Cycle types in carbonate platform facies, Devonian reef complexes, Canning Basin, Western Australia

by R. M. Hocking[1] and P. E. Playford[2]

Abstract

Two principal types of metre-scale depositional cycles, 2 to 12 m thick, can be recognized in reef-flat and back-reef carbonates of the Devonian reef complexes of the northern Canning Basin, Western Australia. Subaqueous infill cycles consist, ideally, of a silty lithofacies overlain by various stromatoporoid lithofacies and capped by fenestral limestone, and contain little or no signs of emergence or subaerial terrigenous progradation. They record infill from relatively quiet, oxygenated water a few metres deep through progressively shallower, more agitated water to shallow subtidal or intertidal flats on which cryptalgal mats thrived. Subaqueous infill to subaerial progradation cycles record moderate- to high-energy subtidal deposition, on stromatoporoid bioherms and in subtidal channels (stromatoporoid limestone and sandstone), followed first by shallow subtidal to ?intertidal deposition (*Amphipora* limestone and fenestral limestone), then by prograding intertidal and supratidal terrigenous deposits (fenestral sandstone). Large-scale stacking patterns can be discerned in places, and repeat the shallowing-upward pattern, but with a longer periodicity spanning four to six cycles. Metre-scale cycles are clearly short term, but are not dated and constrained well enough to favour either short-term orbital forcing or repeated tectonic episodes as the controlling mechanism for cyclicity.

KEYWORDS: Devonian, reef complexes, Canning Basin, stratigraphy, carbonates

Introduction

Reef complexes are spectacularly exposed in Middle and Upper Devonian (Givetian–Famennian) rocks along the northern margin of the Canning Basin in Western Australia (Fig. 1). Platform, marginal-slope, and basinal facies are exposed (Playford, 1980; Playford and Hocking, 1998; Playford et al., 1989, 1999), with associated subaerial (alluvial fan) to deep-marine (basin floor) conglomerates. The reef-flat and back-reef facies are commonly characterized by metre-scale cyclic deposition, with cycles between about 2 and 10 m thick. Two principal types of cycles are present: subaqueous infill cycles, and subaqueous infill to subaerial progradation cycles. Wholly subaqueous, limestone-dominated, shallowing-upward cycles record subaqueous aggradation, or infill, on the platform. Mixed carbonate–clastic cycles of the second type were formed by subaqueous infill followed by subaerial progradation. Recognition of the first cycle type is based primarily on measured sections in the lower Pillara Limestone (Givetian–Frasnian) in the southeast Lennard Shelf and in the Famennian Nullara Limestone, whereas the second type is recognized in the upper Pillara Limestone (Frasnian) in the northwest Lennard Shelf (Fig. 1). Conglomerate-dominated subaqueous to subaerial cycles are an extension of the second cycle type that are present in a specific localized tectonic setting in part of the Sparke Range, in the southeast Lennard Shelf, and are not considered further here.

Subaqueous infill cycles

Subaqueous infill cycles (Fig. 2) contain little or no signs of emergence or subaerial terrigenous progradation. Each cycle records infill from relatively quiet, oxygenated water of a few metres depth (terrigenous lithofacies), through progressively shallower, more agitated water (various stromatoporoid lithofacies), to shallow subtidal or intertidal flats on which cryptalgal mats thrived (fenestral lithofacies). The thin-bedded cap at the top of some cycles is interpreted as the transgressive drowning phase prior to the re-establishment of deep-water conditions in the next cycle. Cycles are 2 to 6 m thick, with an average thickness of 3.5 m. Figure 2 shows an

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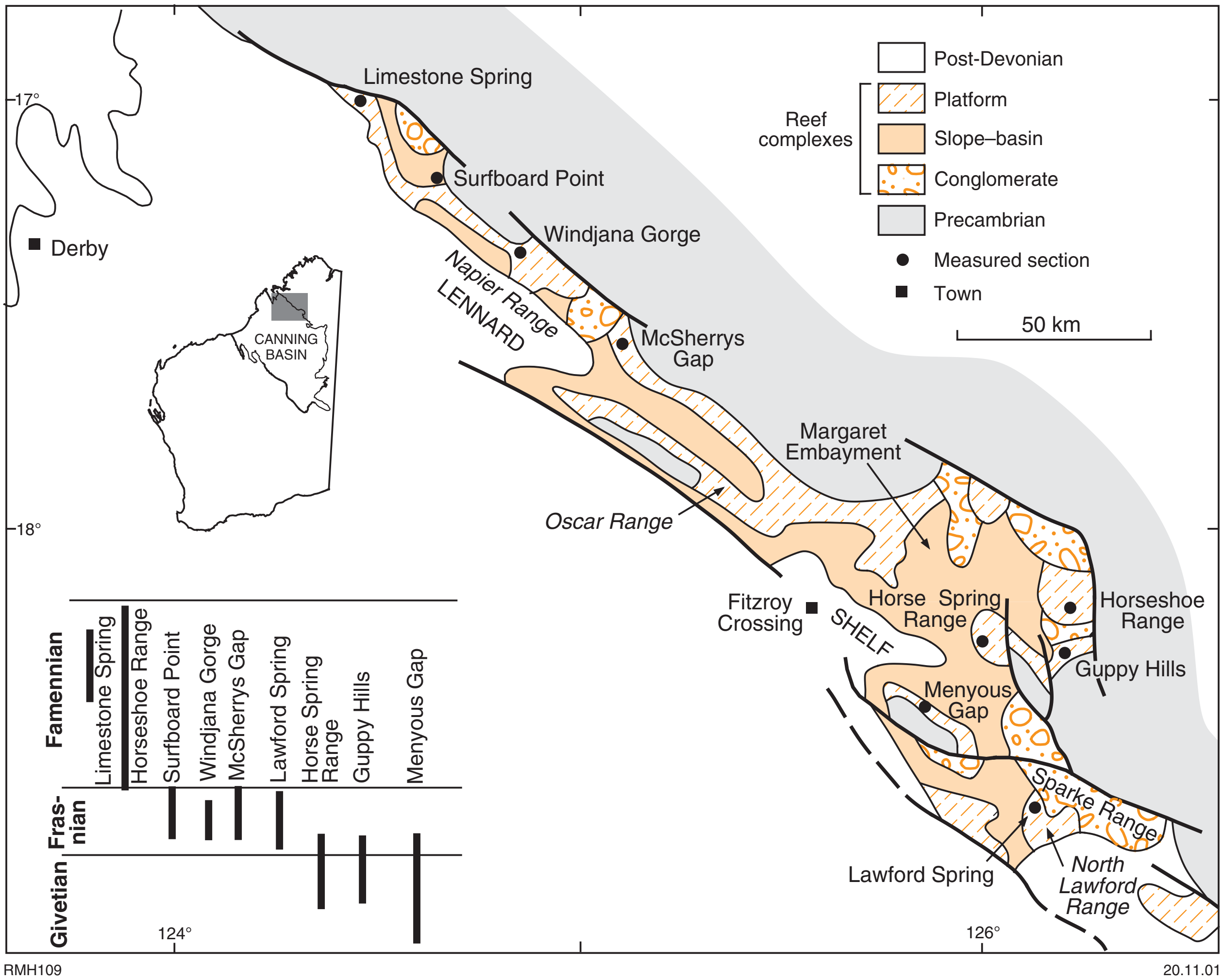

Figure 1. Location of Devonian reef complexes and measured sections, and approximate age relationships of measured sections

ideal cycle, based largely on sections near Horse Spring and through Menyous Gap. Jell and Brownlaw (2000) described these cycles, from the same measured sections. The platform-margin cycles of Webb and Brownlaw (2000) grade laterally into these cycles. We interpret most 'cycles' less than two metres thick as local banks or mounds rather than externally driven cycles, because the stromatoporoid limestones that cap the 'cycles' cannot be traced laterally for more than a few tens of metres.

Subaqueous cycles are present in the lower Pillara Limestone in the southeast Lennard Shelf, in the uppermost parts of the Pillara Limestone in the central Lennard Shelf around McSherrys Gap and Windjana Gorge, and in the Nullara Limestone in the Horseshoe, Oscar, and Napier ranges (Fig. 1). Terrigenous influx in areas such as the Margaret Embayment commonly masks this type of cycle. The cycles described by Read (1973) from Menyous Gap and by Brownlaw et al. (1996) from Guppy Hills are of this type.

Variations from the ideal complete cycle tend to occur as groups of cycles, reflecting longer term controls over accommodation than those applicable to individual cycles. Where the basal siltstone lithofacies is present, cycles commonly shallow up to *Stachyodes* or *Amphipora* limestones and do not have a fenestral cap. Conversely, where well-developed, thick, fenestral limestone units are present, the basal siltstone and tabular-stromatoporoid limestone lithofacies are commonly absent. This may reflect medium- to long-term deeper and shallower areas, on which short-term metre-scale cyclicity was superimposed.

Stromatoporoids are absent in Famennian cycles. Oolitic and oncoid limestones are present in similar positions to stromatoporoid limestones in Givetian and Frasnian cycles, and there is far more cyanobacterial binding apparent. Fenestral limestones and tepee-like deformation are more abundant than in Frasnian platform facies, perhaps reflecting wider and shallower platform areas in the Famennian.

Subaqueous infill – subaerial progradation cycles

Cycles that show subaqueous infill followed by subaerial progradation

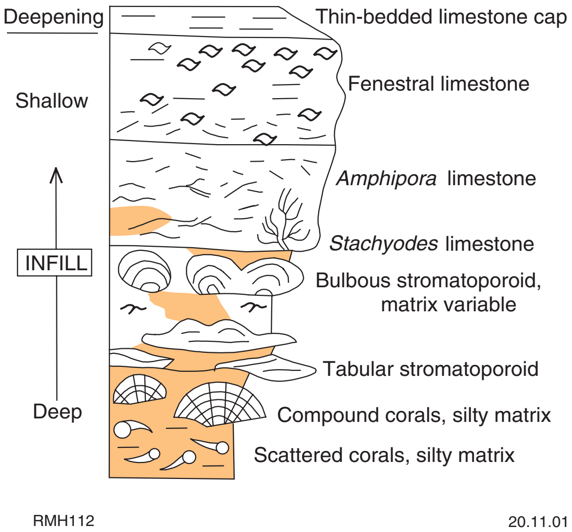

Figure 2. Ideal subaqueous cycle, Pillara Limestone. Cycle thickness 2 to 6 m, average about 3.5 m. Shading indicates terrigenous sediment; dashed lines indicate bedding; see Figure 4 for legend

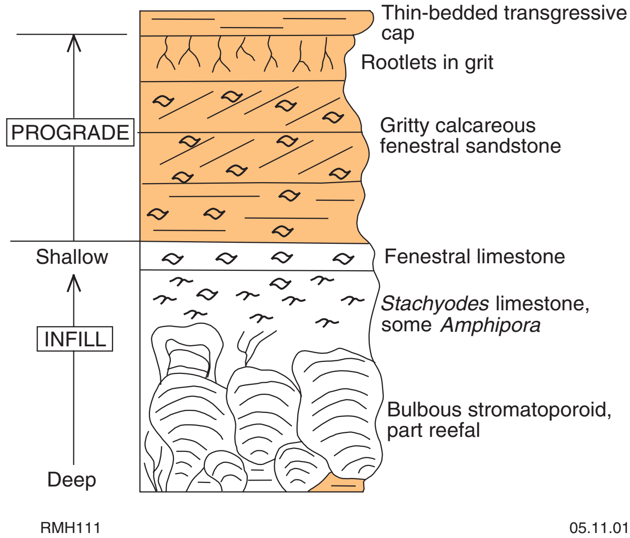

Figure 3. Ideal subaqueous–subaerial cycle, Pillara Limestone. Cycle thickness 2 to 12 m, average about 4 m. Shading indicates terrigenous sediment; dashed lines indicate bedding; see Figure 4 for legend

(Fig. 3) are common in the upper Pillara Limestone in the central to northwest Napier Range. These are the cycles recognized and briefly described by Playford (1980) and Playford et al. (1989). Each cycle records moderate- to high-energy subtidal deposition on stromatoporoid mounds and in subtidal channels (stromatoporoid limestone and sandstone), followed first by shallow subtidal to intertidal deposition (*Amphipora* limestone where present, and fenestral limestone), then by prograding intertidal and supratidal terrigenous deposits (fenestral sandstone and sparsely bioturbated sandstone, locally with recognizable rootlets). The thin-bedded caps on some cycles represent the transgressive drowning phase, and herald the start of the next cycle. Cycles are 2 to 12 m thick (average about 4 m), and vary in lithology more than the subaqueous cycles.

Cross-bedded sandstone is commonly present at the base of cycles instead of stromatoporoid limestone. Moderate sorting, doubly draped foresets, wrinkly toesets, and stromatoporoid and shelly debris indicate that these sandstone units are tidal channel and bar deposits, deposited at shallow-subtidal depths between stromatoporoid mounds and in areas where terrigenous influx was sufficient to inhibit stromatoporoid development. Some tidal channels and bars are clearly erosively based, and significantly affect average cycle thickness. One large lateral-accretion surface on the side of a tidal bar in the Surfboard Point (Fig. 1) section is 8 m thick. This lateral gradation is similar to that noted by Adams and Grotzinger (1996) from the Cambrian of California, where parasequences commonly displayed facies changes when traced laterally over hundreds of metres. On the Lennard Shelf, many parasequence (cycle) boundaries and vertical boundaries between major facies can be followed for several kilometres on the ground or on 1:25 000-scale aerial photographs, and thus appear more laterally persistent than the boundaries of Adams and Grotzinger (1996).

Poorly sorted, gritty sandstone, commonly with a calcareous cement and a fenestral texture, is present in the upper parts of cycles, above stromatoporoid and fenestral limestone. This sandstone was deposited in intertidal and supratidal conditions by fluvially dominated channels and sheetflood processes. Rootlets and possible soils, highlighted by clay-filled or sand-filled tubes, branching subvertical fenestrae, and diffuse mottled textures suggest supratidal conditions. Evaporite pseudomorphs have not been found.

Cycle stacking patterns (large-scale cycles)

In each section, some cycle boundaries are clearly more significant than others. In places a repetitive pattern can be discerned. They mark larger scale packages of metre-scale cycles, into large-scale cycles. Recognition of these large-scale cycles is more subjective and tentative than for metre-scale cycles because of their size and because the results of other long-term changes in sediment influx and tectonic activity mask the large-scale cyclicity.

At Surfboard Point, McSherrys Gap, and the northern Lawford Range (Fig. 1), large-scale cycle-stacking patterns can be seen in the upper Pillara Limestone. They follow a general pattern of gradual shallowing spanning several metre-scale cycles, followed by abrupt deepening to the next large-scale unit. Regular, repeated, large-scale cycles are most readily recognized near the east end of Windjana Gorge in the upper Pillara Limestone (Figs 4 and 5). Here, the metre-scale cycles are arranged into sets of four to six cycles. The sets are 20 to 30 m thick. The metre-scale cycles grade from limestone-dominated cycles at the base of the cycle set (large-scale cycle) to sandstone-dominated cycles at the top. There is an abrupt shift from sandstone-dominated

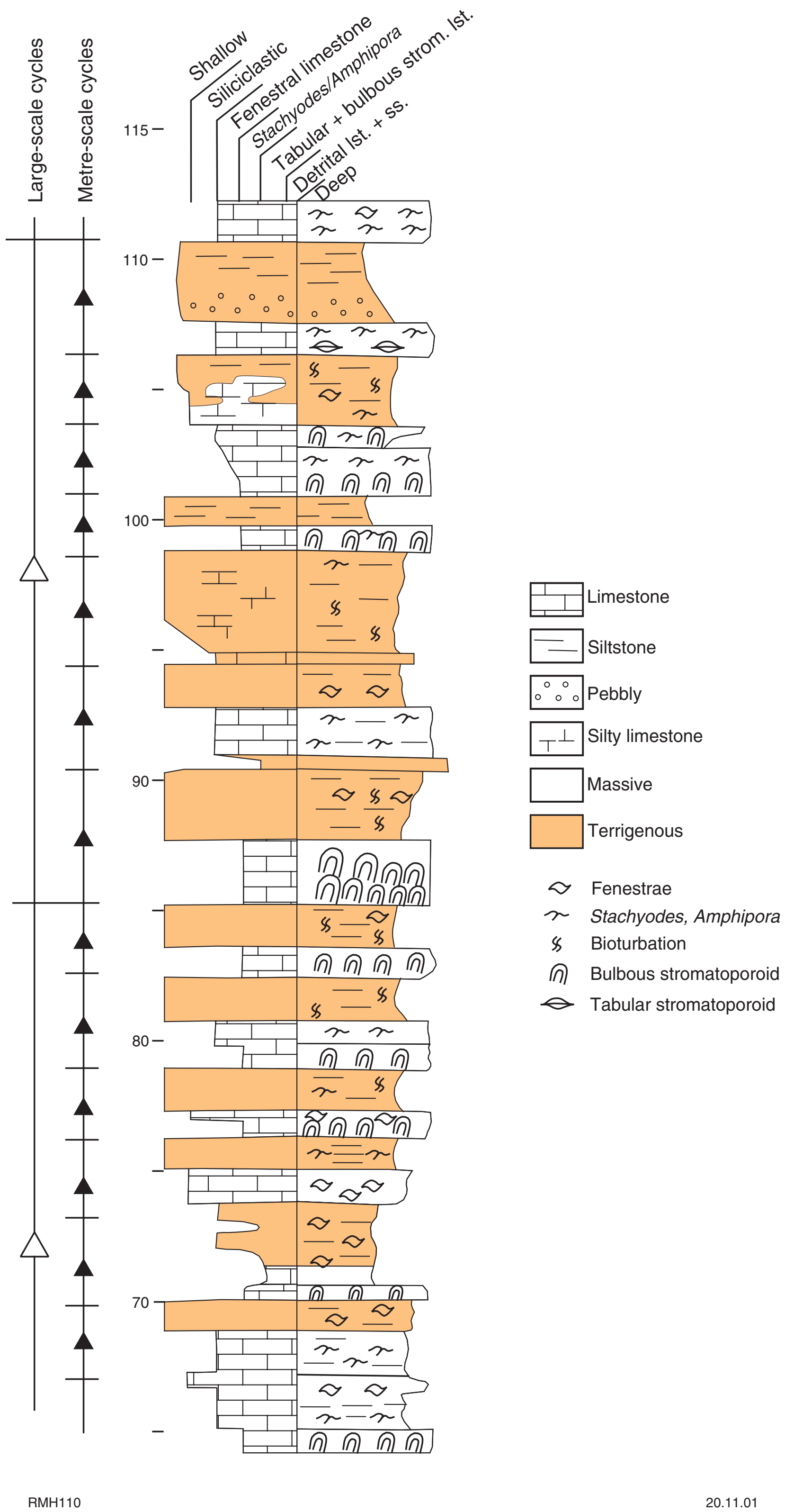

Figure 4. Partial measured section, near east end of Windjana Gorge, showing metre-scale cycles and cycle stacking patterns. Section located at approximately AMG 708200E, 8074200N, upwards in gorge from location shown as Mingun (fishing rock) on Playford and Hocking (1998). Thickness is from full measured section extending from about AMG 708700E, 8074200N over saddle at Malambeea (wait-a-while); lst. = limestone, ss. = sandstone, strom. = stromatolite

below to limestone-dominated above at the boundary between each large-scale cycle, so they are similar to, but of larger scale than, normal subaqueous–subaerial metre-scale cycles from Windjana Gorge. Both metre-scale and large-scale cycles record a pattern of gradual shallowing of the depositional environment through infill, followed by abrupt deepening.

Sections through the lower Pillara Limestone do not show large-scale stacking patterns to the same degree as those in the upper Pillara Limestone. Groups of cycles are apparent in Guppy Hills in aerial views (Fig. 6), but these are not obvious in a section through the western end of the hills, except as a broad alternation of groups of deeper water facies and shallower water facies. In Menyous Gap, there are broad trends in lithofacies abundance (and thus comparative water depth) through the section, but stacking patterns involving several metre-scale cycles are not obvious.

Controls on cyclicity

Both metre-scale cycles and large-scale cycles are the product of repeated relative sea-level fluctuations, with shallowing-upward phases separated by abrupt deepenings. Greenstone conditions (Read, 1995) can be inferred from the relatively small variations in bathymetry throughout the cyclic succession. The carbonate-dominated, lower parts of metre-scale cycles are interpreted as the products of deposition in transgressive to early-highstand conditions, when accommodation was high and carbonate productivity was highest, leading to rapid stromatoporoid, oolith, and oncoid growth . Terrigenous material was either trapped along the basin margin or, if silty, carried to deeper areas to form the coral-bearing terrigenous siltstone lithofacies at the base of some cycles. As accommodation decreased, platform areas shallowed markedly, and terrigenous progradation or cryptalgal mat development (or both; forming fenestral limestone) began. During and after the late-highstand period, platform areas became choked by cryptalgal mats, which formed widespread,

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Figure 5. Aerial view of subaqueous–subaerial metre-scale cycles, east end of Windjana Gorge. Resistant beds are columnar and subspherical stromatoporoid limestone. Large-scale cyclicity is not apparent in this photo

commonly thick, fenestral limestone bodies. In areas of terrigenous influx, sands and gravels prograded over the platform. The subsequent return to deeper water conditions is poorly preserved except as local thin-bedded limestones. The large-scale cycles also reflect gradual infill with lessening accommodation and (where terrigenous influx was sufficient) increasing progradation, followed by rapid drowning.

The cause of the cyclicity in the platform carbonates is equivocal. Orbital forcing (Milankovich cyclicity; Fischer and Bottjer, 1991; De Boer and Smith, 1994; House and Gale, 1995) influences deposition over wavelengths of 20 to 25 ka (precession), 41 ka (obliquity), 100 ka (short-term eccentricity) and 400 ka (long-term eccentricity). To tie the metre-scale and large-scale cycles of the platform facies to these mechanisms requires both precise control on the age of the sections, in terms of biostratigraphic age, and precise correlation of the biostratigraphy to absolute age (chronostratigraphy). The errors implicit in estimates of the age and duration of each section render a choice of either precession or obliquity for metre-scale cycles very subjective, given that platform facies are poorly dated compared to the marginal-slope facies. Consequently, estimates of cycle duration such as those of Jell and Brownlaw (2000) are not attempted here.

A tectonic control over cyclicity is possible. The Lennard Shelf lies along the northern margin of the Canning Basin, adjacent to the King Leopold Orogen, and in the southeast abuts the southern end of the Halls Creek Orogen. In the Devonian, the Lennard Shelf was in an intracratonic, west-opening extensional setting (Baillie et al., 1994; Hocking and Preston, 1998). Faults extend from the Halls Creek Orogen into the Devonian succession in the Sparke Range area, and Devonian movement is established in the Margaret Embayment area by intra-Devonian angular unconformities, as well as in the Ord Basin to the northeast (Thorne and Tyler, 1996). A tectonic control would have to act very regularly over the length of the Lennard Shelf, about 500 km, on a 5 to 10 m scale, by repeated episodic step-wise subsidence (jerky subsidence).

Jerky subsidence as a possible control on cyclicity was debated by Hardie et al. (1991) and Read et al. (1991). Hardie et al. (1991) noted that major earthquakes (M_s 8 to 9) should have a frequency in the same range as Milankovich cyclicity, and can drop areas 100 to 200 km wide by several hundreds of kilometres long (the size of the Lennard Shelf), by 2 to 4 m. The controlling mechanism would be periodic fault movements due to release of tension as a threshold was reached.

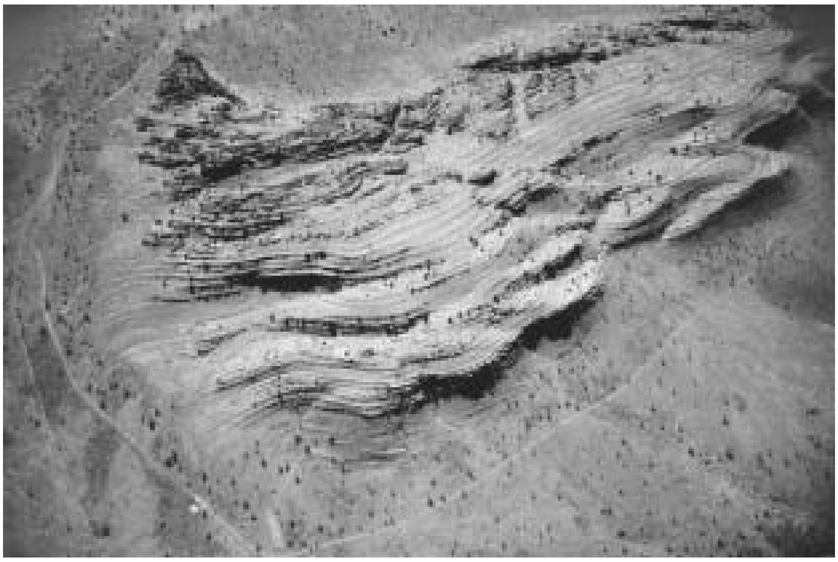

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Figure 6. Aerial view, west end of Guppy Hills looking east. Groups of cycles can be seen here, but are not obvious on the ground

Earthquakes are far more common on compressional margins than extensional margins (Isacks et al., 1968; Condie, 1997), so it is reasonable to assume repeated major earthquakes should also be more common in a compressional setting rather than an extensional setting such as the Devonian Lennard Shelf. However, Read et al. (1991) noted that the established earthquake record is very brief geologically, so these comments and those of Hardie et al. (1991) are largely conjectural. Additionally, there should be abundant smaller earthquakes triggering collapse of unstable sediments in any setting with repeated major earthquakes. The smaller earthquakes may be reflected in the debris-flow deposits characteristic of the marginal-slope facies (Playford, 1984; George et al., 1994), leaving larger earthquakes as a trigger for metre-scale cyclicity as a distinct possibility in the extensional setting of the Lennard Shelf.

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