Clay modelling of the Fitzroy Graben

L. K. Rixon

Parallel shear, generated by sliding tongue and grooved boards past each other with clay on top produced, initially—in addition to the commonly recognised conjugate strike slip faults—a set of gently plunging folds at 30-45° to the wrench zone. Essentially vertical Riedel shears may subsequently become part of reverse drag structures as rotation of the clay, in response to the shearing couple, introduces a tensional component.

A single right-lateral movement in the model has reproduced the orientation of the major faults and folds within the Fitzroy graben of the Canning Basin. Major features such as the offshore depression on the southern margin of the Leveque shelf and part of the Halls Creek mobile zone may have been produced, as simulated in the model, by major dextral wrenching and, in the case of the Leveque shelf, by later subsidence of basement rocks. Absorption of lateral movement by the Halls Creek mobile zone may account for the less deformed, more platform-like northeast Canning Basin.

Experiments on the formation of faults, folds, and fractures using deformed clay or wax models have been conducted by several workers, including Mead (1920), Cloos (1955, 1968), and Wilcox, Harding & Seely (1973). Two of the more important experiments are those of Cloos, who has established the reproducibility and constancy of fracture angles developed in strained clay models; and Wilcox and others, who in studying wrench tectonics have shown an agreement between the fractures predicted from the theoretical strain ellipse, and observed folds and faults, in both model and real situations.

Tchalenko (1970) has critically examined the similarities between shear zones of different magnitudes, from microscopic up to earthquake faults on a regional scale, and shown the remarkable similarity in structures at all scales and in greatly varying materials. His analysis supports the contention that modelling of structures is a valid exercise.

This paper demonstrates that both tensional and wrench structures produced in the laboratory (and recorded by the above authors) can be reproduced in the one model by simple shearing of clay. The similarity between the fault and fold patterns produced in the model and those mapped in and adjacent to the Fitzroy Graben suggests that wrench movements may have been significant in the development of the graben. Rattigan (1967), and Smith (1968), advanced hypotheses of dextral wrenching of basement blocks to explain the folds and associated fracture systems of the Fitzroy Graben. Similarly, Willcox and others (1973) suggested that the Fitzroy Graben is probably a right-lateral wrench graben. Lack of unequivocal geological or geophysical evidence for major basement wrenching has prompted this attempt to reproduce the structures of the Fitzroy Graben by simple shearing of clay, and thus to test the wrench hypothesis indirectly.

The Fitzroy Graben forms the northern portion of the Canning Basin, which lies between the Kimberley and Pilbara blocks of Western Australia. The area has been mapped by Guppy, Lindner, Rattigan & Casey (1958), and Veevers & Wells (1961). Rattigan (1967), and Smith (1968), summarised the regional geology with special reference to the boundary lineaments and structure within the graben, the main features of which are outlined below.

The northern and southern margins of the graben have been mapped as northwest-southeast-trending fault systems. Both systems consist of a group of named faults, including the Dummer Range, Dampier and Fenton faults in the south, and Pinnacle, Pender Bay, Markham, Mueller, and Beagle Bay faults in the north (Figure 8). Large vertical displacements have been seismically mapped across most of the major bounding faults, with displacement of more than 4000 m on the Pinnacle and Markham faults. The southeastern limit of the graben has not been clearly defined. Most of the faults at the eastern end of the graben are mapped as en echelon zones: the Stansmore Range fault, which extends northwest for more than 160 km from the eastern end of the graben, is the exception.

Folding within the cover rocks consists of east-west trending anticlinal and synclinal systems (Figure 8). The southern anticlinal belt (Guppy and others, 1958) consists of five culminations; the central anticlinal belt has two culminations, the axes of which are en echelon or sinuous, and gently plunging away from the culminations. They are referred to here as the St George Range and Grant Range anticlines respectively. The Millyit Syncline is an asymmetric southeast-plunging syncline (Towner, R. R., in press) south of the St George Range anticline.

Experimental techniques

The apparatus consisted of four tongue-and-groove floor boards, arranged on a base board so that they could be slid past each other. Basement wrenching can be simulated by laying a clay cake 2 or 3 cm thick on top of the boards, and generating shearing couples by sliding the underlying boards. Wrenching in pre-existing grabens or against growth faults can be simulated by fixing extra boards on top of the original boards. Controlled simultaneous movement of two or more boards was produced by a lever system, with a piece of wood placed across the ends of the boards to ensure their equal movement (Fig. 1); when such movement was not required the lever system was used without the end piece of wood.

Divergent wrenching was achieved by placing a piece of sheet steel (1 mm thick) diagonally across a join in the boards (Fig. 2). Movement of the underlying board in a parallel fashion produced oblique (divergent or convergent depending on the sense of movement) wrenching in the clay overlying the steel.

Friction between the clay and underlying boards was varied in some trials by placing thin plastic sheet or

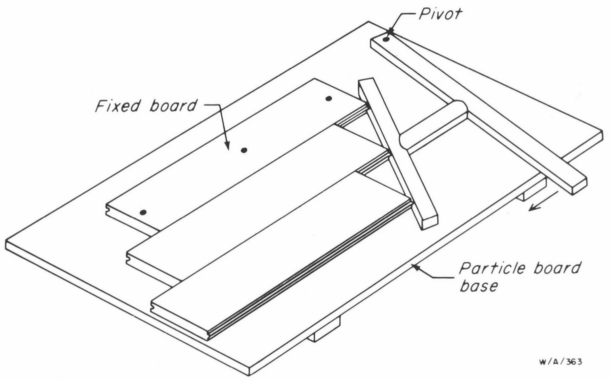

Figure 1. Board arrangement for simple parallel shear with controlled simultaneous movement.

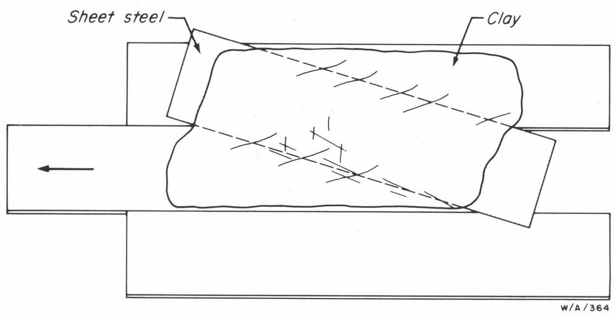

Figure 2. Diagonal arrangement of sheet steel ensures divergent wrenching in the overlying clay when the boards are moved in the direction indicated by the arrow above.

greaseproof paper between the two to enhance rotation and transmission of stress throughout the clay.

The red potters clay used for the experiment was prepared so that it had a tacky consistency, and clung tenaciously to the fingers. Development of both tensional and compressional features was enhanced by trowelling the clay surface with liberal quantities of water.

Structures observed in the model

Faults

Parallel shear, generated by sliding the tongue and grooved boards past each other with the clay on top, initially produced a conjugate set of strike slip faults with dihedral angle of about 60°, one set at 70-90° to the deforming couple (antithetic faults or conjugate Riedel shears), and one set at 10-30° to the couple (synthetic faults or Riedel shears).

Rotation of the strike-slip faults occurred on further application of the external shearing forces. Internal rotation and wedging of the clay for a right-lateral wrench tends to move the synthetic faults anti-clockwise parallel to the main wrench, while external rotation moves them away from the main wrench (Fig. 3). The resultant is little change in angle between the synthetic faults and the main wrench zone. Antithetic faults however have an internal rotation opposite to that of the synthetic faults, that is clockwise, and coupled with external clockwise rotation leads to rotation of these faults in a clockwise direction (Fig. 3). Thus synthetic faults remain favourably oriented in relation to the main wrench, so that they are able to accommodate large amounts of lateral movement—whereas antithetic faults become perpendicular to the wrench and can accommodate only small amounts of lateral movement. Further movement of the underlying boards caused the en echelon synthetic faults to coalesce into a major shear zone; still further movement leads to isolation of separate blocks within the main shear zone, either by development of shear lenses (Skempton, 1966) and/or by strong buckling of the adjacent synthetic faults and intervening clay. With the exception of strong buckling this sequence of events has been documented for shear zones of microscopic and mesoscopic scale (Morgenstem & Tchelenko, 1967) and postulated for large-scale earthquake faults (Tchelenko & Ambraseys, 1970). Buckling of strike-slip faults has been studied by Merzer & Freund (1975).

Divergent wrenching also developed a set of strike slip faults. However, tensional faults appeared first, with the orientation predicted by the strain ellipse—that is approximately 45°-50° to the shearing couple, bisecting the angle between the conjugate set. Sub-

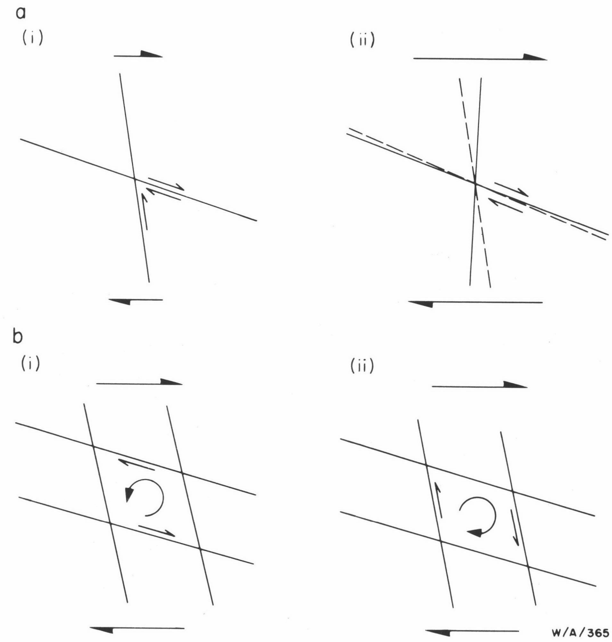

Figure 3. (a) Rotation of conjugate faults by shear movement. (i) Initial faults. (ii) Rotation after further movement. (b) Relative motions within individual shear blocks. (i) Internal rotation on synthetic faults. (ii) Internal rotation on antithetic faults.

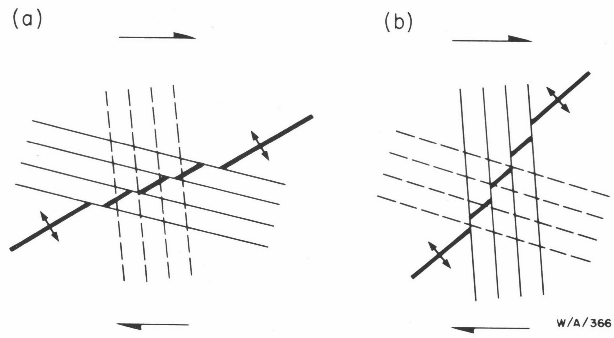

Figure 4. Rotation of fold axes by movement on either synthetic or antithetic faults. (a) Movement on synthetic faults results in clockwise rotation of the fold axis. (b) Movement on antithetic faults results in anticlockwise rotation of the fold axis.

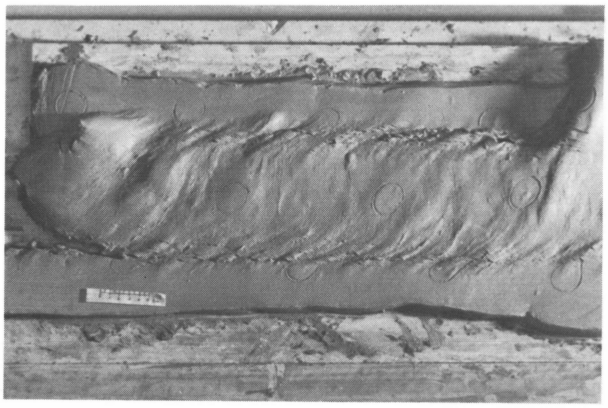

Figure 5. General view of one of the experimental trials showing the nature of the structures developed by simple parallel shear. The folding in the upper left and upper right of the clay represents the structural complexity in the King Sound area and the Halls Creek Mobile Zone respectively. The rift in the lower left corner of the clay represents the offshore depression south of the Leveque shelf.

Figure 6. Simple divergent wrench model showing vertical tension faults which appear first and rotate before most of the conjugate shear faults become visible.

sequent movement quickly rotates these faults so that by the time the conjugate set appears the tensional set is at about 60° to the couple (Fig. 6).

Folds

Gently plunging folds developed at about 45° to the wrench zone, without the aid of plastic layers on or within the clay.

Close to the main shear zone, where rotation is maximal, the folds and antithetic faults were dragged into sigmoid shapes. Folds which first appeared at approximately 30°-45° to the wrench zone were rotated clockwise or anticlockwise depending on the predominance and relative displacement of either synthetic or antithetic faults, and plastic deformation. If synthetic faults predominate then slip is lateral and the folds are extended, reducing the angle between the fold axis and the wrench zone (Fig. 4a). If slip is largely on the antithetic faults and rotation anticlockwise for a dextral wrench then the angle between the folds and the main wrench increases in that zone (Fig. 4b). Thus folds with sinuous axes occur. The sinuosity is a function of relative movement on synthetic and/or antithetic faults.

Differential movement may occur along the wrench zone in response to varying resistances to movement when shearing forces are applied. A decrease in friction between the boards and clay at any position on the model may be accomplished by placing thin plastic sheet between the two at that position. Figure 5 shows the result of right-lateral wrench with increasing resistance to movement at the eastern end of the model. Compression produced folding of the clay and development of conjugate and tensional faults as predicted from the strain ellipse. Wrenching with extension usually lead to formation of graben-type structures with curving synthetic and antithetic faults.

Reverse Drag

Reverse drag (Hamblin, 1965) also called downbending, turnover, rollover, or sag is a structure often associated with down-to-basin faults, and refers to the beds on the downthrown block dipping into the fault plane in a manner exactly opposite to the flexure produced by drag.

These structures are best developed in areas of pure tension. Where transition from tensional to mainly wrench or strike-slip movement occurs, the curving master fault becomes vertical and displacement is strike-slip rather than dip or oblique-slip (Fig. 7).

External rotation

External rotation and deformation of the clay resulted in sigmoid shapes for the main fault zones in all the models. The major wrenches rotated clockwise upon application of dextral shearing forces. If the ends of the clay cakes were free to move simple rotation followed. However, if the ends were constrained either by wooden boards or by differential friction against the underlying boards (Fig. 5), then rifting occurred where rotation was away from the constraint or compressional folding, and overthrusting occurred where rotation was towards the constraint.

Figure 7. Close up view of reverse drag structures developed at the end of an essentially vertical wrench zone.

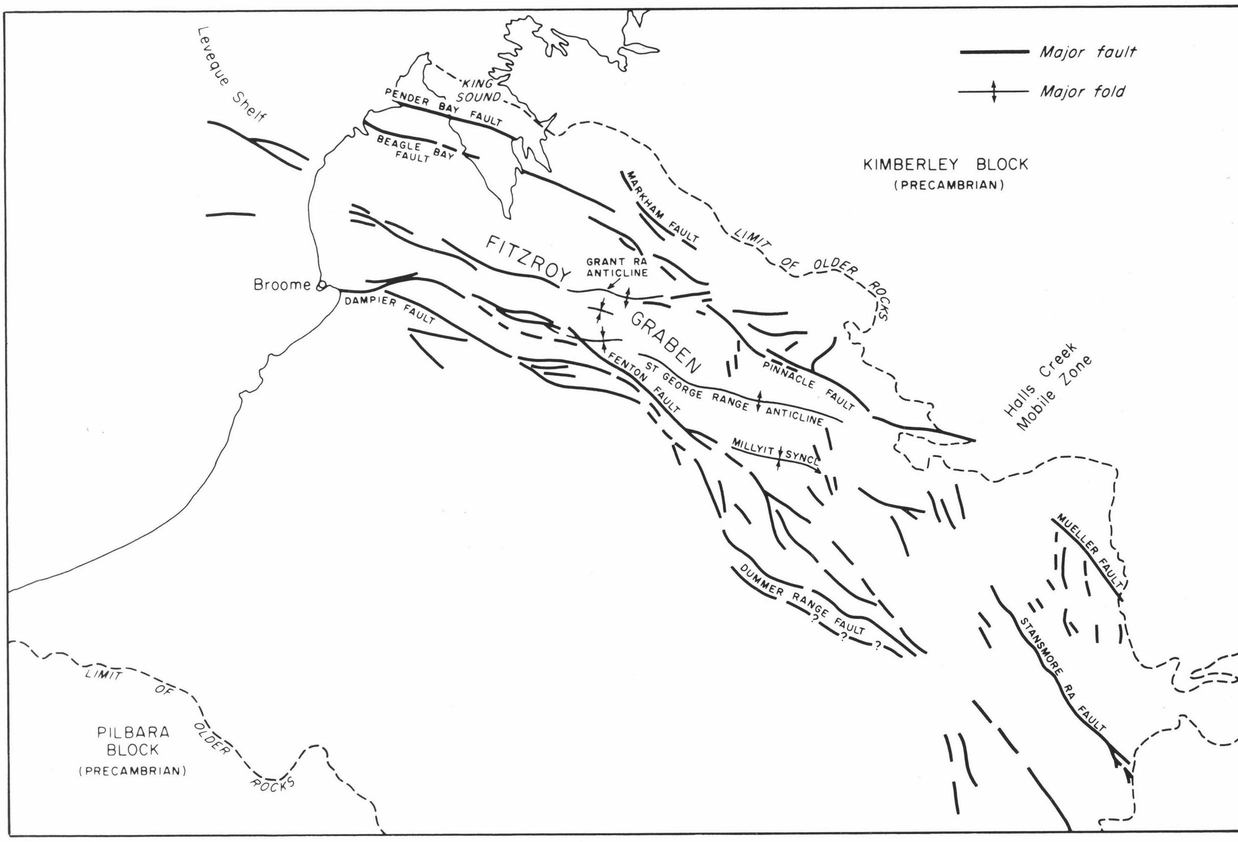

Figure 8. Structure of the Fitzroy Graben and associated tectonic elements. Fault system is subsurface (Lower Palaeozoic) and folds are surface mapped anticlines and synclines.

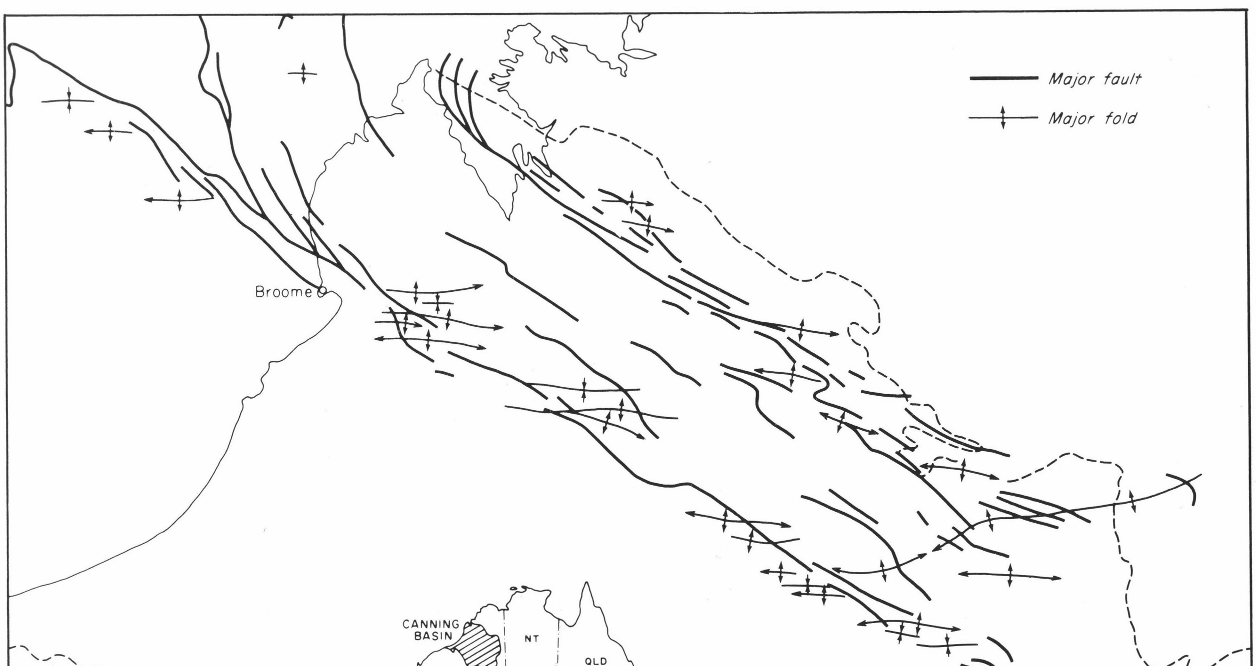

Figure 9. Major structures traced from a photograph of the clay cake that had been subjected to simple dextral shear. Coastline and limit of older rocks have been added for comparison with Figure 8.

The structural model applied to the Fitzroy Graben

The major fault systems of the Fitzroy Graben have been reproduced in a general fashion by the models. Comparison between the model and mapped structures can be made by referring to Figures 8 & 9. Figure 8 shows the subsurface basal Palaeozoic and possibly basement structure within the graben, and Figure 9 shows the major structures traced from a photograph of the model. North-south faults of the graben can be explained by tensional faulting as predicted from the theoretical strain ellipse for a dextral shear couple, and the faults at low angles to the fault system (synthetic) are the low-angle half of the conjugate set.

Reverse drag and rotating fault planes as described previously are present in Devonian rocks on both the Dummer Range and Pinnacle faults in areas where, according to the model, extension may be expected if dextral shear was a major tectonic influence.

The open upright style and gently plunging east-west axes of the major folds mapped in the cover rocks of the graben have been reproduced in the model by dextral shear. It seems likely that basement folds, although ill defined by seismic reflection traverses, will reflect the surface fold pattern. Seismic traverses approximately normal to and crossing the St George Range anticline reveal that the surface folds extend at least 4000 m below the surface into Late Palaeozoic rocks.

The King Leopold mobile belt (Fig. 8) has been simulated in the model by right lateral movement along the northern fault system. Simulation of the southern portion of the Halls Creek mobile belt has been achieved by increasing the resistance to movement at the eastern end of the model.

Moderately plunging folds at the western end of the northern fault system on the model (Fig. 7) were produced by compression caused by rotation of the central block against the northern block—which had been deliberately extended for that purpose. Structural complexity in the area north of King Sound is apparent from various geological and tectonic maps; the westward change in strike of the limits of uppermost Permian and Triassic sedimentary rocks shown on the maps corresponds to an area of relative uplift during the deposition of those rocks. This uplifted area may be analagous to the folded area on the model.

The pronounced arcuate V-shaped tear in the clay at the western end of the model (Fig. 5) is the result of dextral wrench movement, which caused clockwise rotation of the central block away from the southern block and coeval bifurcation of the southern wrench zone. This pattern of fractures is remarkably similar to the Fenton fault system, which bifurcates and runs offshore into the southern margin of the Leveque shelf. Clockwise rotation of the proto-Leveque Shelf may have caused initial basement rifting and bifurcation of the Fenton fault system which allowed subsidence of the southern part of the shelf under the load of subsequent sedimentation.

Basement subsidence in the graben has not been imitated by the models although some depression of the clay near the wrench zones is evident. The origin of the original basement weaknesses is unclear, but thickening of the post-Late Devonian sequence in the graben is evidence for subsidence since then. The causes of subsidence has yet to be determined.

Conclusions

The experiments have demonstrated the feasibility of basement wrenching as a likely cause of structures mapped in the Fitzroy Graben. A single right-lateral movement in the model has reproduced the orientation of major faults and folds within the graben. The large, open, upright, gently plunging folds developed in the model appear to have a similar style to those mapped in the cover rocks of Fitzroy Graben. Folding of basement rocks is not sufficiently well-defined by seismic reflection data to ascertain if there is any correlation between basement folds and the folds in the cover rocks.

Strike-slip faults that initially have vertical fault planes can develop into curving master faults, and become part of reverse drag structures in areas where deformation introduces a tensional component.

Major features such as the offshore depression on the southern margin of the Leveque Shelf, and part of the Halls Creek mobile zone, may have been produced, as simulated in the models, by major dextral wrenching, and in the case of Leveque Shelf by later subsidence, of basement rocks. Absorption of lateral movement by the Halls Creek mobile belt may account for the less deformed, more platform-like northeast Canning Basin.

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Delny-Mount Sainthill Fault System, eastern Arunta Block, Central Australia

R. G. Warren

Introduction

The Delny-Mount Sainthill Fault System, a distinctive feature on satellite photographs, can be traced as a well-developed geological and geophysical feature extending some 130 km across the Arunta Block, central Australia. It has a slightly north-of-west trend, from 4 km south of Mount Thring (22°49′S, 136°02′E) to 5 km south of Delny Outstation (22°33′S, 134°49′S) (Figs 1, 2). The deformed nature of the rocks at Mount Sainthill was first noted by Smith and others (1960), who described a blastomylonite derived from nearby granite, and recorded the gradational contact between deformed and undeformed units. Shaw & Warren (1975) mapped the Delny section of the Fault System. The nature of the remainder of the Fault System and its continuity was recognised during rapid reconnaissance to provide data for interpretation of new coloured aerial photography in the 1976 field season.

Regional geology

The Arunta Block is considered to contain three major depositional units, each with probable stratigraphic significance, but recognised primarily by their distinctive lithologies (Shaw & Warren, 1975; Shaw & Stewart, 1976; Stewart & Warren, 1977, see Fig. 2). Division I consists principally of volcanogenic rocks and immature sediments, usually at the granulite grade of regional metamorphism. Division II (equated with the Warramunga Group in the Tennant Creek area) contains a larger proportion of derived sediments. Division III units (equivalent to Hatches Creek Group) contain mature quartzite and pelite. They overlie rocks of Division II unconformably.

In the region affected by the Delny-Mount Sainthill Fault System Division I is represented by the Kanandra Granulite, a unit of the Strangways Metamorphic Complex, cropping out mainly in a fault-bounded block extending eastward from south of Delny. It consists of garnetiferous felsic gneiss, with pods and thin layers of mafic granulite and lesser proportions of metasediments. South of the Fault System these granulites are intruded by small bosses of Mount Swan Granite (see below), but north of the Fault System they occur as rafts in the Mount Swan Granite (and possibly in the Dneiper Granite).

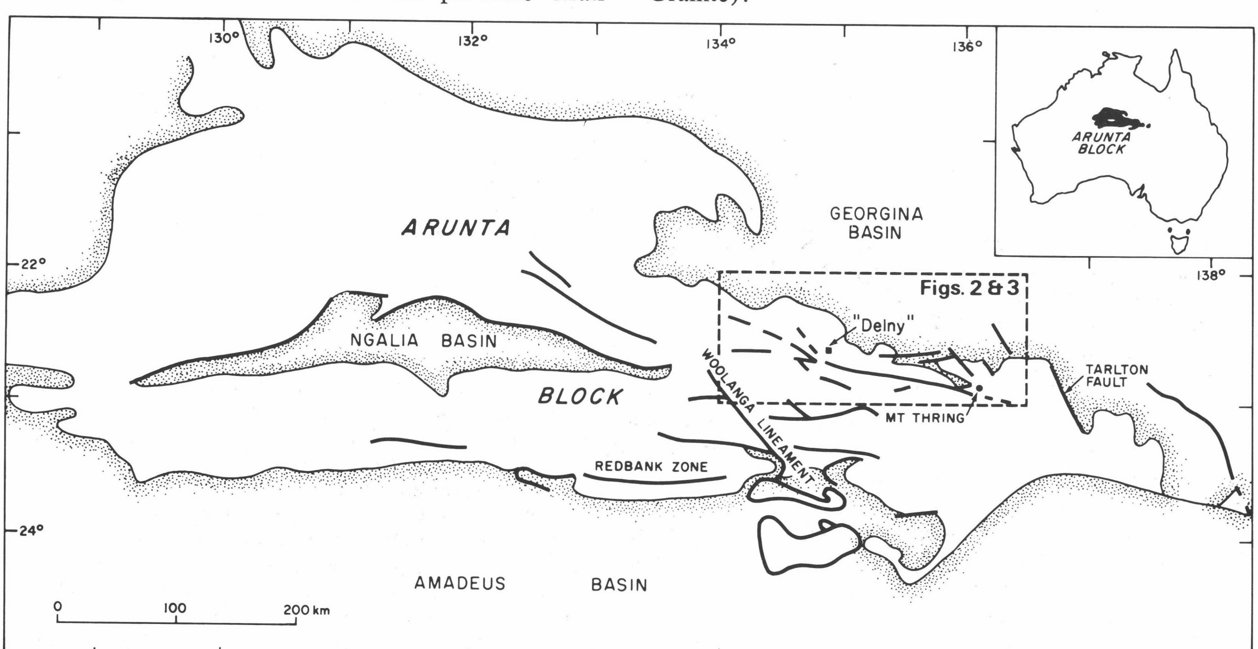

Figure 1. Major faults within the Arunta Block, central Australia.