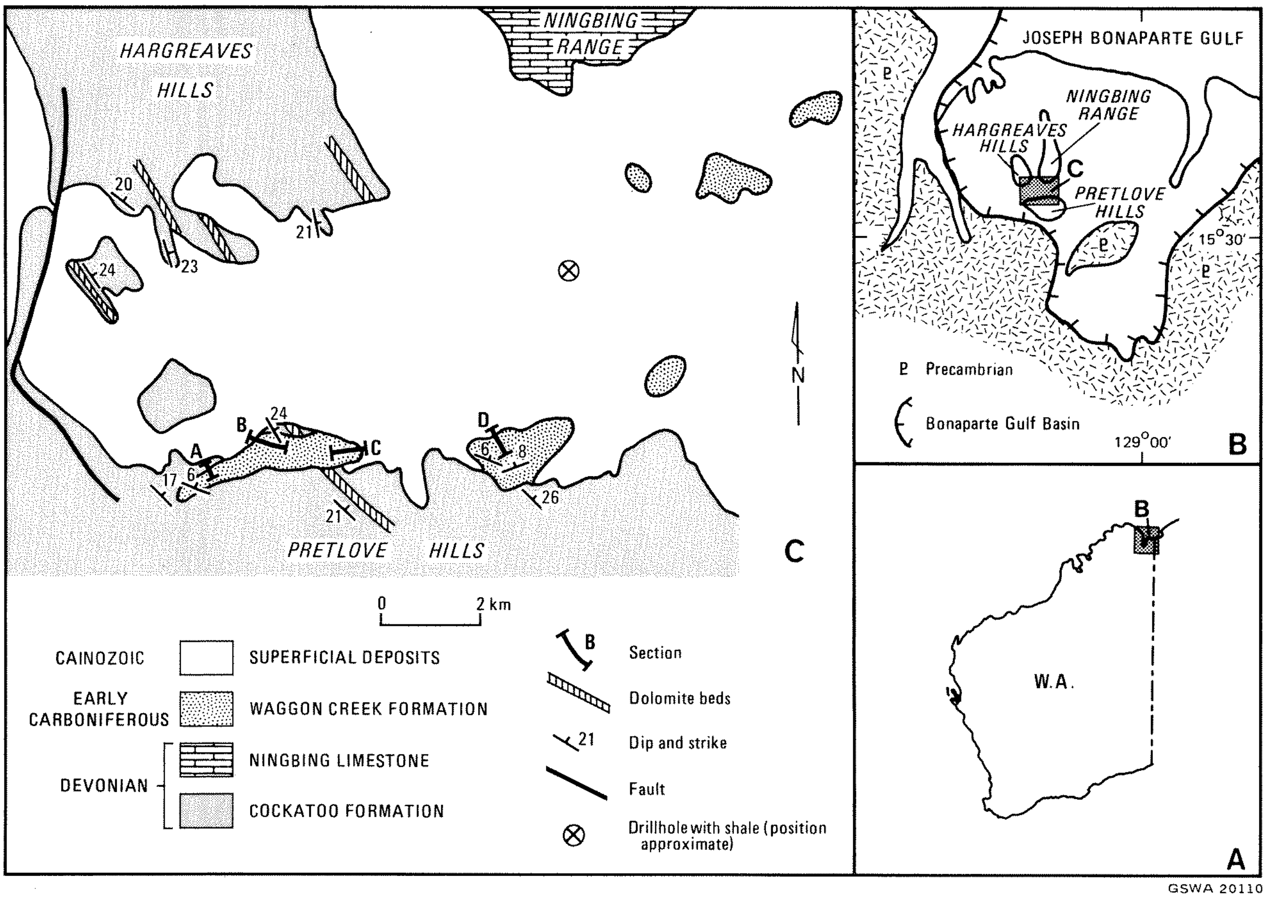

Figure 1. Location of the Bonaparte Gulf Basin (A, B) and geological map of the Waggon Creek area (C). Sections A, B, and C are in the "Waggon Creek Breccia", and section D the "mid-Tournaisian breccia" (Veevers and Roberts, 1968). Most other outcrops of the Waggon Creek Formation were originally mapped as Point Spring Sandstone.

AGE		UNIT	LITHOLOGY	ENVIRONMENT
EARLY CARBONIFEROUS	NAMURIAN	BORDER CREEK FORMATION	SANDSTONE + CONGLOMERATE	FLUVIATILE
		POINT SPRING SANDSTONE	SANDSTONE	
	VISEAN	BURVILL BEDS	SANDSTONE + SHALE	
		?—?—? WAGGON CREEK FORMATION ?—? MILLIGANS BEDS	SHALE	SHALLOW MARINE
	TOURN-AISIAN			
DEVONIAN		NINGBING LIMESTONE	LIMESTONE	REEF COMPLEX
		COCKATOO FORMATION	SANDSTONE + DOLOMITE	SHALLOW MARINE

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Figure 2. Stratigraphy, lithology and environmental interpretation of the sequence in the Waggon Creek area (modified from Veevers and Roberts, 1968).

A mid-Tournaisian age (Veevers and Roberts, 1966) has been ascribed to exposures on the southern side of the outcrop area (Fig. 1). These rocks are lithologically similar to the Waggon Creek Formation and are here tentatively assigned to that formation. The older age may be due to a reworked fauna, but if so, it is not clear why a Tournaisian fauna has not been recovered from other outcrops.

Preliminary interpretation of field data suggests the Early Carboniferous sequence above the Milligans Beds is a shallowing sequence, probably associated with delta progradation. The clay mineralogy in Milligans Beds suggests it was deposited in a nearshore environment (Veevers and Roberts, 1968, p. 136).

FACIES DESCRIPTION

Four sections were examined in the two main outcrops (Fig. 3). One complete section (B) was examined through the central part of the western outcrop. Section C is located near the original type section of the "Waggon Creek Breccia". Because exposure consists mainly of tumbled blocks up to several metres in diameter, with rare *in-situ* exposure, only diagrammatic facies are shown in the sections in Figure 3. Weathered shale horizons are believed to control the nature of outcrop, and a qualitative estimate of the shale content was made according to the "rubbliness". Facies thicknesses were estimated by plotting keypoints identified on aerial photographs onto the 1:100 000 Carlton topographic sheet. Two major facies associations containing seven facies are recognised (Table 1).

Coarse-grained facies association

This facies association is at least 40 m thick and is characterized by pebbly sandstone and conglomerate with shale fragments and locally abundant dolomite clasts. Erosive bases are common and shale horizons may be a minor part of the corase-grained facies association. Dolomite cementation occurs in coarser parts of the unit. Facies include bedded conglomerate (both matrix supported and clast supported), massive and normally graded pebbly sandstone, and interbedded conglomerate and sandstone with interbeds both well-defined and gradational (Table 1.). Thin- and thick-bedded sandstone, and massive sandstones are present but are more typical of the fine-grained facies association. Individual facies within the association do not have consistent vertical sequences or thicknesses between sections, a factor which indicates lensoidal distribution (Fig. 3). Abraded dolomite cobbles and boulders up to 0.7 m in diameter include stromatolitic, oolitic, laminated, massive and sandy types, and a single cobble of the coral *Syringopora*. Large boulders up to 15 m diameter of laminated dolomite occur in the lower parts of sections B and C. A block of sandstone with trilobites occurs near the base of section C.

Fine-grained association

The fine-grained facies association is up to 80 m thick and characterized by medium- to fine-grained massive and bedded sandstone showing sole markings. Shale horizons form an important part of this association. Individual facies within this association include massive sandstone, thin and thick bedded structured sandstone, and shale (Table 1). Thick bedded structured sandstone, only occurs at the base of section D in the coarse-grained facies association.

DOLOMITE CLAST PROVENANCE

The provenance of dolomite clasts in the Waggon Creek Formation yields important clues to transport and depositional processes. Pre-Early Carboniferous dolomites in the Bonaparte Gulf Basin are common at several levels in the Devonian Hargreaves Member of the Cockatoo Formation, and also within the Cambrian Skewthorpe Formation.

Hargreaves Member dolomites include laminated dolomite and intra-clast breccia dolomite. Oncolitic and brachiopod dolomites are uncommon. Stromatolitic dolomite is rare and occurs mainly as gently convex laminae. Venvers and Roberts (1966) also report oolitic dolomite.

Laminated dolomite clasts in the Waggon Creek Formation are similar to dolomites in the Hargreaves Member. The large boulders of laminated dolomite occur near outcrops of the underlying Hargreaves Member and are probably locally derived.

The Cambrian Skewthorpe Formation includes oolitic dolomite and dolomite with well-formed columnar stromatolites similar to those found in the Waggon Creek Formation. Additionally, the boulder of sandstone with trilobite fragments in section C is similar to the Cambrian Clarke Sandstone. Cambrian rocks outcrop in a belt to the west and south, and the Cambrian boulders in the Waggon Creek Formation are at least 3 km from a possible source.

DEPOSITIONAL PROCESSES

Most facies in the Waggon Creek Formation lack traction-developed structures (cross-stratification, plane bedding) and a mechanism is needed to account both for this and the transportation of large clasts over a distance of several kilometres. The presence of some Bouma sequences and sole marks

TABLE 1:
FACIES DIVISION AND CHARACTERISTICS IN THE WAGGON CREEK FORMATION

Facies Association	COARSE-GRAINED			FINE-GRAINED			
Facies	CONGLOMERATE	INTERBEDDED CONGLOMERATE AND SANDSTONE	PEBBLY SANDSTONE	MASSIVE SANDSTONE	THICK STRUCTURED SANDSTONES	THIN STRUCTERED SANDSTONES	SHALE
Thickness	<15 m	<10 m	<10 m	30 m in F.F.A. 10 m in C.F.A.	10 m in C.F.A.	25 m in F.F.A. 15 m in C.F.A.	—
Bed Thickness	0.2-1.5 m	0.5-1.0 m	0.3-1.5	0.5-1.5 m	1-1.5 m	5-30 cm	—
Texture	Pebble to boulder clast- and matrix-supported Subangular to sub-rounded clasts	*Conglomerate* Clast to sand supported *Sandstone* Coarse to fine	Pebbly, fine to medium sandstone, Moderate to poor sorting	Fine to coarse, Well to poorly sorted	Medium to fine, Moderately sorted	Fine to medium Rare coarse sand and pebbly conglomerate	Sandy
Sedimentary Structures	Layered Moderately sorted, coarse tail, Internally massive, Grading, imbrication absent, Irregular upper and lower contacts, Tabular clasts define parallel stratification, Rare vertical tabular clasts	Well defined or gradational interbedding, *Conglomerate* Erosive base, massive bedded basal unit, minor horizontal stratification, or rare cross-stratified tops. *Sandstone* Stronger lamination with finer grainsize, rare thin cross-bedding, coarse sand to granule lag	Massive, or coarse tail fining upward, grading, Erosive and non-erosive base, Rare parallel laminated to low-angle cross-stratified top, Dolomite cementation	Massive, Minor sole marks (including scours and tool marks), Erosive base, pebble base, Distribution grading, lag conglomerate Rare dish structure, Laminated and interference rippled tops, Poor cross-bedding	Incomplete Bouma sequences: Massive, graded base to diffuse lamination to strong lamination to interference rippled top, shale Sharp non-erosive base, undulating tops	Massive, Sole marks common (flutes and tool marks), Minor normal grading, ripple cross lamination, thin parallel bedding, interference ripples Rare ferruginized shale concretions	Horizons of yellow-brown concretions
Clasts	Local boulders to 15 m, quartzite <15 cm, shale <20 cm, dolomite <70 cm, Q > S > Dol	Quartzite, shale, dolomite, <15 cm	Quartzite <12 cm, shale locally abundant, dolomite rare	Quartzite pebbles and shale cobbles in C.F.A.	Small pebbles of quartzite and shale at base	—	—
Fossils	—	Fragmented	Fragmented	Wood fragments (F.F.A.) brachiopods and crinoids (C.F.A.)	—	Wood fragments in sandstone, fragmented fauna in shale	Brachiopods gastropods fish plates

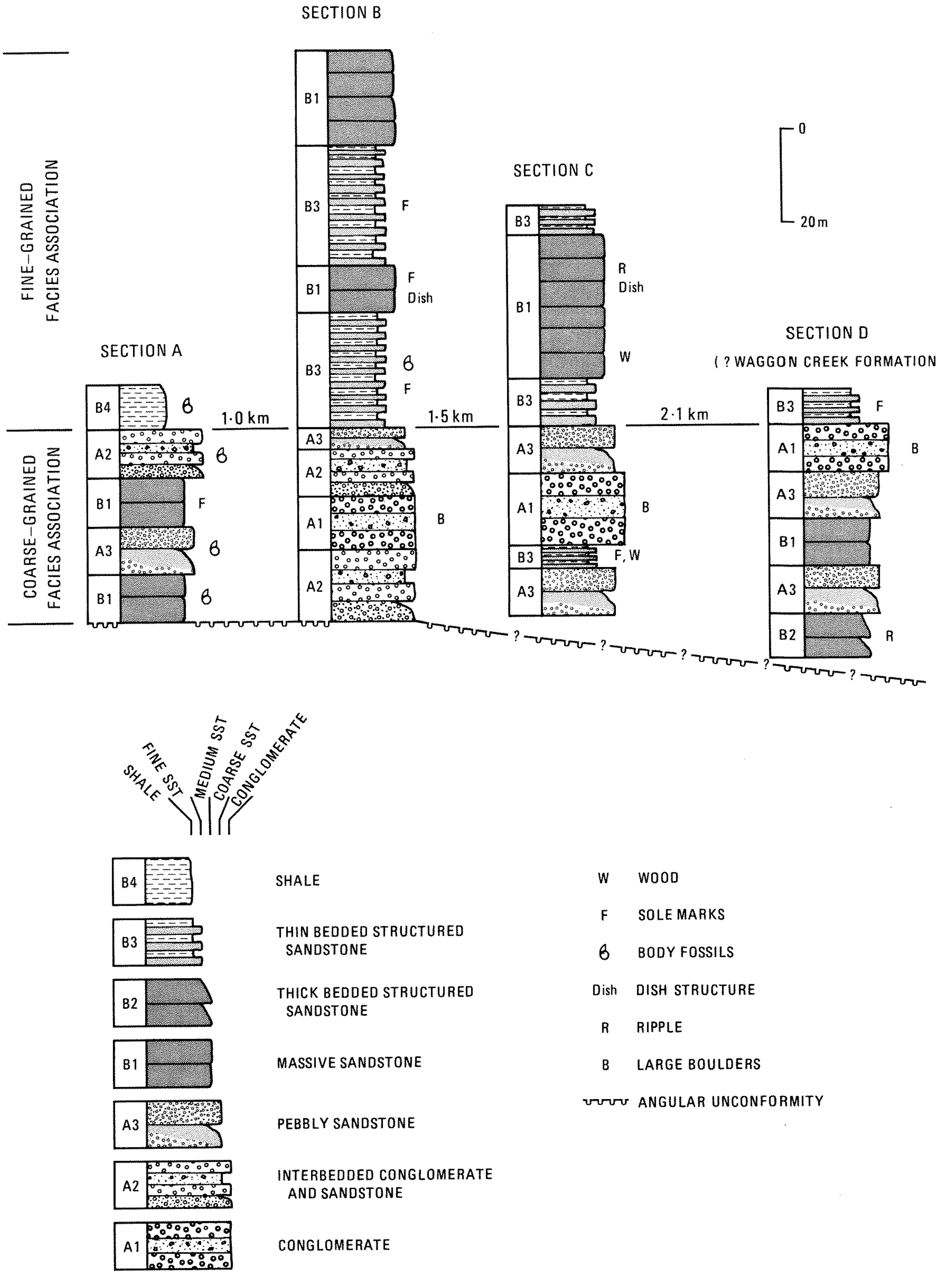

Figure 3. Diagrammatic facies distribution in the Waggon Creek Formation. Facies in the coarse-grained facies association are more lenticular than in the overlying fine-grained facies association. Section D was originally mapped by Veevers and Roberts (1968) as mid-Tournaisian breccia.

suggests turbidity current or other related mass-gravity flows (Middleton and Hampton, 1973). In the following section depositional processes for each facies are interpreted.

Structured Sandstone

The sequence of structures in the thick-bedded structured sandstone includes incomplete Bouma sequences (Rupke, 1978) which were probably deposited by turbidity currents. Most beds in the thin-bedded structured sandstone do not show the Bouma sequence, but have individual features such as sole marks, graded bedding, massive bedding, and ripple cross-lamination suggesting turbidity current deposition.

Massive Sandstone

Scour- and tool-marked bases, a normally graded basal unit and some poorly developed traction current structures at the top of beds, indicate turbidity-current deposition. The lack of internal structures in massive sandstone beds is believed to be due to their degradation by grain collision and a gentle escape of pore fluids in the final phase of deposition (Walker, 1978). Dish structures are thought to be a dewatering feature (Walker, 1978) and those in the Waggon Creek Formation were probably formed by a relatively rapid fluid loss.

Graded pebbly sandstone and interbedded conglomerate and sandstone

Structures in these rocks reflect typical turbidity-current deposition. In a turbidity current, initial rapid deposition from suspension is followed by slower deposition from traction currents (Middleton and Hampton, 1973). Structures in the interbedded conglomerate and sandstone best reflect this sequence of depositional processes, starting with a massive conglomerate at the base, passing up into stratified pebbly sandstone, followed by increasingly fine-grained sandstone with lamination or, rarely, crossbedding, Well defined interbeds of massive conglomerate and structured sandstone suggest either interrupted deposition from different regions of a turbidity current, or the stacking of deposits from turbidity currents of different loads or flow conditions. The presence of lag deposits within some of the sandstone supports the first hypothesis.

Bedded conglomerate

Clast-supported conglomerate lacking internal structure or fabric is similar to Walker's (1978) disorganized bed conglomerates which he believed formed as a lag during rapid deposition on relatively steep slopes. Alternatively a sharp decrease in competence of a current at a marked change in slope may cause rapid deposition of the coarser part of the load, and inhibit the development of structures. Bedding in the Waggon Creek Formation conglomerate is defined by changes in texture and clast composition. Beds defined by a particular clast type have undergone sorting of the coarse fraction. Given a similar provenance, different flow conditions and sorting within a turbidity current will produce such bedding. Matrix-supported conglomerate and massive conglomerate capped by irregular boulder beds are probably debris-flow deposits. These are typically matrix supported, massive (Middleton and Hampton, 1973) and characterized by upward projecting clasts at the top of a bed (Walker, 1978). Debris flows may also account for the formation of the U-shaped channels in pebbly sandstones described by Veevers and Roberts (1966) from the base of section C (not re-located in this study).

DEPOSITIONAL ENVIRONMENT

Turbidity-current and debris-flow deposition are common in submarine fans but are also known from lacustrine environments (Collinson, 1978). The stratigraphic setting of the Waggon Creek Formation within a marine sequence renders a submarine fan environment more probable. Each facies in the formation can be related to the submarine fan model proposed by Walker (1978).

Coarse-grained Facies Association

The coarse-grained facies association is interpreted as a channel deposit on an upper fan. The well-defined channel in the western parts of the outcrop, filled with conglomerate and pebbly sandstone, suggests deposition near the fan head. Bedded conglomerate and massive pebbly sandstone rapidly deposited by turbidity currents, and debris-flow conglomerate were probably deposited in the deepest part of the channel. The coarse-grained facies, representing slower turbidity-current deposition, (interbedded conglomerate and sandstone, graded pebbly sandstone, thick-bedded structured sandstone), were deposited above the channel floor on terraces. Lenses of flaggy sandstone represent overbank turbidity-current deposition on levees flanking the channel. Abundant shale clasts suggest lateral migration of channels with reworking of most overbank shales into the channel deposits. Similarly, some dolomitic sandstone clasts were derived from early-cemented overbank sandstones.

Large laminated dolomite blocks were locally derived from the underlying Cockatoo Formation; however, it is not known how far, if at all, they were transported. The blocks could have been eroded from the floor and sides of the channel, and left as a lag. Alternatively, slides and debris flows (Rupke, 1978) can transport boulders and the large boulders in the Waggon Creek Formation may have been transported by a slide or debris flow from higher up the feeder channel.

Fine-grained facies association

The fine-grained facies association is interpreted as a suprafan lobe deposit in the mid-fan area. Massive sandstone, deposited by a combination of turbidity current and fluidized flow, represents a braided channel deposit. Thin-bedded sandstone was deposited by overbank turbidity currents in interchannel areas. Shales accumulated in areas not affected by clastic input from turbidity currents.

PALAEOGEOGRAPHY

The Waggon Creek Formation occurs near the base of a basin-fill sequence of nearshore shale, shallow marine sand, and fluvial sand. Ancient submarine fans are associated with shallow-water facies in three settings (Rupek, 1978): (a) a prograding delta-front fan in relatively stable tectonic conditions; (b) slope instability at a delta front; and (c) slope instability and local topographic relief produced by basin-margin faulting. Coarse-grained turbidite deposits are found in the last two settings, and conglomerate is associated with basin-margin faulting.

Although the Waggon Creek Formation (and Milligans Beds) is overlain by probable deltaic sediments, the conglomerates of the Waggon Creek Formation suggest a faulted basin-margin setting. In a comparable setting in the Eocene-Oligocene of the Santa Ynez mountains of California, conglomeratic turbidites were initially deposited at the toe of a steep, non-depositional slope formed by faulting. This lay seaward of, and separate from, a shallow water environment (van de Kamp and others, 1974). In time the separate environments were connected as the basin became shallower. Similarly, in the Bonaparte Gulf Basin, Early Carboniferous deltaic sediments above the Milligans Beds may have been deposited on the shallow shelf, and the Waggon Creek Formation deposited at the toe of the slope. As the basin shallowed, the shelf sediments prograded over the Waggon Creek Formation and Milligans Beds. Cambrian clasts in the Waggon Creek Formation were derived from the west, suggesting faulting in this direction.

The Waggon Creek Formation occupies a valley between the Ningbing and Pretlove Hills. Laws (1981) suggested that the northern side of the valley represented the original depositional edge of the Devonian carbonate platform. Fluviatile erosion in the Early Carboniferous has also been postulated (Veevers and Roberts, 1966). However, interpretation of the Waggon Creek Formation as submarine fan and the channel form of the westernmost outcrop suggests that the valley may have formed by submarine erosion in the Early Carboniferous.

CONCLUSION

The Waggon Creek Formation is an Early Carboniferous coarse-textured submarine fan, associated with shallow marine shale and sandstone of a basin-fill sequence. Distinctive boulders of Cambrian stromatolitic and oolitic dolomite, and sandstone with Cambrian trilobites were derived from several kilometres to the west of the present Waggon Creek Formation outcrop, suggesting that the fan developed in response to faulting in the area to the west. Two facies associations are recognized in the Waggon Creek Formation. The lower coarse-grained facies association was deposited in an upper fan channel, and is characterized by conglomerate and pebbly sandstone. Thin- and thick-bedded structured sandstone and massive sandstone are also present. Turbidity currents deposited most facies, and the texture, fabric and internal structures of each facies depended partly on its site of deposition within the channel, and partly on the flow regime of each turbidity current. Debris flows were probably important in depositing matrix-supported conglomerate and pebbly sandstone. Boulders of laminated dolomite up to 15 m in diameter were locally derived from the underlying Devonian Hargreaves Member of the Cockatoo Formation. Abundant reworked shales suggest lateral channel migration.

The overlying fine-grained facies association of thin-bedded structured sandstone and shale, and massive sandstone were deposited in the mid-fan area, in interchannel and braided channel environments respectively. Turbidity currents were the main depositional process but massive sandstones were probably affected by late stage fluidization.

The valley now occupied by the Waggon Creek Formation may have been formed by submarine erosion associated with the fan in Early Carboniferous time.

REFERENCES

Collins, J. D., 1978, Lakes, *in* Reading, H. G., (ed.) Sedimentary environments and facies: London, Blackwell Sci. Pub.

Jones, P. J., 1958, Preliminary report on micropalaeontology of samples from the Bonaparte Gulf Basin: Australia Bur. Mineral Resources Rec. 1958/26.

Laws, R., 1981, Petroleum geology of the onshore Bonaparte Basin: The APEA Jour. v.21, part 1, p.5-15.

Middleton, G. V., and Hampton, M. A., 1973, Sediment gravity flows: mechanics of flow and deposition, *in* Turbidites and deep-water sedimentation: Soc. Econ. Palaeontologists and Mineralogists Short Course Notes, p.1-38.

Rupke, N. A., 1978, Deep clastic seas, *in* Reading, H. G., (ed.) Sedimentary environments and facies: London, Blackwell Sci. Pub.

van de Kamp, P. C., Harper, J. D., Conniff, J. J., and Morris, D. A., 1974, Facies relations in the Eocene-Oligocene in the Santa Ynez mountains, California: Geol. Soc. London Jour., v.130, p.545-565.

Veevers, J. J., and Roberts, J., 1966, Littoral talus breccia and probable beach rock from the Visean of the Bonaparte Gulf Basin: Geol. Soc. Australia Jour., v.13 p.387-403.

Veevers, J. J., and Roberts, J., 1968, Upper Palaeozoic rocks, Bonaparte Gulf Basin of Northwestern Australia: Australia Bur. Mineral Resources Bull. 97.

Walker, R. G., 1978, Deep water sandstone facies and ancient submarine fans: models for exploration for stratigraphic traps: Am. Assoc. Petroleum Geologists Bull. v.62 (6) p.932-966.