6 GEOLOGICAL STRUCTURE MAPPING

The subdued topography and general lack of geological exposure in the western Lake Eyre region make the recognition of evidence of neotectonics difficult. Outcrops of Tertiary sediments and exposures of Quaternary deposits are generally limited to alluvial channel banks. The majority of the channels are incised by about a metre into the surrounding landscape. Along the Neales River, however, significant incision has developed, exposing up to 20 m vertical sections of Quaternary and Tertiary sediments. Geological structures within these sediments were examined for evidence of neotectonic activity. These exposures were the basis of a climatological and palaeo-environmental reconstruction that used thermoluminescence dating to constrain the age of deposition of sedimentary sequences (Croke *et al.*, 1996, 1998). At their Section C (Figures 6.1, 6.2 & 6.3), Croke *et al.* (1996) observed a dolomitic outcrop of Etadunna Formation that appeared to be gently folded. They deduced that no primary lamination was visible within the massive dolomite and the influence of tectonic warping could not be distinguished from that of erosion.

6.1 NEALES CUTBANK

Approximately 1 km upstream of Section C, a bedding layer may be clearly distinguished within the otherwise massive Etadunna Formation. This bed is tilted and is truncated by the erosional surface that separates the Warmakidyaboo Beds from the underlying Etadunna Formation (Figures 6.3 & 6.4). Elsewhere evidence of deformation can be seen in the white, bedded layer of the Etadunna Formation (Figure 6.5). In the large canyon extending east of the Neales River (Location VWS005 on Figure 6.2) the white clay layer, interpreted as Etadunna Formation, is folded. The folded strata has been truncated by the overlying unconformable Warmakidyaboo Beds. From thermoluminescence dating along Section C, the Warmakidyaboo Beds are approximately 100–177ka (Croke *et al.*, 1998).

Measurements taken from the assumed bedding feature demonstrate that this bedding is mildly warped, dipping gently to the northeast in the northern part of the section and swinging gradually around and gently dipping to the southwest along the southern part of the section (Figure 6.2). The trend of the fold axis, interpreted between this change in dip direction, approximately corresponds to the trends of minor folds in the nearby canyon (Table 6.1 & Figure 6.5).

Table 6.1: Trend and plunge of folds at the Neales Cliff.

LOCATION	TREND	PLUNGE
Section C	319	01
VWS004	310	12
VWS005	343	18
VWS006	354	10

An equal-area projection of the poles of the measured bedding plane along this fold displays a general elliptical pattern consistent with a very open fold that is gently plunging (Figure 6.6). The calculated beta-axis corresponding to the fold axis is calculated as plunging sub-horizontally to the southeast.

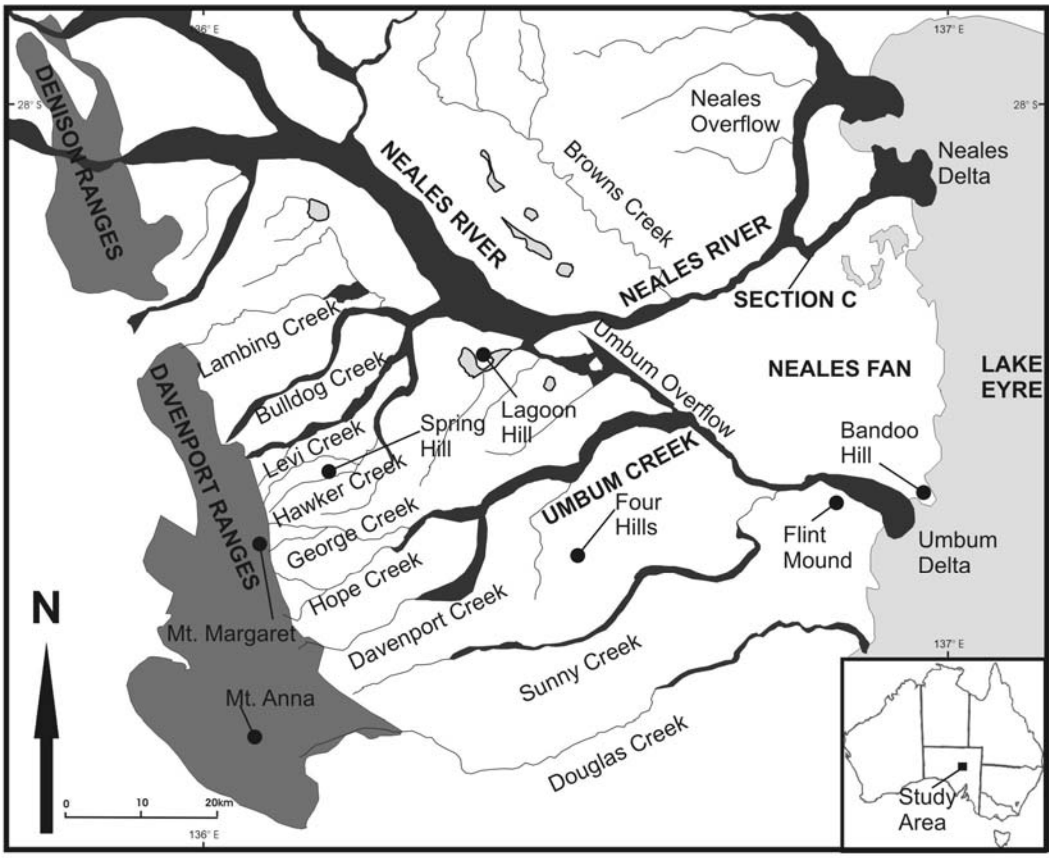


Figure 6.1: Location map showing the location of Section C at the Neales Cliff.

NOTE: This figure is included on page 6-3 of the print copy of the thesis held in the University of Adelaide Library.

Figure 6.2: Structural data showing folding in the Etadunna Formation plotted on an ASTER greyscale image. Croke *et al*. (1998) Section C is in the east of the image. Etadunna Formation bedding changes dip from east to west and small-scale folds gently plunge approximately northwest. See Figure 6.1 for location.

NOTE: This figure is included on page 6-4 of the print copy of the thesis held in the University of Adelaide Library.

Figure 6.3: Representative facies profile and TL chronology of Quaternary mainchannel fluvial (Warmakidyaboo Beds), lacustrine (Ghost Yard Beds) and aeolian sediments from the large meander bend at Section C. Facies are laterally continuous around the entire curvature of the bend. The basal deposits of Warmakidyaboo Beds directly overlie silicified deposits of the mid-Tertiary Etadunna Formation (from Croke *et al*., 1998).

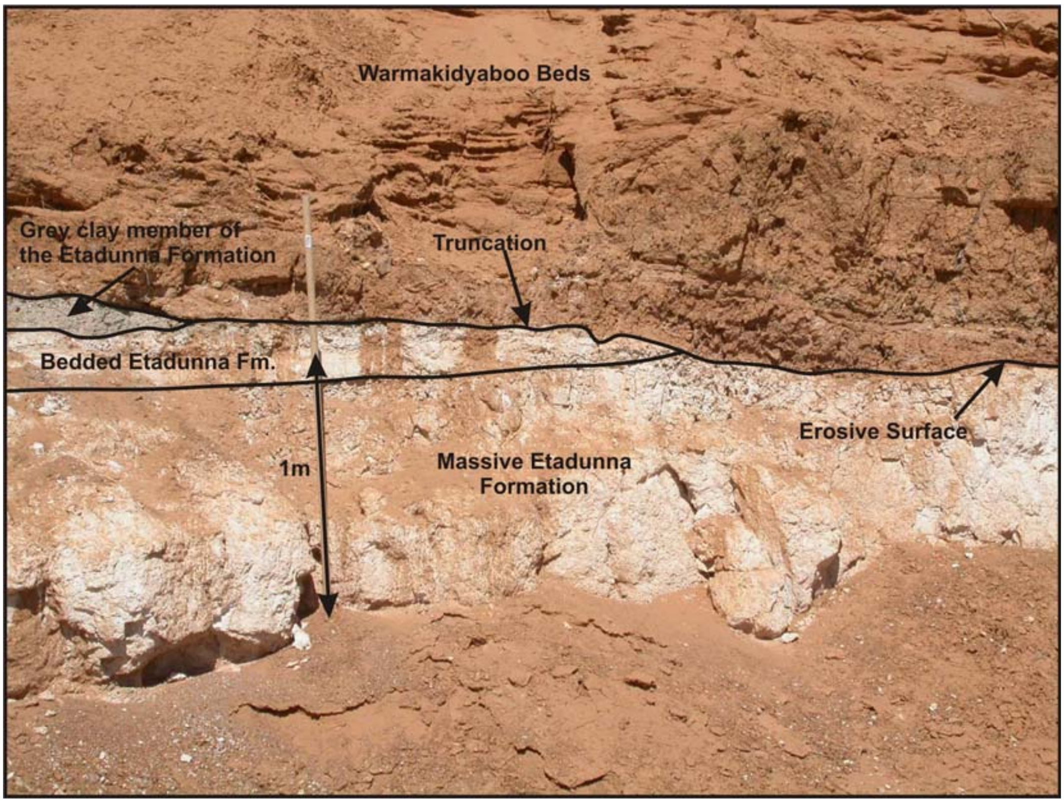
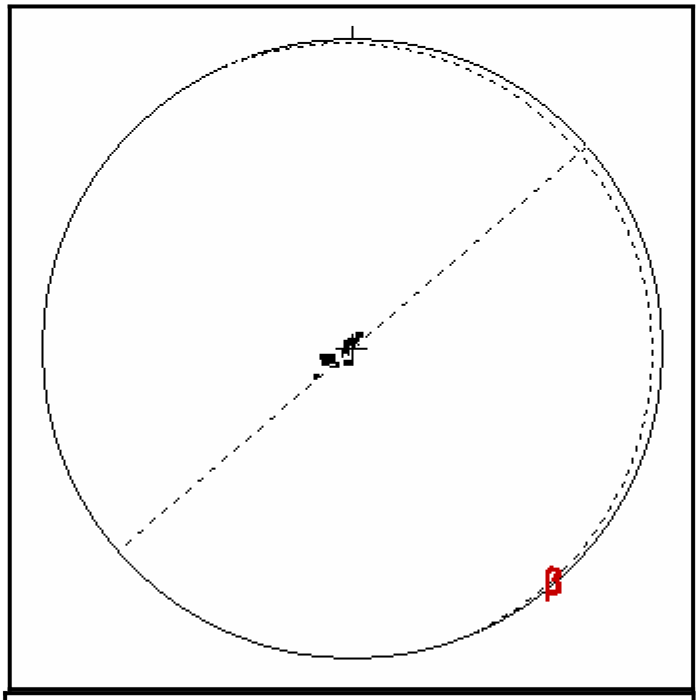


Figure 6.4: Bedding in Etadunna Formation truncated by unconformable Warmakidyaboo Beds, indicating possible deformation between the end of the Miocene and the Late Pleistocene. Location VWS002 on Figure 6.2 (0677491E 6884436N).

Figure 6.5: Folded white clay interpreted as the top of Etadunna Formation indicating post-Miocene deformation. Location VWS005 on Figure 6.2 (0678059E 6884324N).



Mean Principal Orientation = 336/4E
Mean Resultant dir'n = 4-066
Mean Resultant length = 1.00
(Variance = 0.00)
Calculated. girdle: 229/89N
Calculated beta axis: 1-139

Figure 6.6: Equal Area projection plot of assumed bedding planes in the Etadunna Formation showing poles plotted that equate to open, gently plunging folds. The calculated axis of the fold plots at 1º-139º.

Approximately 800 m upstream of Section C (Figure 6.2) is an exposure with discontinuous 'ramps' preserved in beds of the upper Etadunna Formation that are consistent with thrust deformation in a compressive stress regime (Figure 6.7). Associated with these ramps are fracture planes that extend several metres into the lower Ettadunna Formation. Attitude measurements taken from these planes are plotted as a rose diagram in Figure 6.8. The fracture planes fall predominantly into two main groups, a north-south trending set and an east-west trending set. These fracture orientations form a conjugate set of fractures and are consistent with resulting from a southwest-northeast compression.

Samples were taken from the lower massive Etadunna Formation, the bedded Etadunna Formation, the overlying grey clay unit and from the decollement zone. These were submitted for x-ray diffraction analysis.

Both samples taken from the Etadunna Formation have the same mineralogy of dolomite with minor quartz (possibly due to silicification) and trace amounts of mica. Significantly the dolomite is not subject to shrink-swell behaviour and therefore the deformation evident in the bedded layer may be attributable to tectonic processes. The mineralogy of the grey clay layer contains chlorite and consequently can facilitate shrink-swell behaviour. This would allow it to deform plastically around the more rigid beds of dolomite. Along the zone where these two layers interact there is brecciation. This can be seen by the presence of the subdominant and trace evaporite minerals halite and gypsum within the sample. These minerals are likely to have precipitated along fracture planes due to a combination of rainfall infiltration and aeolian processes.

Summary

Deformed bedding planes, small-scale folds and fracture systems indicate a compressive deformation event along an approximately southwest-northeast axis. This folding is not observed in the Warmakidyaboo Beds and constrains deformation between the end of the Miocene and 177 ka.

6.1.1 Lineaments on the Neales Fan

A lineament crosses the centre of the Neales Fan (Figure 6.9). It is associated with a sudden change in stream planform from relatively straight channels to a highly sinuous meander on both the Neales River and Umbum Creek (Figure 6.9). In addition, the Neales Overflow diverges from the main Neales River channel at precisely this location and flows parallel to this lineament. Since similar north-south trending lineaments are interpreted as faults elsewhere (Figure 3.1) it would be expected that a fault underlies this area and acts as a control on stream directions.

Within the Etadunna Formation there is strong evidence of neotectonic disruption. Marker beds have small thrust duplexes consistent with a compressional zone that is supported by the presence of shear-band deformation and fracturing. This is unconformably overlain by relatively flat-lying Pleistocene fluvial and lacustrine sediments. However, given the fault lineament may be active over a relatively small geological timeframe, it would be expected that flat-lying sediments, such as the Pleistocene lacustrine shale (Ghost Yard Beds) preserved in the sequence may display either mild warping or subtle tilting that would not be readily visible. Therefore, a survey utilising a total station theodolite (with an accuracy of ±0.0001 m) was conducted to measure the deformation observed in the Etadunna Formation and the Pleistocene shale (Ghost Yard Beds).

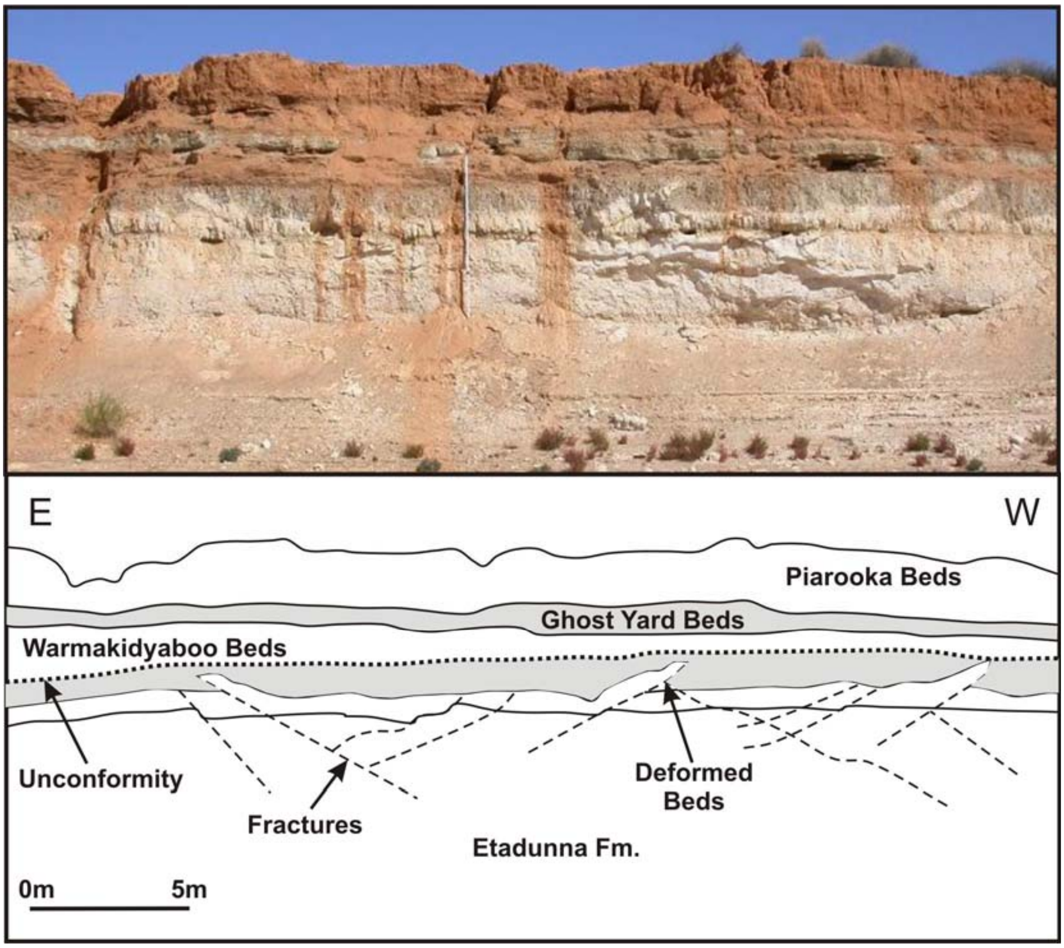


Figure 6.7: Thrusted bedding planes present at the top of the Etadunna Formation and associated fracture planes, indicating tectonic activity following the deposition of the Etadunna Formation. Location VWS001 on Figure 6.2 (0677897E 6884393N).

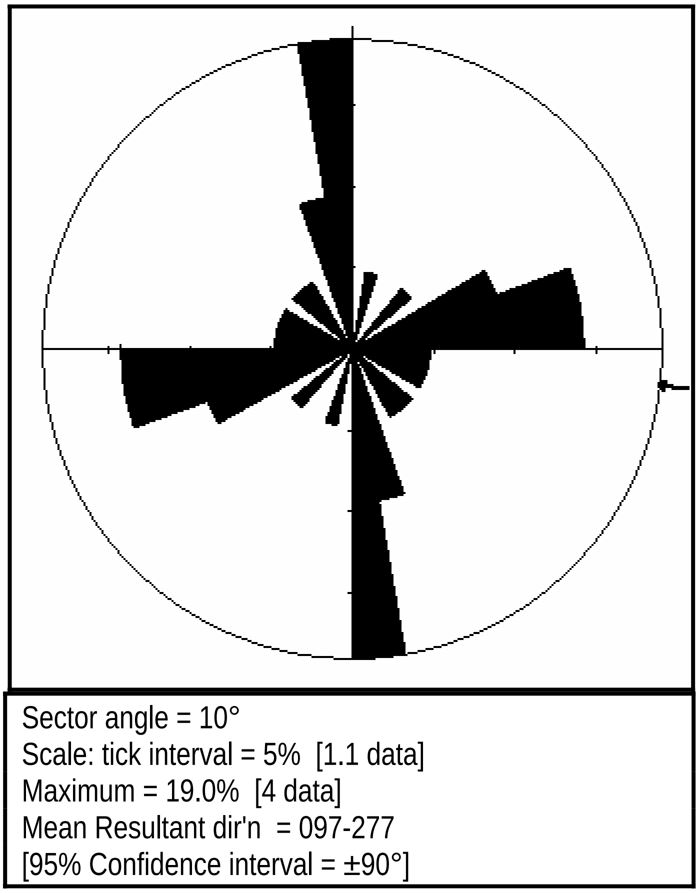


Figure 6.8: Rose diagram of observed fracture planes showing a conjugate set consistent with southwest-northeast compression.

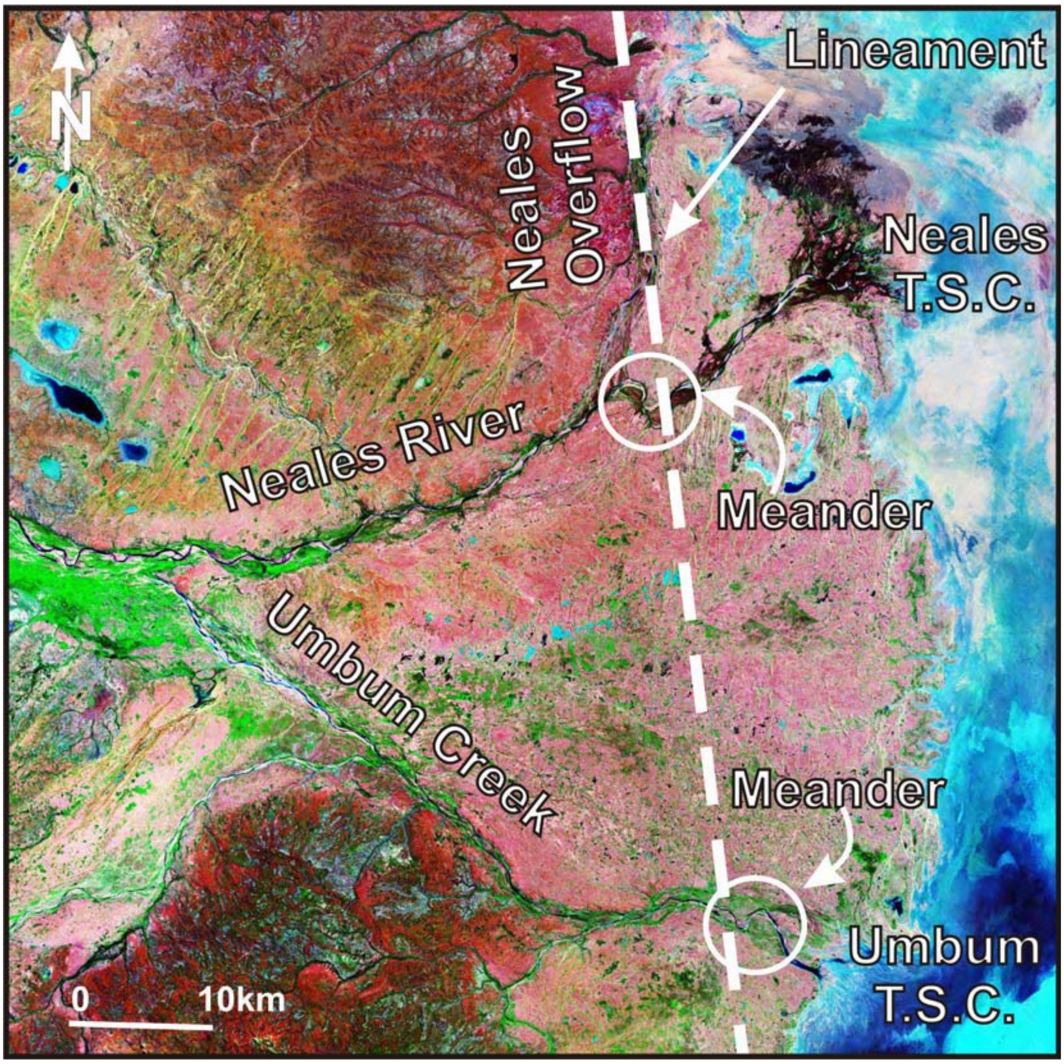


Figure 6.9: Location MAP of the Neales Fan showing the location of an inferred basement fault and associated meanders in the Neales River and Umbum Creek. Note that the Neales Overflow follows the same trend as the fault.

6.1.2 Survey Results

The Miocene Etadunna Formation is deformed at outcrop scale. This is reflected in the survey results (Figure 6.10) that show a monocline preserved in a marker horizon of the Etadunna Formation. The overlying Ghost Yard Beds display some irregularity in thickness. If this were due to folding in the shale, then the thickness of the unit would be maintained equally across the length of the unit. Instead, there is a fluctuation in the thickness of the shale that is attributed to sedimentary draping of underlying fluvial sedimentary structures. The Ghost Yard Beds do not show any signs of tilting. Over some 400 m, the elevation of this unit is maintained at approximately +2 m AHD. These observations indicate that the Pleistocene sediment has not been subject to neotectonic deformation.

Since no deformation can be seen in the Pleistocene sediment, folding does not seem to explain the meandering of the rivers. Therefore, three alternative models are proposed as possible mechanisms causing the meandering: climate, structure and lithology.

6.1.3 Climatic Control

Studies show that climate has fluctuated dramatically within the central Australian region during the Cainozoic with particularly strong, rapid swings in climate during the Pleistocene (Croke *et al.*, 1999; Nanson *et al.*, 1995). Of particular importance is the onset of aridity and dune formation at approximately 59ka b.p. (Croke *et al.*, 1996). At this time, it is possible that large dunes on the flanks of the Neales River developed and increased in size. With the Neales River altering from a perennial to an ephemeral river, it is conceivable that the main channel may have become 'choked' with migrating sand dunes. When flow intermittently resumed in the channel, it was unable to make a pathway through the sand dunes and took the path of least resistance around the dunes, forming the proto-morphology of the meanders left visible today. As climate became wetter in the latter Pleistocene more intense flows would have resumed in the Neales River. The sand dunes continued their migration and the ephemeral channel of the Neales River became unblocked as a result of sand shifting out of the channel and increased flows resuming along the now entrenched meander of the main channel (Figure 6.11).

6.1.4 Structural Control

North-south trending lineaments are interpreted as faults elsewhere in the region (Rogers & Freeman, 1993; 1996). If a fault underlies this area and acts as a control on stream planform, then where the Neales River crosses this fault a localised steepening of the stream longitudinal profile should occur. This steepening would result in the formation of a meander as the stream attempts to expend the extra energy it has gained by lengthening its flow-path (Holbrook & Schumm, 1999). The thalweg profile of the Neales River (Figure 6.12) shows that the gradient decreases across the lineament, inferring that this form of neotectonic structural control does not influence the development of the meanders. However, there is a rapid steepening along the meander reach that flows in a southerly direction (Figure 6.12). Topographic evidence from a regional 9-second DEM (AUSLIG/AGSO, 2003) (Figure 6.13) suggests that there is a possibility that very recent tectonic deformation has tilTed a narrow structural block. The river channel follows along the fault at the base of this block until it reaches a fracture, or zone of weakness, associated with the major lineament, whereupon it flows along the fracture, forming the 'meander' and continuing to flow along the trend of the adjacent fault (Figure 6.14). The faults in this model create zones of weakness that form gullies in the landscape, trending in a northeast-southwest direction. The movement on these faults is not apparent in outcrops as associated erosion and incision of the gully network tends to obliterate readily visible evidence of fault offset in this region.

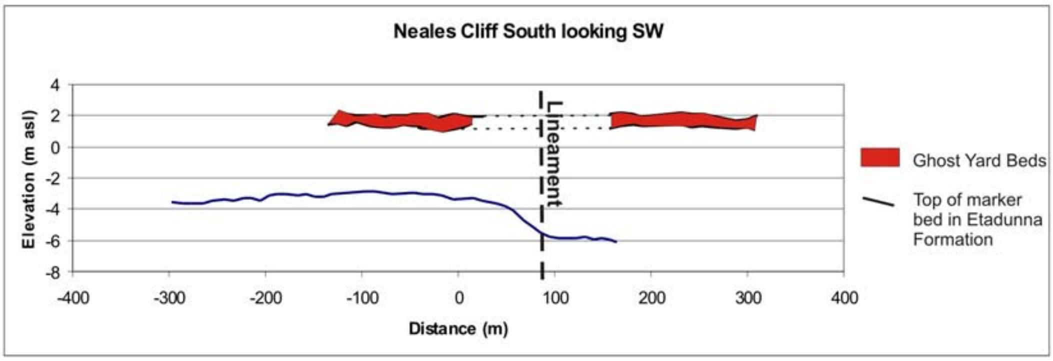


Figure 6.10: Total station survey of sediments exposed in the Neales River bank showing deformation of Miocene sediments (Etadunna Formation) and no detectable deformation of Pleistocene sediments (Ghost Yard Beds).

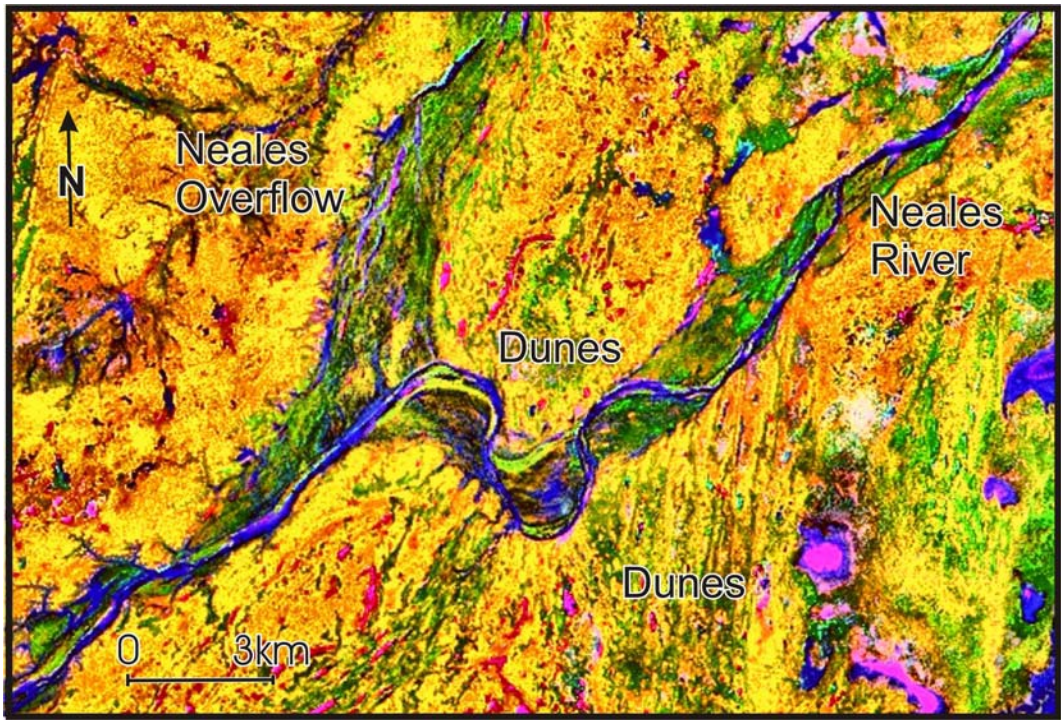


Figure 6.11: Landsat 5 TM image showing sand dunes formed on either side of the Neales River that may have blocked the channel as a result of the onset of aridity in Central Australia.

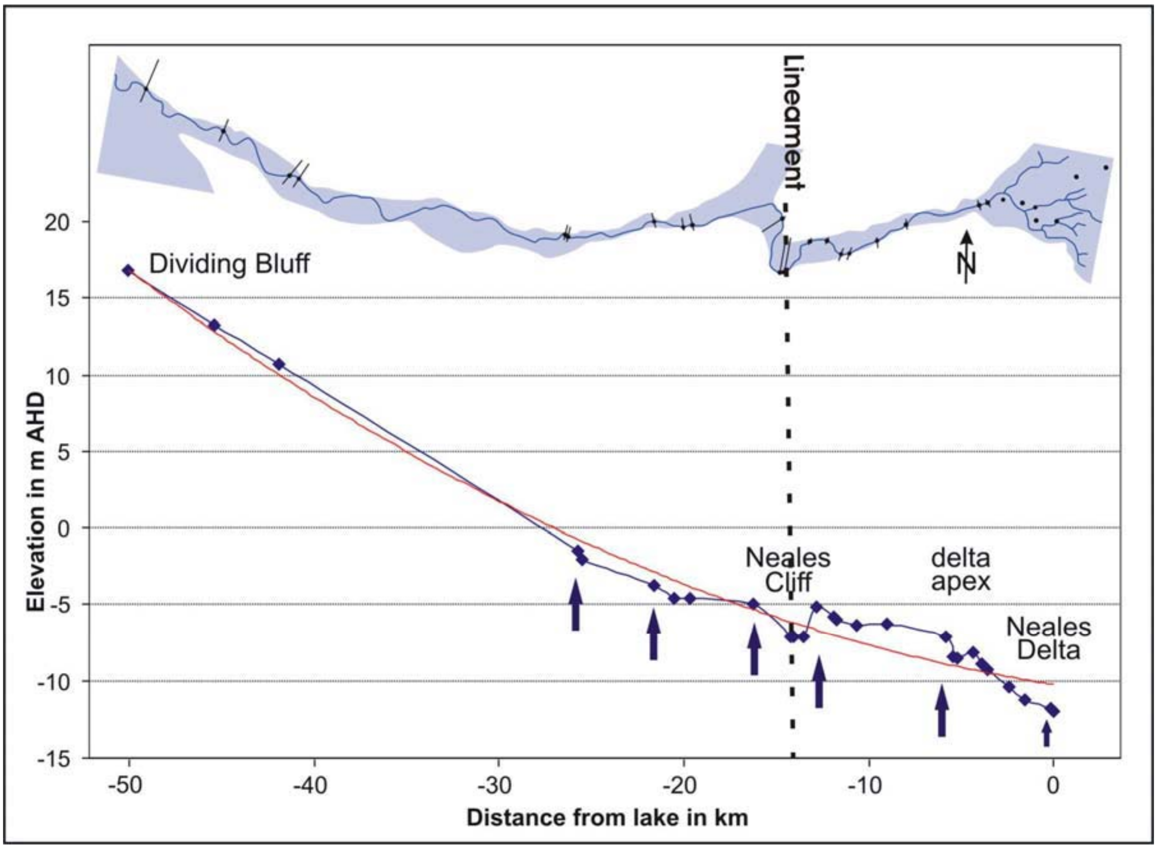


Figure 6.12: Thalweg profile of the Neales River showing the decrease in slope trend across the meander. Arrows indicate nick points in the fluvial profile cut during falls in base level.

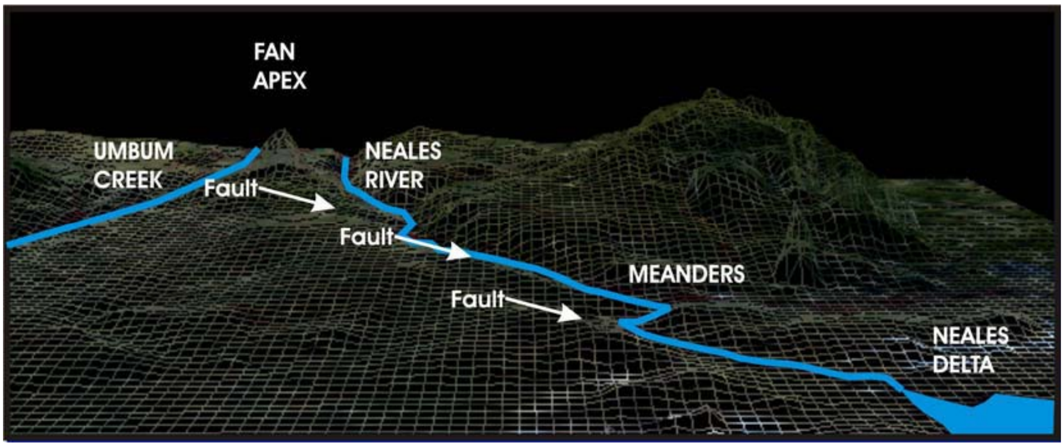


Figure 6.13: DEM wireframe image of landscape at x50 vertical exaggeration showing the locations of potential faults influencing flow along the Neales River meanders. The faults form a series of parallel, narrow blocks that are gently tilted to the southeast. The Neales River flows along the base of these fault-blocks until it reaches a fracture associated with the lineament. Here it follows the fracture and switches to the adjacent en-echelon fault.

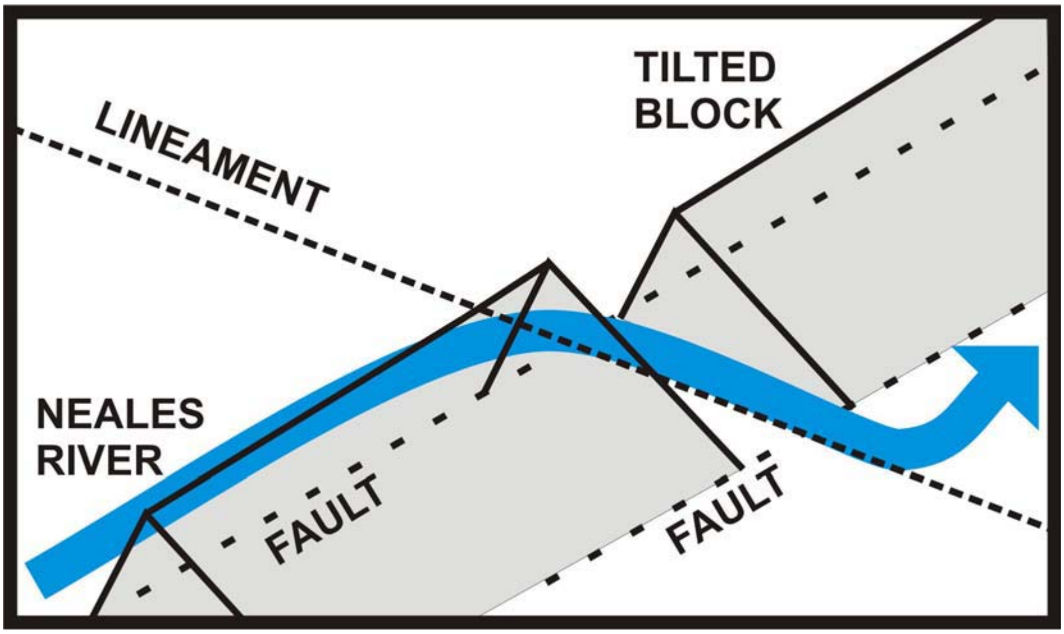


Figure 6.14: Conceptual sketch of structural control of streams by block tilting. The stream flows along the base of one fault block until it reaches a fracture associated with the lineament. The stream exploits this weakness and switches across to the adjacent fault.

6.1.5 Lithological Control

The thalweg profile of the Neales River was constructed from RTK-DGPS data (Figure 6.14). Results from this survey demonstrate that the trend of the thalweg profile decreases in slope at the point where the channel crosses the observed lineament (Figure 6.14). Since no tributary streams provide input upstream of this location, sediment load remains the same and mean discharge appears unlikely to change along this reach. The only observed change in the system is the lithology of the channel substrate. The Miocene Etadunna Formation is a lacustrine unit that extends from downstream to a position generally coincident with the observed lineament that crosses the Neales Fan (Figure 6.9). Upstream from this, the outcrop lithology consists of fluvial sandstones of the Eocene Eyre Formation. These are considerably more friable than the silicified mudrocks of the Etadunna Formation and are more readily eroded. It is therefore postulated that the change in induration of the substrate across this contact causes the stream to meander as it expends energy as lateral erosion rather than incision (Figures 6.15 & 6.16).

6.2 MODEL EVALUATION

It has been shown that each model proposed for the development of the fluvial pattern of the Neales River and Umbum Creek has its own strengths and weaknesses. Damming of channels via sand dune migration has been demonstrated to occur in other locations around the world (Langford & Chan, 1989; Loope *et al.*, 1995; Krapf *et al.*, 2003; Svendsen *et al.*, 2003). However, the lacustrine deposits that are generally associated with the damming of a channel have not been observed upstream of the proposed sand dune barrier. This may be explained here by flow redirection along the Neales Overflow during dune-damming of the main river course. Additionally, the sand dunes may have only partially impeded the river valley, resulting in the diversion of the flow around the base of the dunes. Later erosion may have removed evidence of dam-related deposits. The dune-dammed deposits would have been located at the same elevation as the dunes, presently 10 m above the contemporary river channel. Erosion may have stripped these sediments and they are no longer evident.

The readjustment of the landscape, reflecting underlying neotectonic rearrangement, explains the current geomorphology surrounding the Neales River meanders. In particular, it accounts for the steepening of the channel gradient along the southerly flowing reach. Structural control would also explain the straightness and the sub-parallel, but offset, trends of the reaches upstream and downstream of the meanders. A neotectonic model can also explain the en-echelon arrangement of topography across this region; however, no geological evidence such as faulting of Pleistocene sediments can be seen to validate this model.

The incision of the Neales River would imply that the meanders are an inherited feature. However, the Quaternary sands overlying the Etadunna Formation are readily eroded and would be susceptible to sapping and collapse as the channel moved laterally across the surface of the indurated Etadunna Formation. Therefore, the meanders do not need to form prior to the incision and have been preserved only after the channel incised into the silicified mudrocks of the Etadunna Formation.

It is possible that all of these factors in some way influence the development of the meanders. In this case, the opportunity to compare the models to similar large meanders formed in Umbum Creek, down-strike of the observed lineament (Figure 6.9), allow the determination of the most likely method of meander formation.

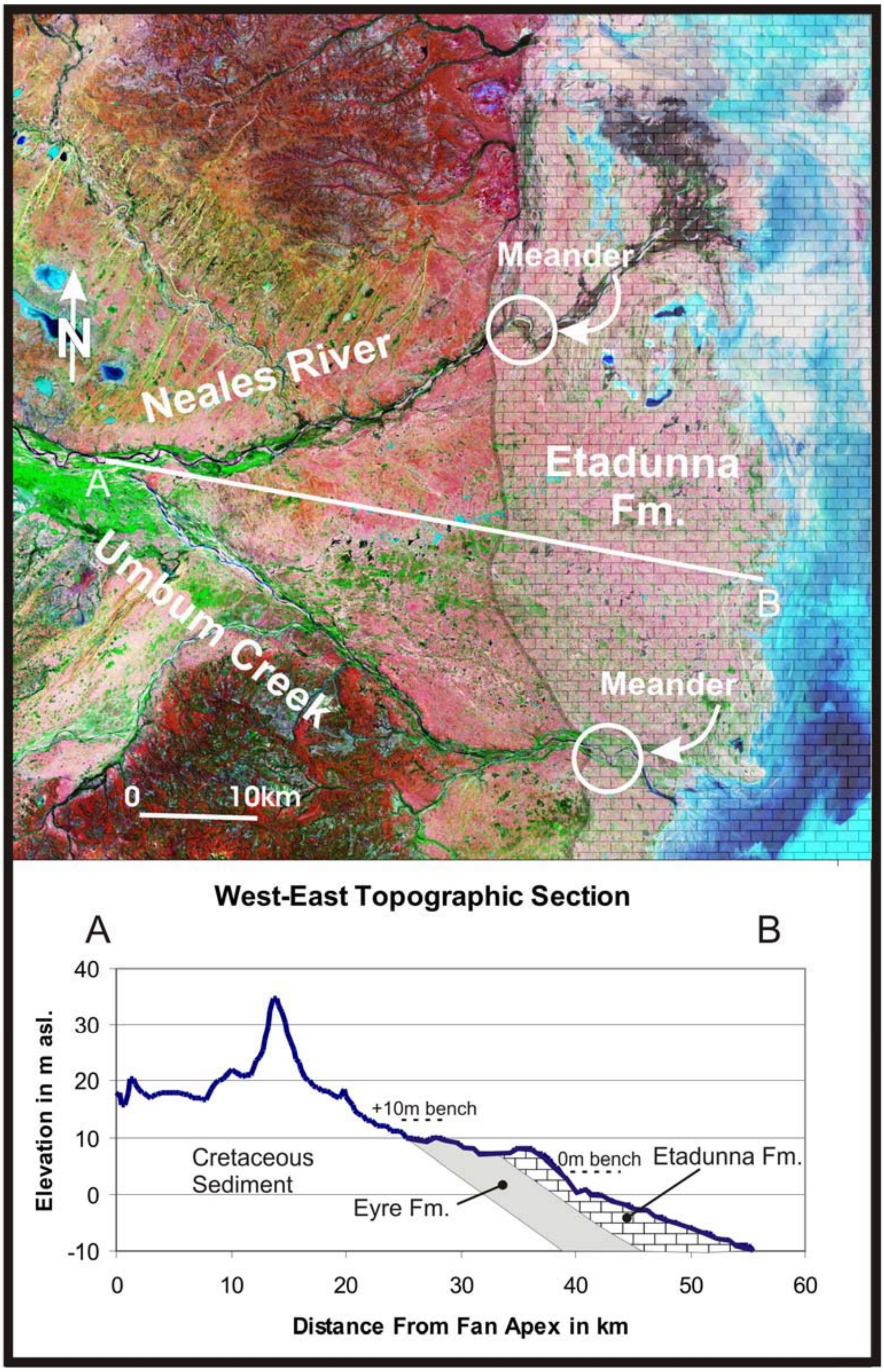


Figure 6.15: Extent of Etadunna Formation showing the close association of significant meanders on the Neales River and Umbum Creek with the change in lithology.

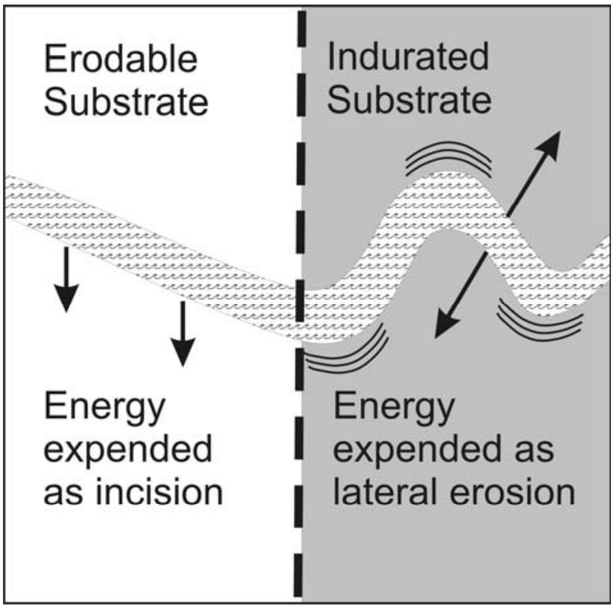


Figure 6.16: Model of lithological control on stream planform showing energy expended as incision over erodable substrate in contrast to energy expended as lateral erosion over indurated substrate.

6.3 UMBUM CREEK

Umbum Creek is as deeply incised in an equivalent style to the Neales River but has a much broader valley with gently inclined walls. The large meanders on Umbum Creek are developed in an area characterised by Quaternary fluvial deposits with abandoned channels, preserved interfluves, shadow bars and chute channels. The Quaternary sediments of Umbum Creek, equivalent to the deposits on the Neales River, unconformably overlie the same silicified Miocene lacustrine mudrock of the Etadunna Formation. The planform of the lower stream appears to reflect the tectonic fabric of the underlying substrate, with at least two reaches displaying highly linear trends that probably reflect control by underlying faults (Figure 6.17). The lineaments appear to control channel directions but only downstream of the meanders (Figure 6.17).

Significant differences between the Umbum Creek Valley and the Neales River Valley show that only one of the models is possible for both locations. Unlike at the Neales Cliff, there are no sand dunes deposited across the Umbum Creek region that could potentially block the channel. The trend of the Umbum Creek thalweg profile through the meanders is consistent, reflecting no local deformation by movement along underlying faults (Figure 6.18) and structural control by underlying faults only occurs downstream of the meanders, indicating that faults have no direct influence on the meander formation (Figure 6.17). However, just upstream of the meanders, the lithology of the channel substrate changes from friable sands of the Eyre Formation to the silicified mudrocks of the Etadunna Formation. This is the only constant condition that occurs at both sites, indicating that lithological control is the dominant factor in the formation of both river valleys within this system.

6.4 GEOLOGICAL STRUCTURE SUMMARY

The deformation of Miocene-age sediments clearly demonstrates that neotectonic activity has occurred. This can, however, be constrained between the Miocene deposition of the Etadunna Formation and the Late Pleistocene deposition of the Warmakidyaboo Beds. This gives a Plio-Pleistocene age for neotectonism in the Lake Eyre region.

Climate change about 50 ka ago decreased the base level in the region, causing the ancestral Neales River to incise (Croke *et al.*, 1998). When this incision reached the Etadunna Formation, the partially silicified substrate proved more resistant to weathering than the Eocene sandstone substrate upstream. As a result, a meander formed as the streams attempted to dissipate excess energy.

Other models including structural deformation of the stream profile and blockage of the channel by sand dunes have been demonstrated to be unlikely factors in the development of the fluvial valleys in this region. However, there is a consistent association of streams with the underlying tectonic fabric preserved in Miocene and older rocks. Geological investigations have failed to demonstrate evidence of neotectonic activity during the Late Pleistocene.

NOTE: This figure is included on page 6-19 of the print copy of the thesis held in the University of Adelaide Library.

Figure 6.17: DEM of the Umbum Creek meanders constructed from 10 m spaced DGPS traverses and showing the control of streams by faults (dotted lines) below the meanders. (Courtesy M. Reilly & A. Hill).

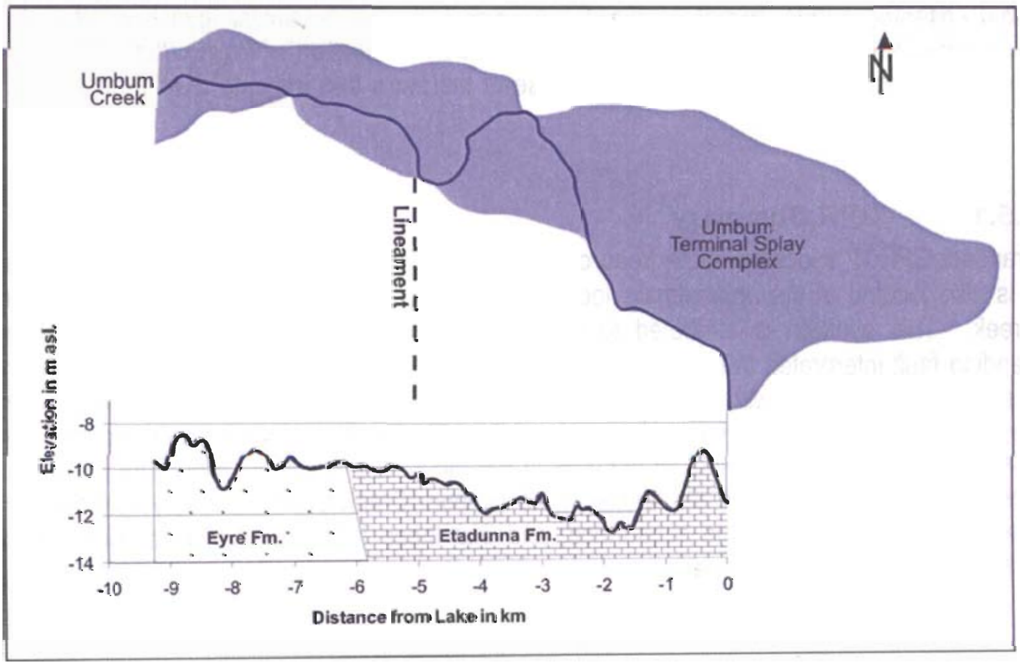


Figure 6.18: Umbum Creek thalweg profile from RTK-DGPS derived DEM showing the consistent trend of the profile associated with the meanders.

6.5 GROUND PENETRATING RADAR (GPR)

Data from Umbum Creek GPR Transect GPR01 was analysed and interpreted to identify structural features within the sedimentary sequence (Figures 6.19 & 6.20). At this location Pleistocene sands directly overlie the Eocene Eyre Formation. This boundary is clearly delimited by a strong radar reflector. Several of the interpreted faults in this transect offset this boundary. In some cases these offsets appear to be truncated by the formation boundary that coincides with an unconformity. This indicates that these faults were active prior to the erosion of the Eyre Formation and they are considered as Late Miocene to Pliocene in age. This is consistent with observations made at the Neales Cliff for a phase of deformation following the deposition of the stratigraphically younger Etadunna Formation.

Other faults also offset the Eyre Formation but continue to propagate through the overlying Pleistocene sands. These faults are evidence of a later phase of tectonism following the deposition of the Pleistocene sands. If these sands can be correlated with the Pleistocene units observed at the Neales Cliff, then these faults are younger than at least 177 ka (Croke *et al.*, 1996), giving them at least a Late Pleistocene age. This evidence accords well with seismic records in the region that demonstrate on-going seismic activity into the modern era (see Chapter 3: Seismicity in the Lake Eyre Region.).

Fault offsets located above the formation boundary appear to form small ‘sag’ basins that do not pass very far down into the sequence. They appear to be related to loss of material at depth. This is probably due to the dissolution of gypsum as the Pleistocene sands contain layers of gypsum-cemented sands and selenite crystals. No gypsum-cemented layers have been observed within sands of the Eyre Formation and a similar gypsum dissolution mechanism for the creation of offsets within the Eyre Formation is improbable. Therefore, neotectonic activity is interpreted as the cause of the faults that truncate Eyre Formation and Pleistocene sediments.

6.5.1 GPR Summary

Transect GPR01 is located at the head of the Umbum Delta and crosses the Lake Eyre Fault. It is also located at the approximate location of a major avulsion feature within the Umbum Creek. This avulsion is attributed to neotectonic movement along a southwest-northeast trending fault interpreted from an observed lineament (Figure 7.17) (see Chapter 7.2.7). This lineament is coincident with the offset observed in the GPR transects (Figure 6.20) providing tangible, credible evidence for neotectonic activity. The geological evidence interpreted from geophysics and geomorphological features in the landscape at this location infer that similar geomorphic evidence visible elsewhere in the Umbum Creek Catchment may confidently be interpreted as features in the subsurface, and that these features have undergone tectonic activity since the Late Pleistocene.

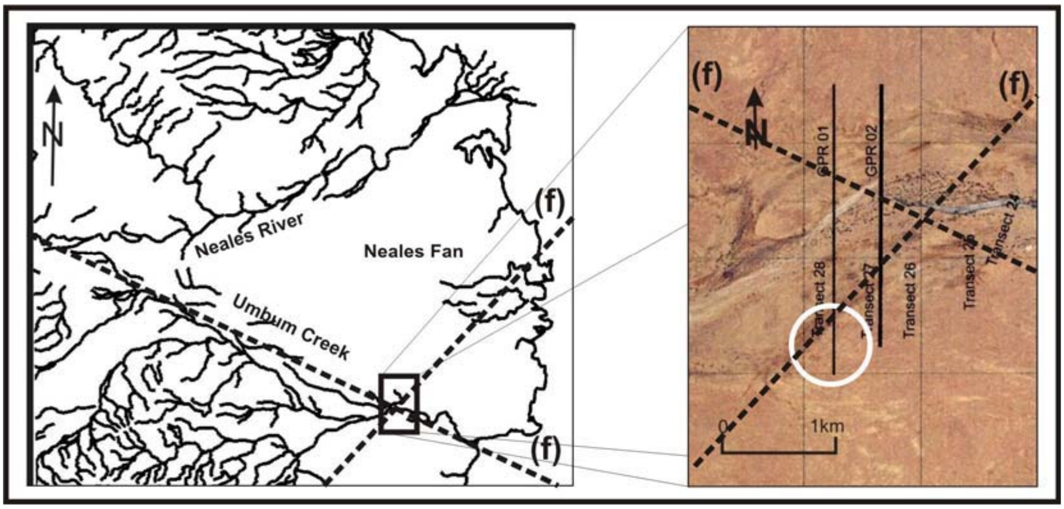


Figure 6.14: Location map for Transect GPR01 showing the location of faults (f) that cross the transect and disrupt the sub-strata. The first 250 m of Transect GPR01 is shown in Figure 6.20.

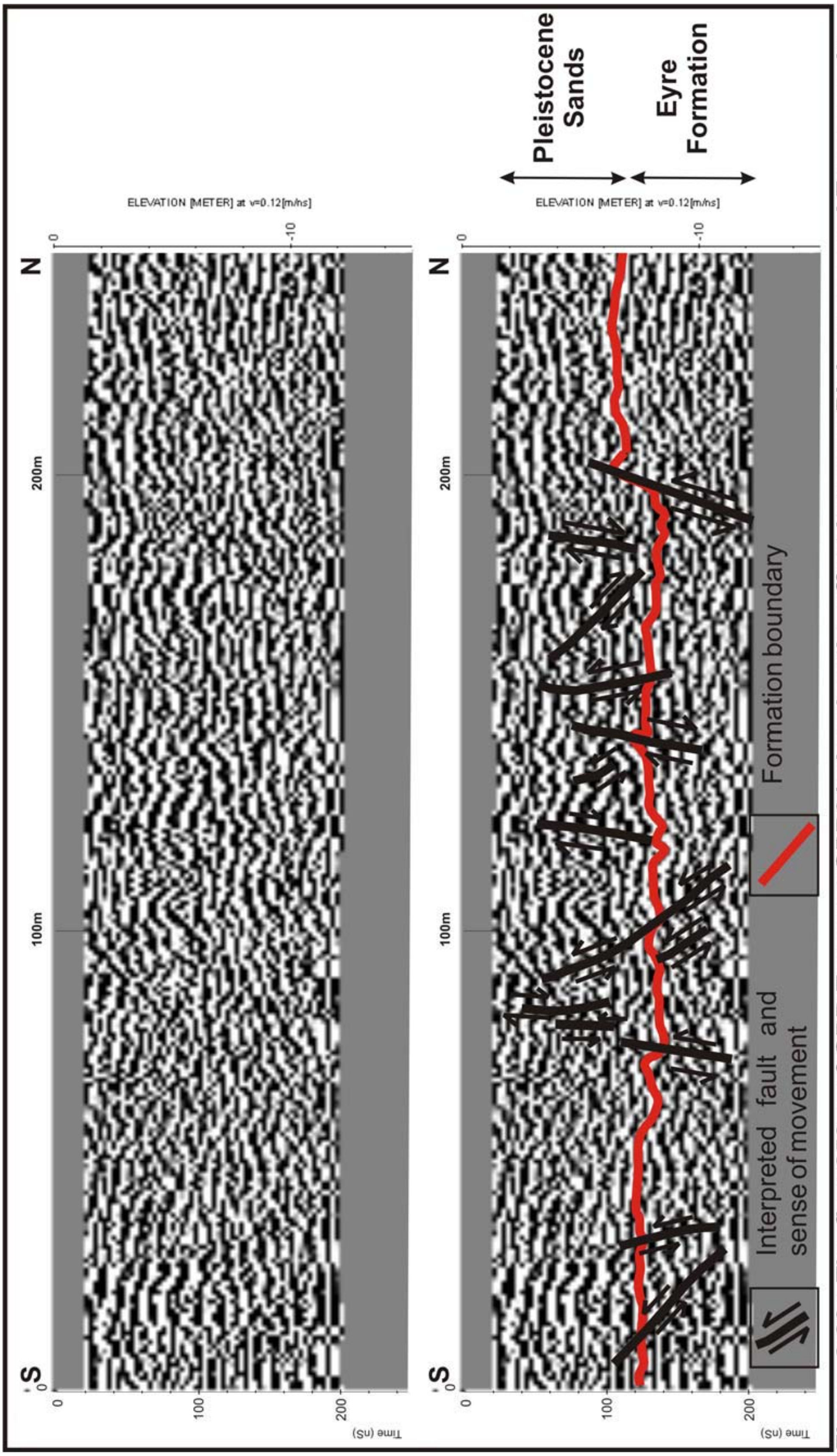


Figure 6.20: The first 250m of GPR Transect GPR01 showing the offset between Pleistocene and Eocene units across the formation boundary indicating Late Pleistocene tectonic activity.