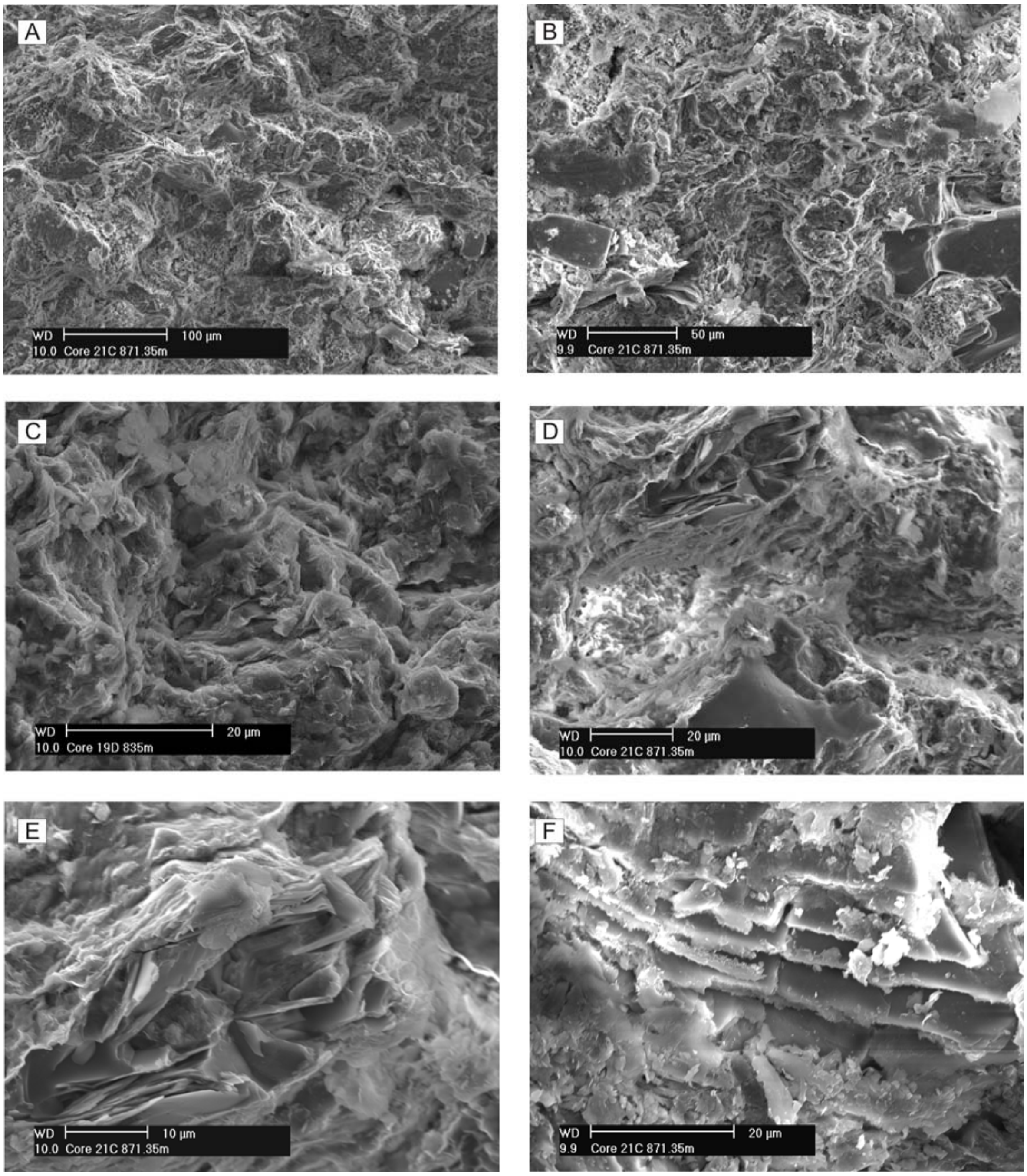


Figure 4.15 SEM images from the lower Unit V in Mocamboro-11. Quartz grains are surrounded by clay matrix (A, B). Illite is the dominant clay mineral (C), and is very tightly packed around the quartz grains (D, E). Clay mineralisation occurs along the edges of what might represent calcareous or carbonaceous material (F).

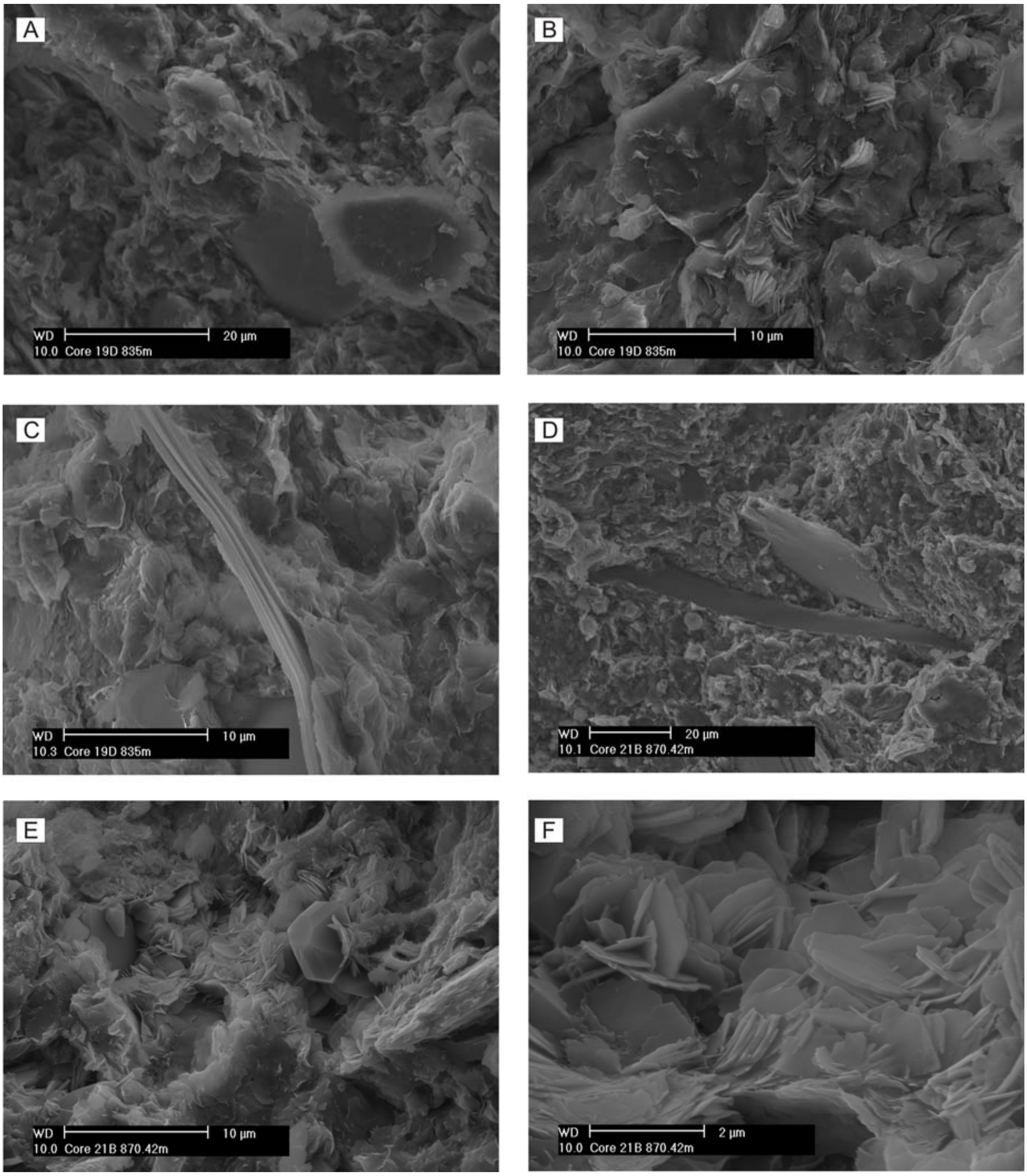


Figure 4.16 SEM images from the lower Unit V in Mocamboro-11. Authigenic clays rim framework grains (A). Authigenic, fan-shaped chlorite platelets are partly replaced and surrounded by illite (B). Detrital mica is present and is surrounded by illite (C, D). Small stacks of face-to-face and fan-shaped, on-edge chlorite platelets are well developed (E, F).

Eumeralla Fm in coal-rich Unit V
Mocamboro-11 Core 706m

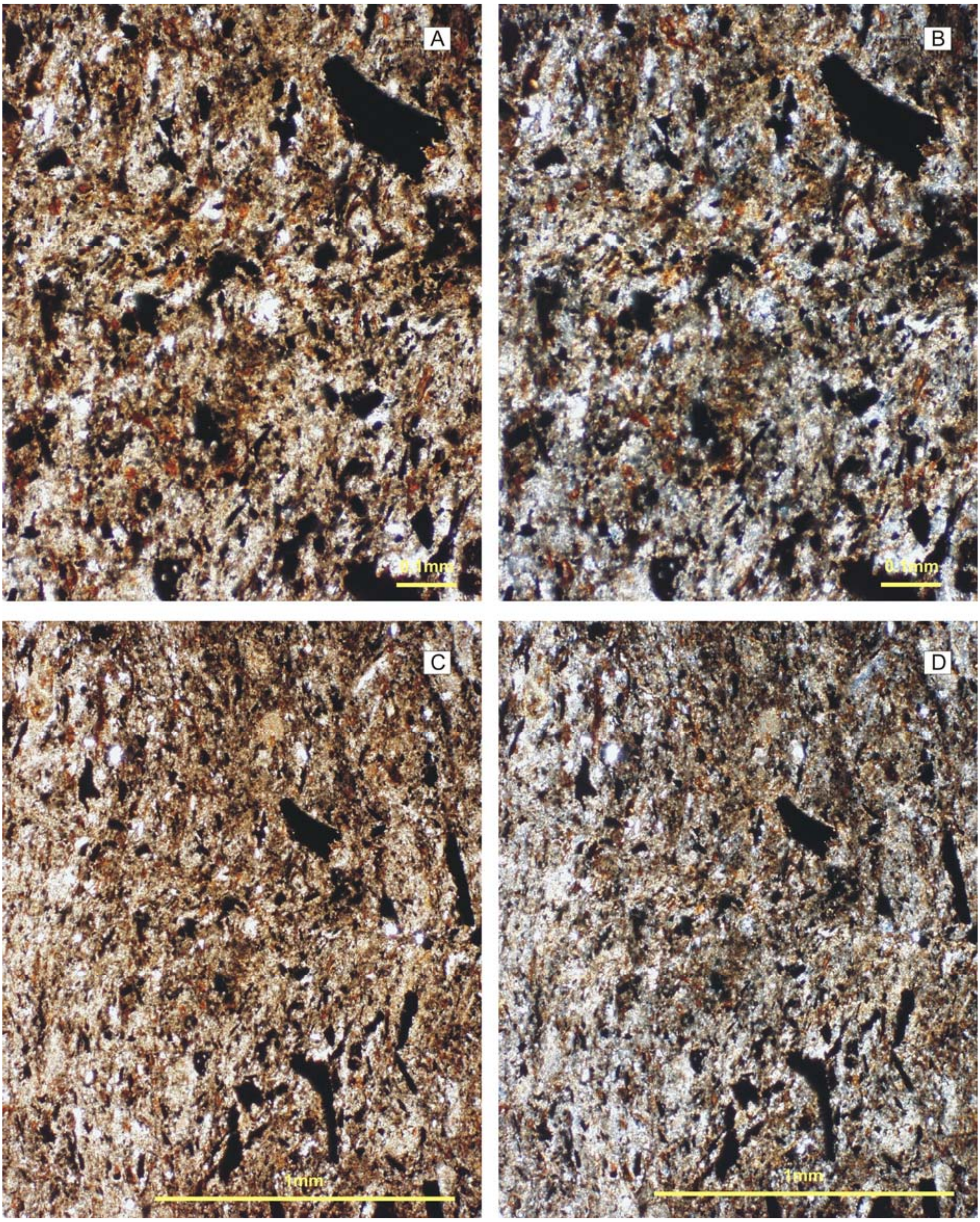


Figure 4.17
Thin sections from a coal-rich interval in Eumeralla Formation Unit V in plain light (A, C) and with crossed polars (B, D). The sediments are very fine-grained, and no grain contacts or boundaries are visible at even high magnitudes. The sediments are very heterogeneous with no laminations. Randomly oriented carbonaceous fragments are abundant and occur in a range of sizes. Quartz is seen as white, shiny specs. There is no visible porosity.

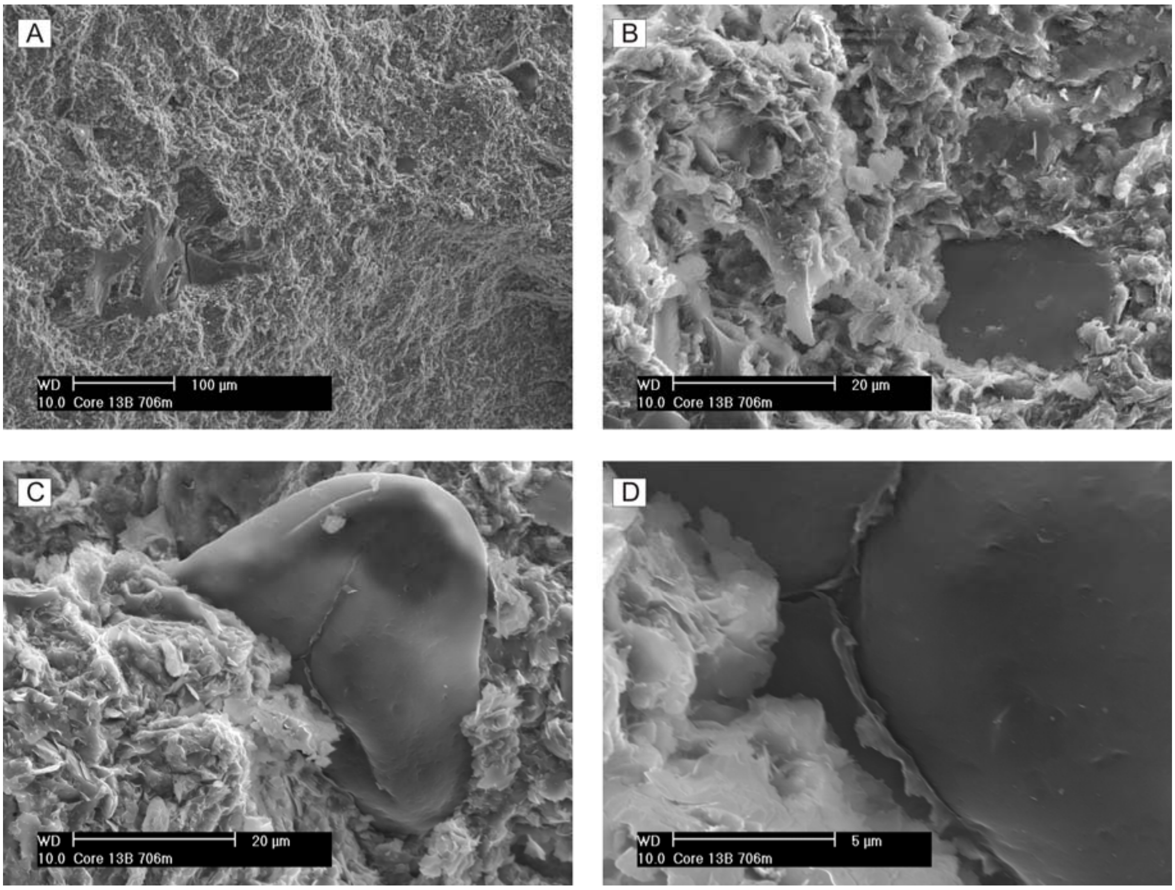


Figure 4.18 SEM images from a black carbonaceous claystone within the coal-rich upper Unit V in Mocamboro-11. Isolated quartz-grains occur in a clay-dominated matrix (A). Illite is the dominant clay mineral (B) and occurs both as matrix and as a pore-filling replacement mineral where the quartz has been dissolved (C, D). The quartz grains are well rounded (C), and smectite is visible as small pit marks on the surface of the quartz grains (D).

Interpretation

The sedimentary structures and varying stacking patterns suggest Unit V represents a dynamic and interchangeable environment. Root traces and coals indicate a floodplain environment. Fine-grained sediments dominated on the floodplain, and oxbow lakes are interpreted to have developed as meander channels shifted. Local coarser-grained crevasse splays were deposited on the floodplain following breach of the channel levees. A varying algal content between the wells suggests that fluvial influence was dominant in some areas while lake environments are more developed in other areas. The fine-grained sediments of the lower Unit V are probably associated with a shallow lacustrine environment, and represent a transitional phase into the overlying floodplain conditions.

Eumeralla Fm Unit V
Mocamboro-11 Core 650.9m

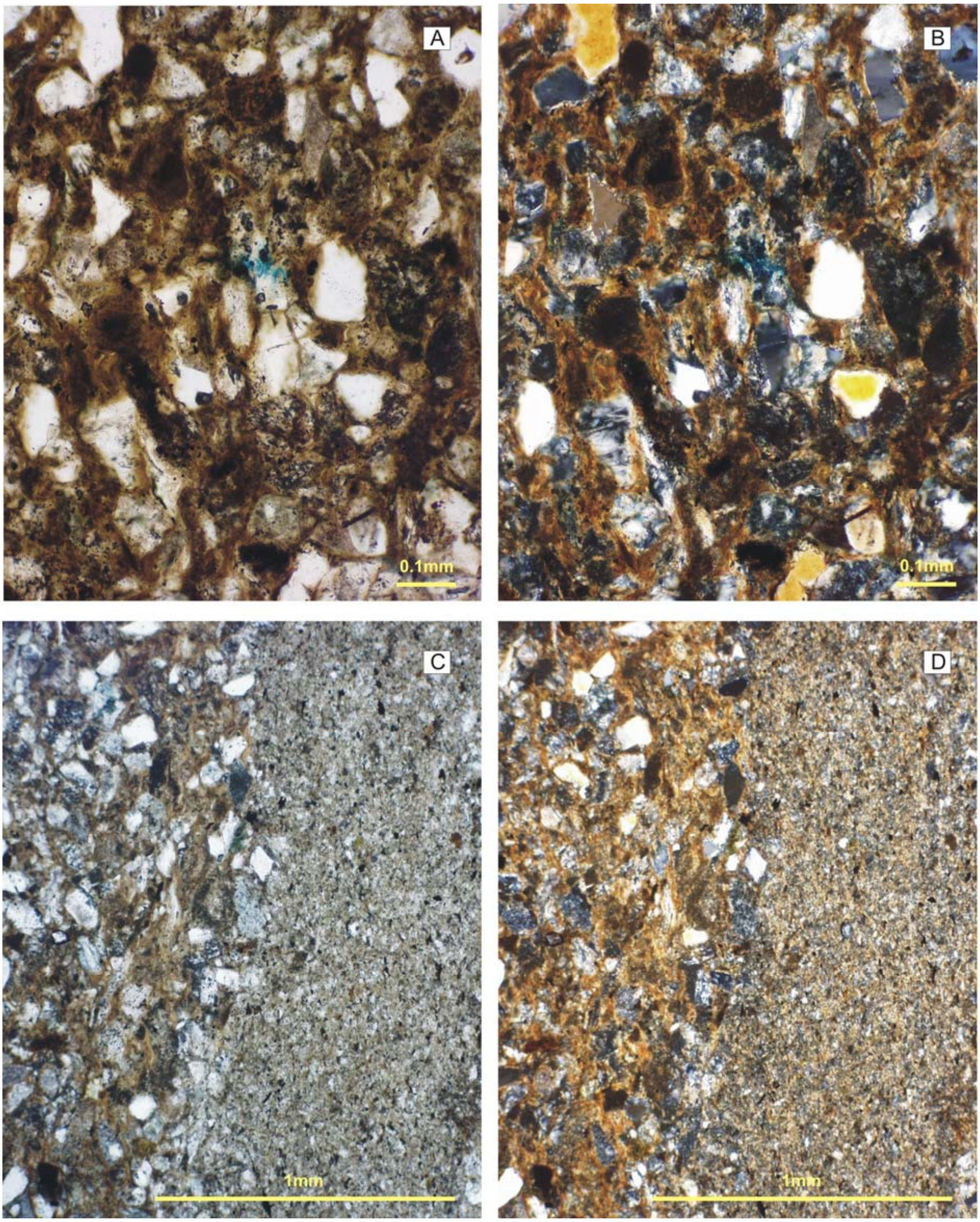


Figure 4.19
Thin sections showing the very variable character of Unit V sediments, in plain light (A, C) and with crossed polars (B, D). Very fine-grained, matrix-dominated sediments occur interlaminated with framework-dominated silts and fine sandstones. Quartz and feldspar are the dominant framework grains. The coarse-grained sediments are surrounded by kaolinitic matrix with ferruginous staining (A, B). Minor secondary porosity occurs within the coarse sediments from dissolution of feldspar.

4.6 Unit IV

Description

Unit IV is dominated by siltstone and mudstone, with minor sandstone interbeds. The mudstones are massive or laminated with common bioturbation and some coals. Ripple cross lamination, slumping and local climbing ripples are present within the coarser-grained sediments (Montague 1989). The SP log is generally uniform in character and implies an overall coarsening-upward trend in some wells. The sediments are fine-grained with only minor deflections on the SP log from sand interbeds (Fig. 4.7). Unit IV is associated with the *P. notensis* palynological zone.

Sediments within Unit IV are relatively homogeneous in core and cuttings. At a smaller scale, the sediments are fine-grained and matrix-dominated with floating framework grains surrounded by chlorite-rich clays and illite (Figs 4.20, 4.21). There is no visible porosity (Fig. 4.20). Quartz and feldspar are the dominant minerals, and minor amounts of kaolinite and chlorite are present in both core and cuttings (Appendix A). Calcite is common in some intervals and is surrounded by illite matrix (Figs 4.20, 4.21). Smectite is present in several samples, with a particularly broad XRD-peak occurring in a core sample from Geltwood Beach-1 (Appendix A).

Interpretation

The abundance of laminated and massive mudstones suggests deposition under relatively quiet conditions. Fine-grained sediments combined with coals and organic material, as wells as the presence of climbing ripples, suggest deposition in a floodplain-dominated environment.

4.7 Unit III

Description

Unit III is dominated by medium to coarse siltstone interbedded with shale and thin sandstones. The siltstone commonly occurs at the bottom of a fining-upward sequence with an erosive base, trough cross bedding, climbing ripples and mud rip-up clasts, and grades into mudstone with thin siltstone interbeds and planar cross bedding. Soft-sediment deformation and escape-structures are abundant within the finer-grained intervals. Bioturbation and organic matter are common, and root traces occur within some sections. The unit typically occurs within the *C. striatus* palynological zone. Unit III is associated with a distinct log-

Eumeralla Fm Unit IV
Mocamboro-11 Core 617.7m

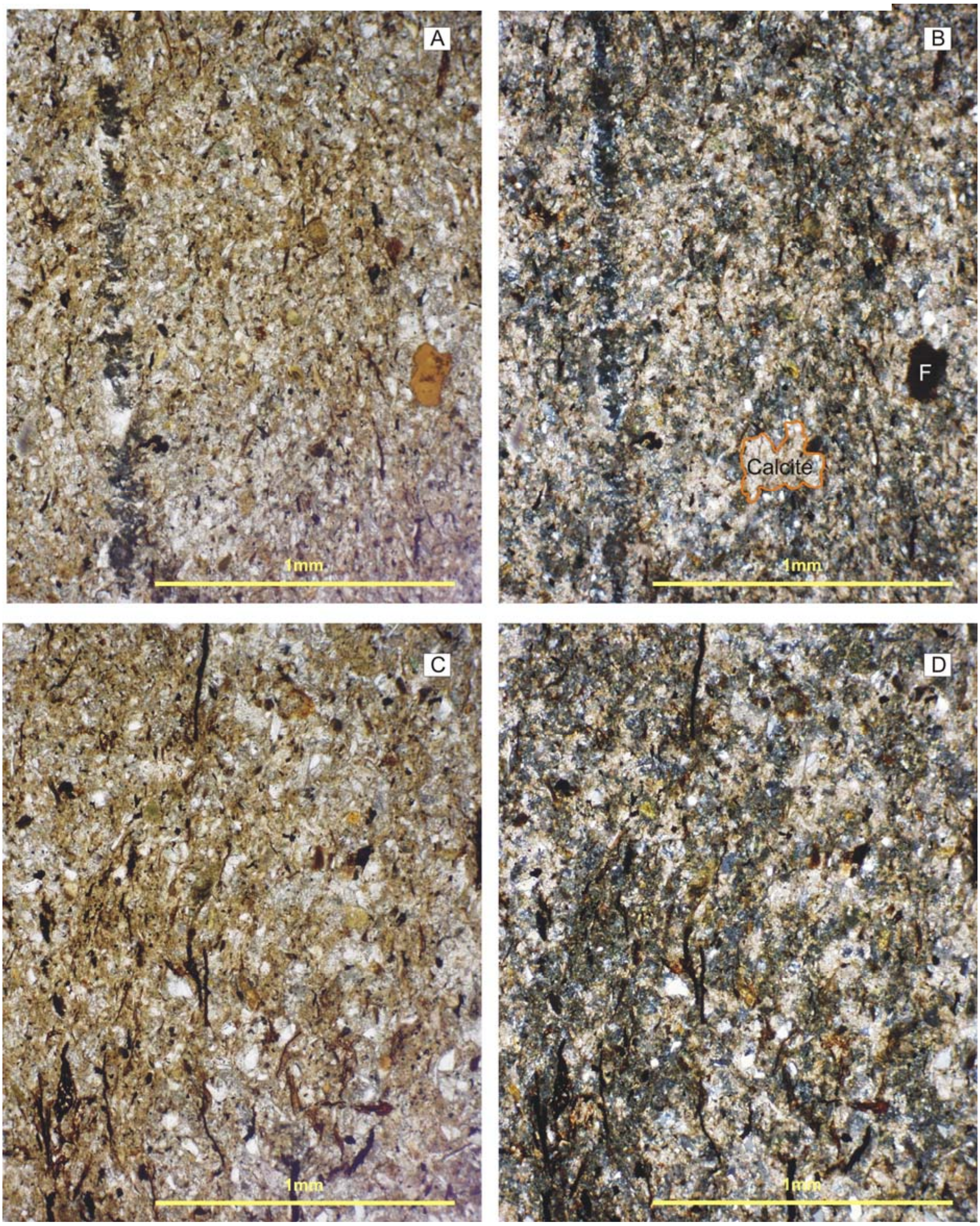


Figure 4.20
Thin sections from Eumeralla Formation Unit IV in plain light (A, C) and with crossed polars (B, D). The sediments are fine-grained and matrix-dominated. Floating framework grains are surrounded by chlorite-rich clays. Quartz is the dominant framework grain, and minor feldspar is present. Calcite occurs as patches of light brown to gray minerals (B, D). Carbonaceous material occurs as elongated, sub-parallel specs. A large piece of basal mica is present (A, B). The sediments are moderately sorted, and there is no visible porosity.

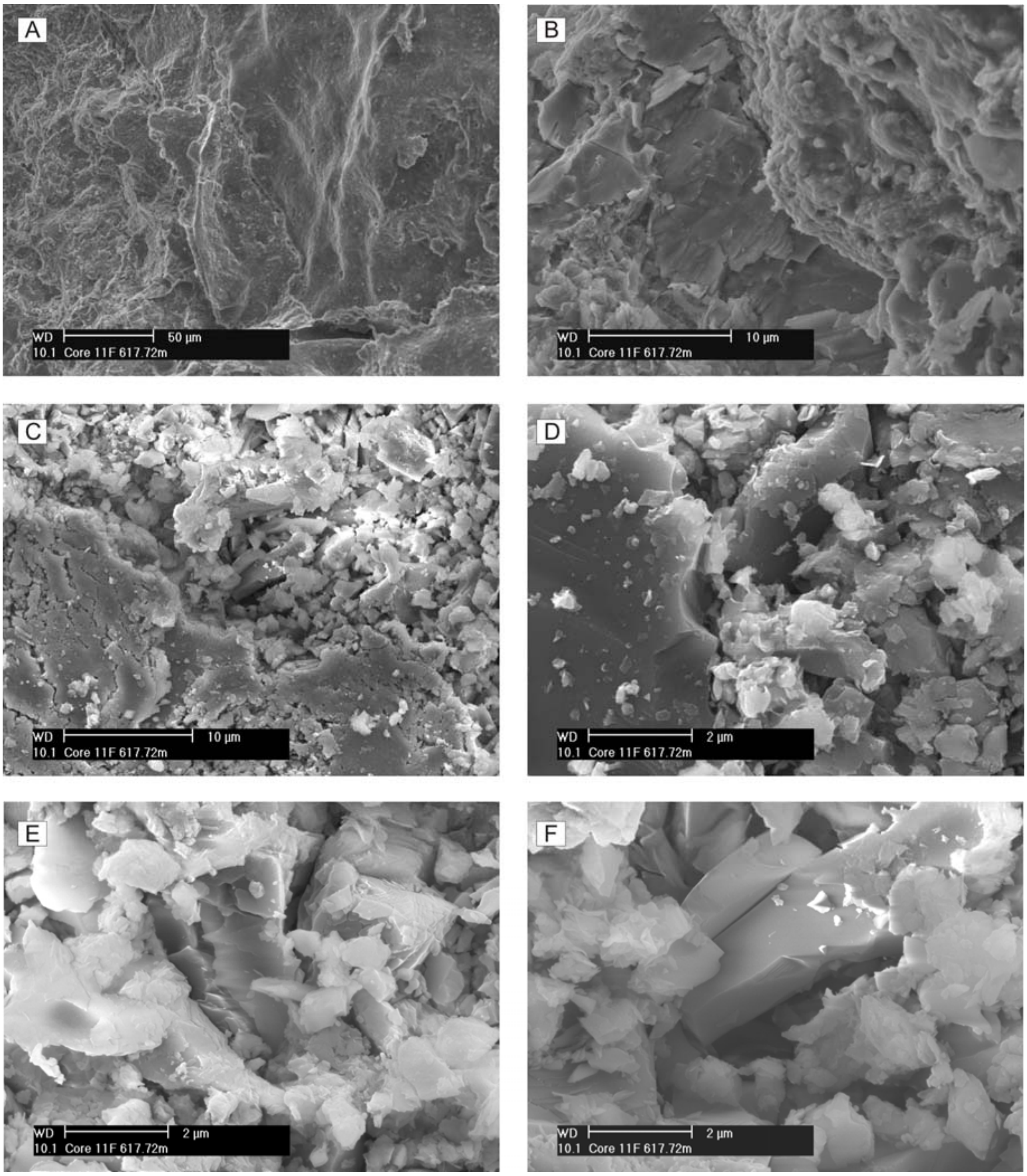


Figure 4.21 SEM images from a coarse siltstone within Unit IV in Mocamboro-11. Framework grains are surrounded by clay-dominated matrix (A). Some remnant mica is present (B). Illite is well developed and is surrounding framework grains (C, D, E). Calcite occurs as blocky cement surrounded by mixed-layer illite-smectite (F).

response (fast sonic, high density, high neutron, high resistivity, low gamma) in several Otway Basin wells (Crayfish-1A, Digby-1, Mocamboro-11 in Fig. 4.7a).

The sediments are dominated by quartz and feldspar, with minor amounts of kaolinite, illite, chlorite and smectite (Appendix A). Calcite occurs within some siltstones (Appendix A). Fine-grained, matrix-dominated sediments containing floating quartz and feldspar framework grains dominate the sediments. The sediments are poorly sorted and have a high porosity within the coarse-grained sediments surrounding the mud rip up clasts (Fig. 4.22).

Interpretation

The *C. striatus* zonation is associated with a non-marine environment, with rare algal acritarchs indicating lacustrine influence (Morgan 1991). Fining-upward sequences suggest deepening and the presence of density currents, together with the occurrence of escape-structures, indicates a lacustrine environment. Common sandstone interbeds and the presence of root traces suggest that water depths were fairly shallow.

4.8 Unit II

Description

Eumeralla Formation Unit II consists of numerous sandstone packages interbedded with siltstones and mudstones. Some of the sandstone bodies are up to 25 m thick, but generally have a thickness of about 10-15 m (Montague 1989). Mudstones are dominant within the lower part of the interval, while coal seams and laminations are present throughout. Bentonitic shale, glauconite and pyrite are present in cuttings. The siltstones occur as both thin interbeds and as approximately 1 m thick fining-upward sequences within the mudstone. Trough cross bedding, planar cross bedding and mud rip-up clasts are common within the sandstones and siltstones. All lithologies have a high organic content, and root traces are abundant within the mudstone. SP log deflections show the sandy nature of the interval, which has an overall coarsening upward trend (Fig. 4.7). Fast sonic spikes are common at the bottom of the unit (Fig. 4.7). Unit II generally occurs within the *C. paradoxa* palynological zone.

Unit II sediments are dominated by quartz and feldspar, and contain minor amounts of kaolinite, illite, chlorite and smectite (Appendix A).

Eumeralla Fm Unit III
Mocamboro-11 Core 328.2m

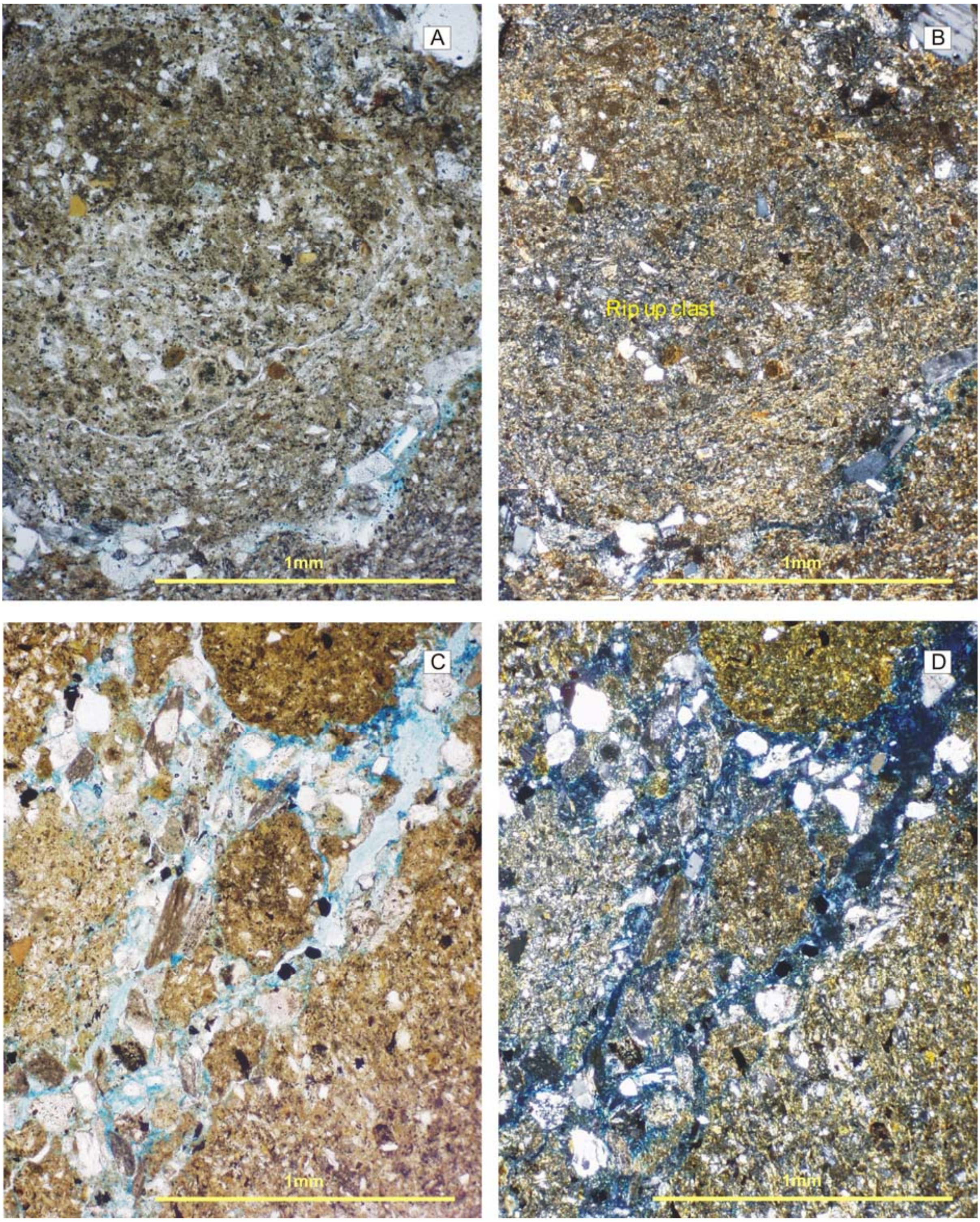


Figure 4.22
Thin sections from a siltstone, which commonly occurs within Eumeralla Formation Unit III, containing mud rip up clasts, in plain light (A, C) and with crossed polars (B, D). The sediments are very poorly sorted. Fine-grained, matrix-dominated sediments containing floating quartz and feldspar framework grains dominate the sediments. These are mud rip up clasts, and are surrounded by much coarser-grained framework grains of quartz and feldspars. There is no visible porosity within the mud rip up clasts. High porosity occurs within the coarse-grained zones between the rip up clasts, and along the outer margin of individual mud rip up clasts.

Interpretation

The *C. paradoxa* zonation is associated with a fluvial non-marine environment (Morgan 1992). Rare algal acritarchs are present in some wells, indicating minor lacustrine influence (Morgan 1992). The sandstone bodies represent stacked or individual fluvial channel deposits, whereas the finer-grained sediments with root traces are associated with quieter conditions within the floodplain. Coals developed within abandoned channels and shallow lakes. Multiple variations in sediment stacking patterns result from alternating deposition of crevasse splays, fluvial channels deposits and fine-grained floodplain and lacustrine sediments. A general coarsening-upward trend suggests decreasing subsidence or increasing sediment supply up-section. Unit II comprises the thickest Eumeralla section, and was deposited in multiple fining-upward and coarsening-upward sequences.

4.9 Unit I

Description

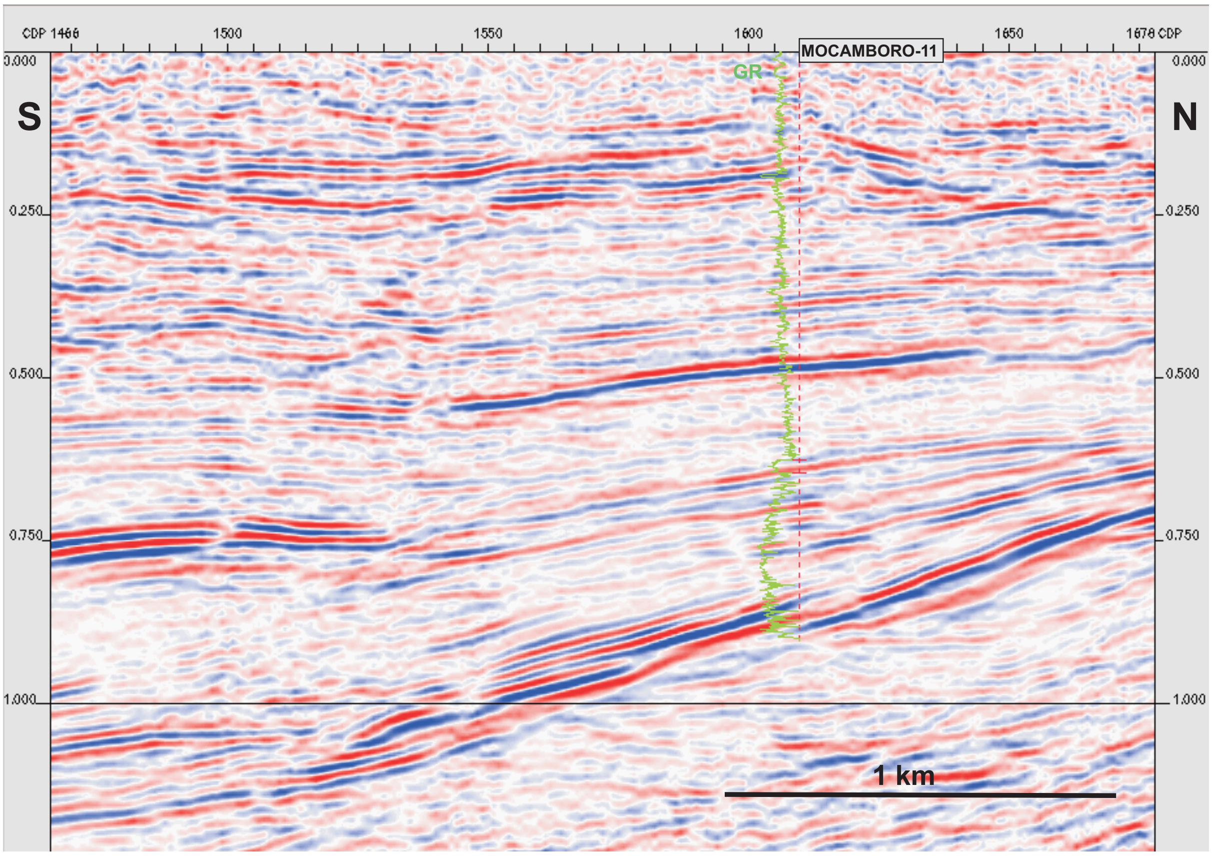
Mudstones and siltstones dominate Unit I, and only minor fine-grained sandstones are developed. The siltstones are planar and ripple cross laminated with slump structures and minor undulating stratification (Montague 1989). The mudstones are commonly massive with some lamination and bioturbation. Coaly detritus is abundant. The interval has a very uniform GR and SP log response with no marked deflections on the SP log (Fig. 4.7), and is associated with the *P. pannosus* palynological zone.

Interpretation

The presence of dinoflagellates and rare spiny acritarchs within the *P. pannosus* zone indicates brackish conditions (Morgan 1988). Marine influence has been documented in the upper Eumeralla Formation (Bao 2002), while non-marine environments are indicated in some wells by abundant and diverse spore-pollen and an absence of saline indicators (Morgan 1990; Morgan & Hooker 1993). The interval represents estuarine conditions with some lacustrine and fluvial influence, an interpretation supported by Montague (1989).

4.10 Seismic Facies

Unit VI and the shallow lacustrine sediments commonly developed within the lower part of Unit V have a distinctly bland seismic signature (Fig. 4.23). The coals within Unit V produce very strong seismic reflections that are easily recognisable throughout the basin (Figs 4.23). The floodplain sediments of Unit IV give a bland seismic signature and discontinuous



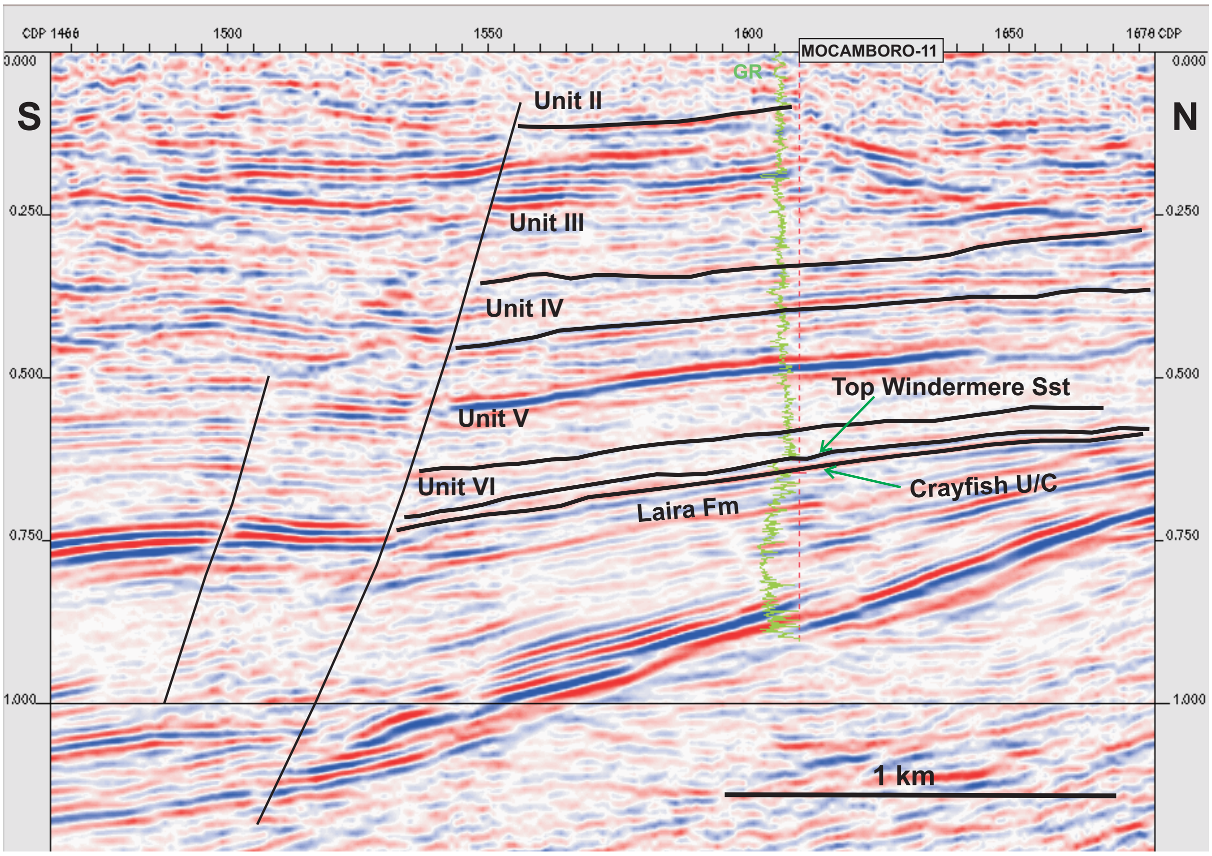


Figure 4.23 Seismic character of the various Eumeralla Formation facies on seismic line omn93a-14 without interpretation (top) and with interpretation (bottom). The full extent of this seismic line is shown in Figure 4.27.

reflectors, as this interval is less coal-prone than Unit V (Fig. 4.23). Very strong and variable reflectors occur within the shallow lacustrine sediments of Unit III (Fig. 4.23). The interbedded sandstones and shales of Unit II give relatively strong and continuous reflectors, while Unit I typically gives very discontinuous reflectors.

4.11 Discussion on Eumeralla Facies

4.11.1 FACIES INTERPRETATION

Unit II was interpreted by Montague (1989) to represent a deep lacustrine interval with lake water depths ranging between 20-40 metres. With additional and more recent well data and palynology available, this interval has been re-interpreted to represent a floodplain environment (Section 4.8). Thick sandstone packages and coal seams and laminations are common, and abundant root traces are present within the mudstone in core (Appendix B).

The distinct log response of the shallow lacustrine Unit III is associated with sandstones and coarse siltstones containing abundant light to medium grey coloured grains that are highly reactive to hydrochloric acid. Thin sections and XRD-analysis suggest this represents concretions of calcite-cemented sandstone. Carbonate concretions of varying sizes are well known from Eumeralla Formation outcrops in Victoria, and have been described by several authors as an early diagenetic mineralisation (Duddy 1983; Watson et al. 2004). The calcite cementation is typically associated with thin sandstone interbeds, and its distinct log signature and abundant occurrence within Unit III aided facies interpretation and correlation between wells.

Eumeralla Formation Unit VI was recognised by Boult (1996) and Boult et al. (2002) based on the occurrence of massive claystones within the basal Eumeralla Formation, as well as an absence of the algae *Microfasta evansii*, in several Otway Basin wells. The occurrence of the algae *M. evansii* was previously assumed to be an indicator of the Laira Formation, but is possibly more indicative of general lacustrine shallow water conditions than of a specific stratigraphic interval (Morgan, pers. comm. 2001). In the Penola Trough, *M. evansii* persists up into the lower Eumeralla Formation and is therefore not a definitive indicator of the top of the Crayfish Group (Price 2000). Boult et al. (2002) suggested that the absence of *M. evansii* within the basal Eumeralla Formation might indicate that a deeper lacustrine environment was developed here. However, variations in palynoforms between the investigated wells suggest that Unit VI is not necessarily associated with an absence or presence of *M. evansii*.

Unit VI and the shallow lacustrine sediments of the lower Unit V were interpreted as two separate facies despite their very similar seismic character (Fig. 4.23). Based purely on seismic data, these intervals could easily be mis-interpreted as representing the same facies. However, other types of data must also be considered. Unit VI typically has a higher GR log response than Unit V (Fig. 4.7a). Within Unit VI, the finest-grained sediments, reflected by a very high GR log response, occur at the bottom of the unit and the sediments have an overall coarsening upward trend (Fig. 4.7a). Investigation of core and cuttings was needed to initially recognize these intervals as two separate facies, and later microscopic investigations confirmed this interpretation.

4.11.2 FACIES DISTRIBUTION

The Eumeralla Formation Units I-V are regional intervals that are correlatable throughout most of the Otway Basin. Unit I is absent in some wells due to erosion, and is difficult to correlate between wells because of the limited palynology available from this interval. Unit I is very limited both in the troughs and on the highs, and can be differentiated from the underlying Unit II by its relatively constant GR and SP log signature (Fig. 4.7). The floodplain sediments of Unit II constitute the thickest Eumeralla Formation interval, and are several hundred meters thick in all South Australian wells (Fig. 4.7). Unit II is poorly developed in the Victorian wells (Digby-1 and Mocamboro-11), where the shallow lacustrine sediments of Unit III are more dominant (Fig. 4.7). Unit III sediments thin over the highs and are best developed in some of the offshore wells and in Victoria (Fig. 4.7). Unit IV sediments are generally best developed within the troughs and thin over the highs, very similar to the underlying Unit V sediments (Fig. 4.7).

Unit VI occurs more locally. Coal-beds representing floodplain conditions occur at the base of most wells, and no Unit VI deep lacustrine environment is developed. Unit VI is not developed in the central Penola Trough and Robe Trough, and has only a limited extent in the South Australian Otway Basin (Fig. 4.24).

Unit VI is well developed in Mocamboro-11 (Figs 4.7, 4.24), which is located on the flank of the Merino High in the onshore Victorian Otway Basin. A 78-meter thick succession is

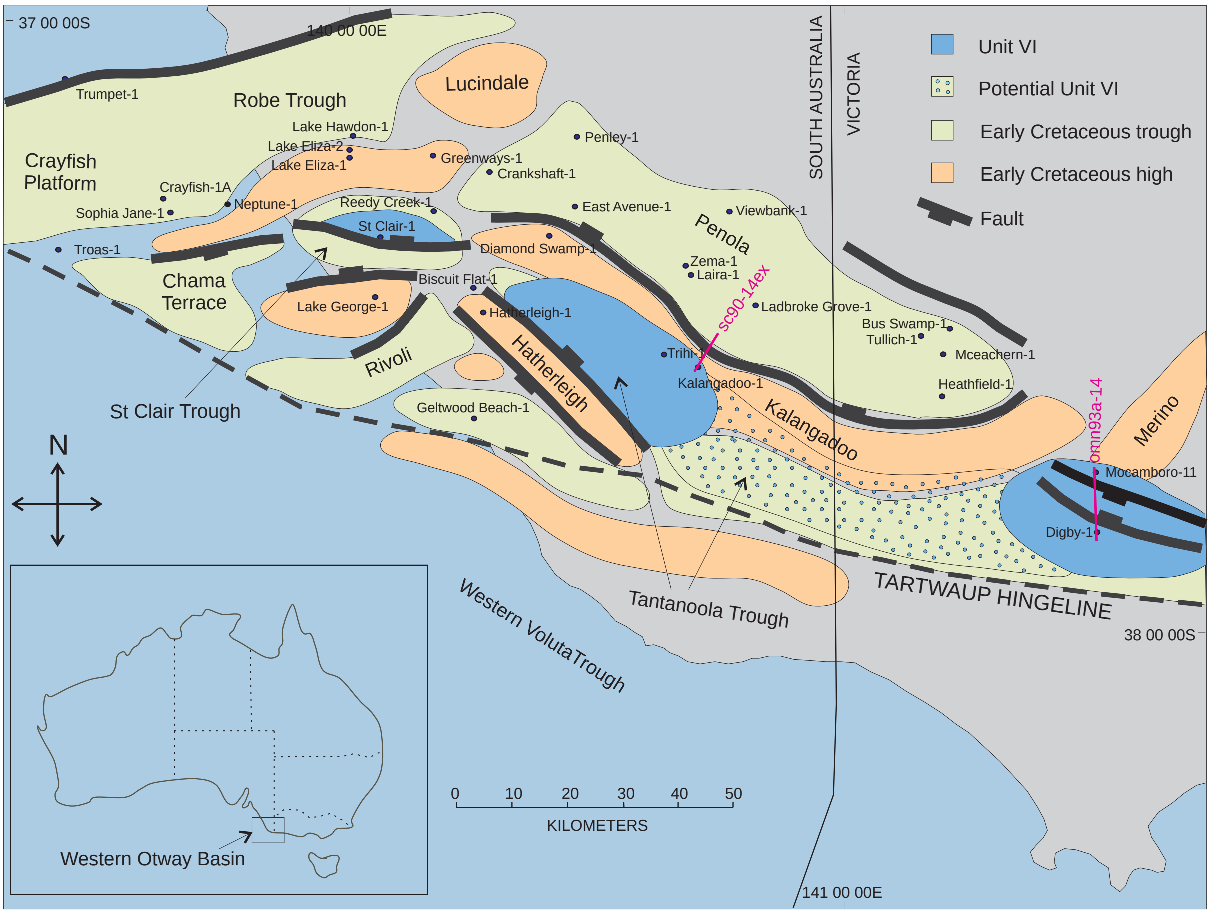


Figure 4.24 Conceptual map showing possible distribution of Eumeralla Formation Unit VI and approximate locations of seismic lines omn93a-14 and c90-14ex.

present in Mocamboro-11 and can be correlated across to Digby-1 eleven kilometres to the south. Digby-1 is located at the junction of the Ardonachie Trough and an eastern extension of the Tantanoola Trough (Fig. 4.24). The presence of Unit VI in this well could imply that the interval is developed throughout the Tantanoola Trough, where there is no seismic coverage and no wells have been drilled.

A smaller section of Unit VI is possibly developed on Kalangadoo High, just north of the western Tantanoola Trough. Its thickness is below seismic resolution, and no seismic lines extend far enough into the trough to fully evaluate its potential.

A 39-meter thick interval of Unit VI is present in St Clair-1 (Fig. 4.7), located centrally in the St Clair Trough (Fig. 4.24). However, the interval is absent in the nearest well, Reedy Creek-1, located approximately eleven kilometres to the northeast (Fig. 4.24).

4.11.3 DEPOSITIONAL MODEL UNIT VI

Unit VI was expected to be better developed offshore and in the troughs (Boult 2002/03), as these areas are more likely to provide accommodation space for deep lakes to develop. Unit VI was identified in four wells, located centrally in a trough, on a high, in the junction of two troughs and on the flank of a high (Fig. 4.24).

The main fluvial drainage during deposition of the Crayfish Group was towards the west (Gravestock et al. 1986; Montague 1989). A continued westward drainage during Eumeralla Formation deposition led to ponding and lake development on the hanging wall blocks of the NW-SE trending faults. The similar orientation of structural grain and main drainage direction indicates that the lower Eumeralla Formation sediments most likely were deposited during axial drainage of the half-grabens (Fig. 4.25). No thick alluvial fan deposits have been found within the Crayfish Group, and axial drainage dominated over local transverse drainage within the main troughs (Jensen-Schmidt et al. 2002). Deposition of Unit VI occurred in a late rift to early sag phase in zones of maximum subsidence along the main faults. Shallow lacustrine conditions with some fluvial channel sands and coals dominated within the larger floodplain, while fine-grained, lacustrine sediments of Unit VI were deposited under quiet conditions along the main fault zones.

In the St Clair Trough, a relatively deep-water lacustrine environment developed in the zone of maximum subsidence adjacent to the major landward-dipping St Clair fault. A succession of massive claystone and siltstone of Unit VI was deposited here. Shallow lacustrine sediments of Unit V dominated on the trough margins and in areas away from the main zone of subsidence. These sediments are coarser-grained and more variable due to a stronger fluvial influence. The absence of Unit VI in Reedy Creek-1 and in the wells adjacent to the trough indicates that the lake system here was not very deep. Consequently, it is considered unlikely that the lake system within the St Clair Trough was deep enough to allow deposition of Unit VI south of the footwall block.

The southern limit of Unit VI within the western Kalangadoo High – Tantanoola Trough region is very uncertain. The top Crayfish Unconformity is seen on seismic to be deepening towards the south, and no major landward-dipping faults appear to be developed immediately south of Kalangadoo High (Fig. 4.26). A deep-water lacustrine system may have developed south of Kalangadoo High within parts of the western Tantanoola Trough (Fig. 4.24).

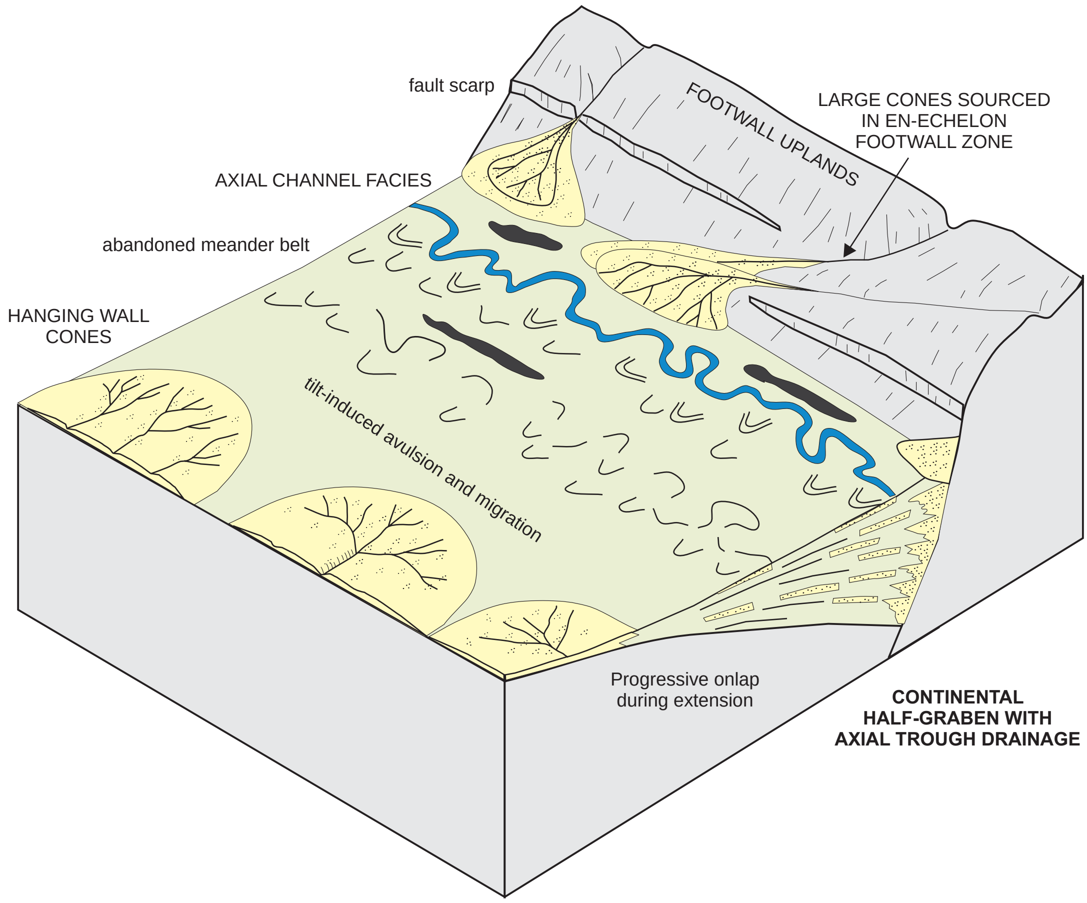


Figure 4.25 Model for continental half-graben rift basin with axial drainage. From Miall (1996) after Leeder & Gawthorpe (1987).

However, this is speculative as very limited data are available. The absence of Unit VI in Biscuit Flat-1, located on a terrace adjacent to the western Tantanoola Trough, suggests that Eumeralla lakes developed in the St Clair Trough and the Tantanoola Trough were not connected (Fig. 4.24).

Unit VI is better developed in Victoria than in South Australia. The main growth fault located just north of Digby-1 was activated early and its displacement is smaller than the displacement on the St Clair fault or the main Otway Basin trough-bounding faults (Fig. 4.27). The lake system was deep enough for deposition of Unit VI to occur south of the fault. No data are available to determine whether this lake system was connected to the western Tantanoola Trough – Kalangadoo High system (Fig. 4.24). Aburas & Boult (2001) interpreted seismic data from the Warrong Trough, a trough located further southeast in Victoria, and noted the occurrence of a relatively thick and extensive package of sediments with a very bland seismic signature. These sediments were overlain by the coal-rich Unit V facies, and indicate that the lacustrine Unit V and Unit VI sediments are better developed in the Victorian

Otway Basin. The thick interval of Unit III lacustrine sediments and the very minor development of Unit II in Mocamboro-11 and Digby-1 suggest that lacustrine conditions were more dominant in the Victorian Otway Basin (Fig. 4.7).

Unit VI could possibly be developed offshore on the Chama Terrace, in the offshore troughs and south of the Tartwaup Hingeline. No wells penetrate to the base of the Eumeralla Formation in this area, and very little is known about the extent of the troughs further offshore because of truncation at the Tartwaup Hingeline.

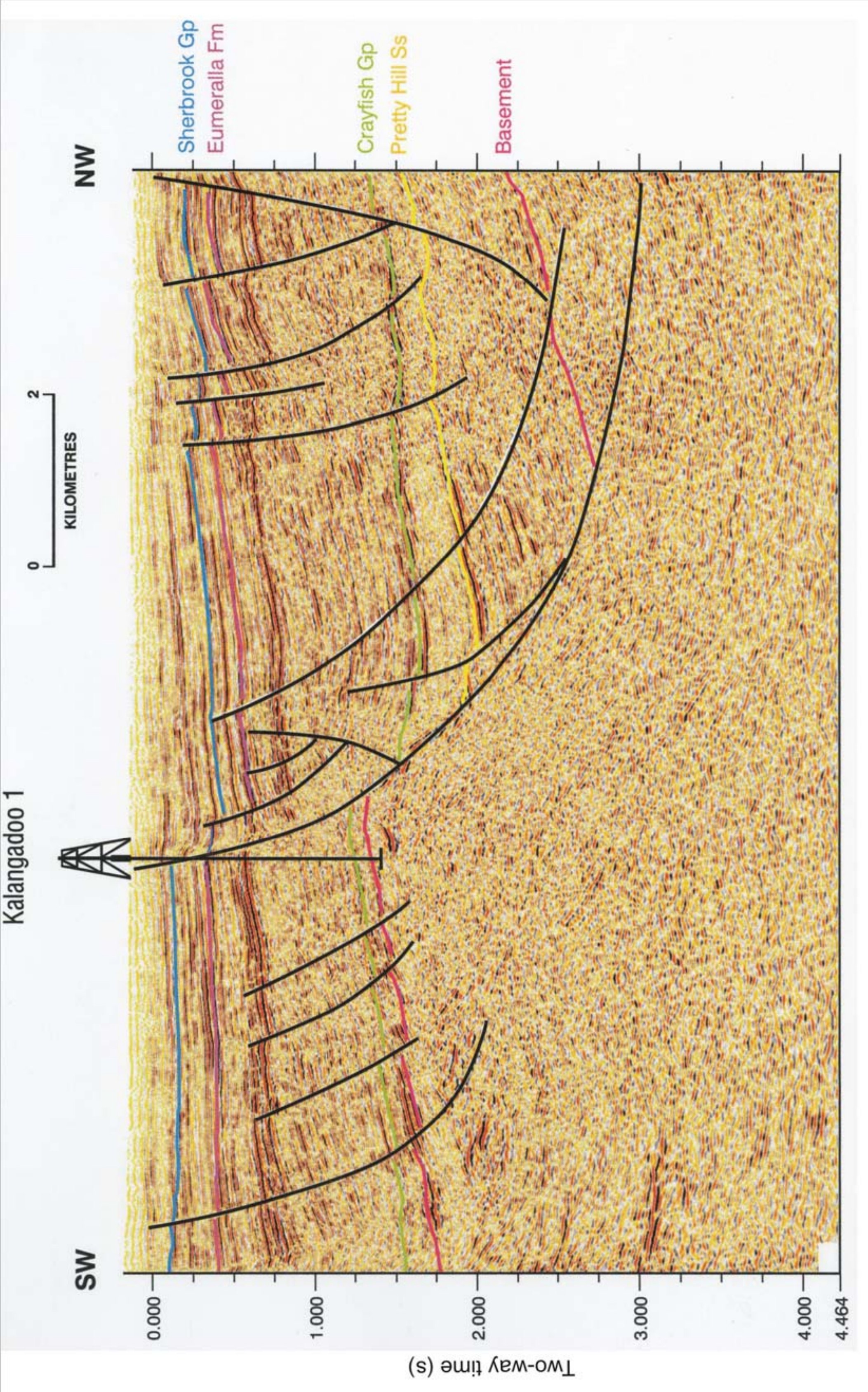


Figure 4.26 Eumeralla Formation Unit VI may be developed within parts of the western Tantanoola Trough. The top Crayfish Unconformity deepens towards the south, and no major landward-dipping faults are developed immediately south of Kalangadoo High. The location of seismic line c90-14ex is shown in Figure 5.5. From Boult & Alexander (2002).

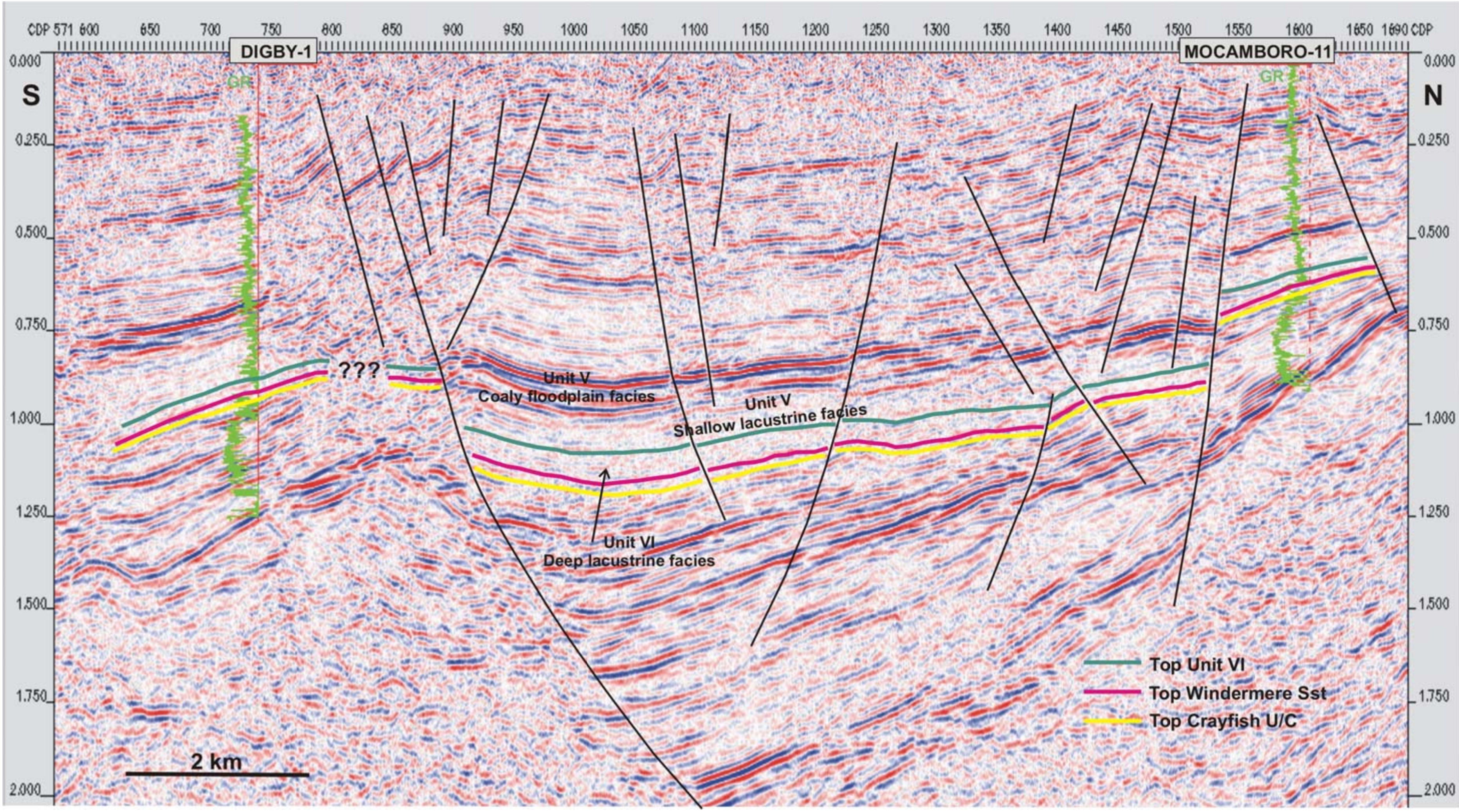


Figure 4.27 Seismic line omn93a-14 showing the half graben separating Digby-1 and Mocamboro-11 and the occurrence of Eumeralla Formation Unit VI south of the footwall block. Seismic line location is shown in Figure 5.5.