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GEOLOGY OF THE UPALINNA DIAPIR
CENTRAL FLINDERS RANGES

by

I A DYSON
Regional Geology

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4 November 1992

To Ian Dyson
Regional Geology
Department of Mines and Energy

YOUR REF: 36G36/A06/735000

Results of STABLE ISOTOPE measurements on 4 samples were as follows:

Sample	Yield(%)	$\delta^{13}C$/PDB	$\delta^{18}O$/PDB
WWA1	40	9.18	-14.04
WWD	25	7.62	- 8.86
WWT	36	8.69	-12.74
UCG2	59	-3.50	- 0.51

Yield is calculated by expressing the volume of CO_2 produced as a percentage of the volume inspected from that weight of pure sample.

KEITH TURNBULL

DEPARTMENT OF MINES AND ENERGY
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Geology of the Upalinna Diapir, Central Flinders Ranges.

I A DYSON

Investigation of the Upalinna Diapir, 20 km east of Wilpena Pound in the Adelaide Geosyncline, has identified a number of structural and sedimentary features normally associated with evaporite diapirs. The Upalinna Diapir is a small, polygonal-shaped structure that is centrally located within a domal anticline defined by bedding of the Umberatana Group. It is structurally asymmetrical, being fault-bounded on the western side. These faults may be an upper level expression of basement-anchored master faults that acted as conduits for brecciated material, or may be related to the growth of withdrawal features that offset strata of the Tapley Hill Formation. The brecciated core of the diapir is dominantly composed of siltstone, heavy mineral-laminated sandstone and well-bedded limestone that are assigned to the Niggly Gap Beds and Arkaba Hill Beds of the Callanna Group. Brecciation of the Niggly Gap Beds is interpreted as the result of large-scale dissolution of salt. It is suggested that salt in this unit was responsible for the viscosity contrast that led to diapiric emplacement of Callanna Group sediments. Outcrop of the diapir appears to display an erosional section through a mushroom-shaped bulb that contains a number of small diapirs within a larger diapiric body. The mushroom model has important implications for the concept of diapirism in the Flinders Ranges and exploration of domal structures in the Adelaide Geosyncline. The Umberatana Group, adjacent to the Upalinna Diapir, is a succession of late Precambrian shale, sandstone and dolomite. Sequence stratigraphy of the upper Umberatana Group has provided a framework for intra-regional chronostratigraphic correlation and has identified 4 major sequence boundaries. Each is represented by an unconformity at the base of the Wilyerpa Formation, Tapley Hill Formation, Tarcowie Siltstone and Elatina Formation. Sequence analysis has also been used to explain the apparent diachronous nature of the Etina Formation and suggests that the base of the Marinoan in the Adelaide Geosyncline is a sequence boundary. A relatively thin succession of shallow marine sediments, belonging to the Wilyerpa Formation, is interpreted to have been deposited during diapiric emplacement of the breccia. A low-angle unconformity between the Wilyerpa Formation and Tapley Hill Formation also suggests that the diapir was possibly active at the time of sedimentation. A number of members of the Tapley Hill Formation have been differentiated. The Wockerawirra Dolomite Member of the Tapley Hill Formation is unconformably overlain by a thin oolitic limestone. The oolitic limestone is assigned to the Cox Sandstone Member of the Tarcowie Siltstone. The occurrence of these prominent unconformities in close proximity to the Upalinna Diapir suggests an intimate relationship between periods of active diapirism and the development of sequence boundaries in the Umberatana and Wilpena Groups of the central and northern Flinders Ranges.

INTRODUCTION

Diapir is the genetic geological term applied to ductile intrusive structures. The central Flinders Ranges contains most of the diapiric structures in the Adelaide Geosyncline (Fig. 1). Webb (1960, 1961) was the first to suggest an intrusive origin for the Blinman Diapir and other tectonic-breccia structures. A small number of these breccia bodies have been mapped in detail and include those at Arkaba, Blinman, Enorama, Oratunga, Wirrealpa and Worumba.

These bodies are considered to have resulted from diapiric intrusion (Dalgarno and Johnson, 1966, 1968; Haslett, 1976; Lemon, 1985; Murrell, 1977; Mount, 1980; Preiss, 1979, 1987). A number of theories exist as to their origin (Dalgarno, 1983).

There has been renewed interest in the economic potential of diapirs in the Flinders Ranges following recent exploratory drilling at Blinman. Most diapirs and domal structures have not been previously mapped in detail, including the Upalinna and Yadnapunda Diapirs and the domal structures at Martins Well and Bibliando.

The relatively small Upalinna Diapir was mapped over a period of 21 days in the field (including 5 days travel) from April to June 1992, using aerial photographs enlarged to a scale of approximately 1:10 000. Another 6 days were spent examining diapirs at Oraparinna, Arkaba, Warrakimbo, Worumba and Yadnapunda. Major aims of the investigation were to identify structural and stratigraphic evidence for movement of the diapir and correlation of raft stratigraphy within the diapir. A suite of samples was collected for petrographic, chemical and isotopic analysis. The results of the analyses are found in Appendices 1, 2, 3 and 4.

LOCATION AND ACCESS

The area of investigation is located between latitude 31°33'00" and 31°37'30" and longitude 138°45'00" and 138°51'00, approximately 20 km east of Wilpena Pound (Fig. 2). The Upalinna Diapir is a polygonal-shaped structure about 2.5 x 1.5 km in size, situated near the centre of the map area and can be reached only by 4-wheel drive vehicle with high clearance. Access from the north side is via the Willow Springs H.S., about 15 km from the Wilpena Pound turn-off on the Hawker-Blinman road. The 35 km trip from the homestead normally takes about 90 minutes. An alternative southern route of some 35 km, more suited to larger vehicles, is via the Martins Well turn-off near Rawnsley Park. From here, travel 25 km to Baldoura Creek. Take the track to the left, about 50 m east of the creek to Wilpena Creek, for a distance of nearly 3 km. After crossing Wilpena Creek, the track continues northwards for 4.5 km to a rabbit-proof fence and marks the south-east corner of the diapiric complex (Fig. 2). This is the preferred access to the Upalinna Diapir and only takes about 45 minutes from the Hawker-Blinmans Road under good weather conditions.

STRATIGRAPHY AND SEDIMENTATION

Regional Setting

The Upalinna Diapir was mapped as part of the PARACHILNA 1:250 000 geological sheet (Fig. 3) by Dalgarno and Johnson (1966). This area includes rocks ranging from early Willouran to Cambrian in age (Table 1). No Torrensian sediments have been recognised in the region nor have any early Sturtian stratigraphic units been previously mapped adjacent to the diapir. Dalgarno and Johnson (1966) mapped the diapir boundary and the rim rock stratigraphy, but did not differentiate units within the diapir.

Callanna Group of the Upalinna core complex

The brecciated core of the Upalinna Diapir is dominantly composed of siltstone, heavy-mineral laminated sandstone and well-bedded limestone. Mallee is extensively developed over the calcareous and dolomitic bedrock (Plate 1). Sedimentary contacts are rarely observed. Larger rafts of limestone, commonly up to tens of metres in length, are strongly folded near the core of the diapir. Bedding within rafts that rim the diapir is sub-parallel to the margin (Plate 2). Sedimentary contacts are rare and rafts are commonly enclosed within carbonate breccia. Evaporite pseudo-morphs, possibly after 6-sided gypsum crystals, are abundant. Minor deposits of gypsum and barite are also present. Basic igneous rocks occur as small xenoclasts on the northern and southern sides of the diapir.

The source of the diapiric breccia is thought to be from the Curdimurka Subgroup of the Callanna Group. The raft stratigraphy of the core complex was correlated with the formalized stratigraphic units of the Callanna Group in the Worumba Anticline (Fig. 4; after Preiss, 1985).

Niggly Gap Beds

The Niggly Gap Beds are extremely brecciated and characterized by micaceous and heavy-mineral laminated, fine-grained, pinkish to greyish-red sandstone that is interbedded with grey siltstone. Sedimentary features include cross-bedding, truncated ripple cross-lamination, occasional halite casts, graded bedding and small-scale soft-sediment deformation. Less common are interbeds of massive to laminated, dark grey limestone ranging from a few centimetres to a few metres in thickness.

The Niggly Gap Beds were possibly deposited in a shallow water environment between fairweather wave base and the intertidal zone. The brecciation is interpreted to have formed from extensive salt dissolution.

Arkaba Hill Beds

The distinctive Arkaba Hill Beds consist of alternating carbonates and clastics. The unit at Upalinna closely resembles the succession described in the Worumba Anticline by Preiss (1985). Well-laminated dolomite is composed of alternating calcitic and dolomitic cryptalgal laminations and is often associated with ferroan laminated dolomite. Some well-laminated dolomite contains teepee structures (Plate 3) and diagenetic quartz geodes and nodules (Plate 4), possibly after gypsum.

Other limestones are characterized by the abundance of quartz pseudomorphs after evaporate minerals. Most common are large 6-sided crystals, possibly after gypsum (Plate 5). Rare 4-sided quartz crystals have also been identified and may be pseudomorphs of sodium carbonates such as trona and shortite (Rowlands *et al*, 1980). These evaporite pseudomorphs are associated with pale grey and buff weathered, well-laminated to stromatolitic limestone. The limestone is often interbedded with pale grey, fine-grained, ripple cross-laminated sandstone and dark grey siltstone.

Some smaller rafts consist entirely of breccia that is composed of large (ca. 1-2 cm) sandstone clasts within a finer-grained matrix of limestone and siltstone. This implies re-brecciation of former rafts. The breccia was attributed by Preiss (1985) to result from tectonic crushing and diapiric mobilisation, but also from solution collapse.

The Arkaba Hill Beds are interpreted to have been deposited in shallow water environments. These include carbonate-rich tidal flats and lagoons and fairweather sedimentation of interbedded carbonates and siliciclastics.

Undifferentiated Callanna Group

Many of the smaller rafts within brecciated carbonate of the core complex cannot be correlated with confidence to the formalized stratigraphic units. Most common are cryptalgal laminated dolomite, buff crystalline dolomite and laminated siltstone. These may relate to the Wirrawilka Beds but could also be assigned to the Arkaba Hill Beds.

Igneous Rocks of the Upalinna core complex

Nine xenoclasts of basalt and dolerite, commonly ranging in size from 10-20 m, were mapped within the core complex (Plate 6). The largest is about 100 m in diameter. The xenoclasts are confined to two relatively small areas at the northern and southern ends of the core complex (Fig. 5).

The mafic rocks do not normally exhibit contacts with sediments of the Callanna Group. Observed contacts with carbonate breccia occur out of stratigraphic context and are interpreted as tectonic in origin. However, one isolated occurrence (sample 6634 RS 205, Appendix 1) shows a dolerite intruding greyish-red sandstone of the Niggly Gap Beds. A possible chilled margin and layering of the intrusion can be observed. The other xenoclast occurrences are interpreted to have been emplaced within carbonate breccia by the diapiric intrusion.

The basaltic xenoclasts are considered to be equivalents of the Wooltana Volcanics. However, at Worumba, (Preiss, 1985) argued that dolerites were younger than the basalts unconformably below the Niggly Gap Beds because they intruded sequences overlying the volcanics. This relationship is supported by observations at Upalinna where some of the dolerites may post-date the Niggly Gap Beds, and possibly the whole Callanna Group (Preiss, 1985).

A tholeiitic magmatic association is suggested from petrographic examination of the basalts and dolerites. Petrography and chemistry of the basalts and dolerites are described in Appendices 1 and 2 respectively.

Umberatana Group of the Upalinna rim complex

The Upalinna Diapir is surrounded by a succession of late Precambrian shale, sandstone and dolomite of the Umberatana Group that was assigned to the Tapley Hill Formation (Dalgarno and Johnson, 1966). The concepts of sequence stratigraphy (Van Wagoner *et al*, 1988) have been applied to the upper Umberatana Group.

Previously unrecognized, a relatively thin succession of conglomerate, sandstone, dolomite and fine-grained diamictite at the base of the succession is assigned here to the Warcowie Dolomite Member of the Wilyerpa Formation.

Wilyerpa Formation

At Upalinna, the Wilyerpa Formation is either poorly exposed or absent. On the northern and western sides of the diapir, the Wilyerpa Formation is lenticular (Fig. 5). A stratigraphic section through the Warcowie Dolomite Member on the northern edge of the core complex is shown in Figure 6.

A basal polymict conglomerate, about 2 m thick, is composed of sedimentary, volcanic and felsic crystalline lithic fragments. The lithic fragments consist of black chert, granite, basalt, trachyte, mica schist and carbonaceous shale (Sample 6634 RS 221, Appendix 3). The angular shapes of the fragments suggest proximal deposition of the conglomerate. The base of the conglomerate appears to be an unconformity, but is not well exposed. A 1-2 m thick, off-white sandstone, occasionally displaying large-scale planar-tabular cross-bedding, overlies the conglomerate and also contains lithic fragments. The sandstone passes upwards into pebbly limestone (Plate 7), diamictitite and thinly-interbedded sandstone and shale.

The Wilyerpa Formation is confined within localized channels that were possibly formed when the diapir was exposed. Lithic fragments within the basal conglomerate are not inconsistent with derivation from diapiric breccia. The clean overlying sandstone was deposited in a shallow marine environment under possible tidal influence and is in turn overlain by progressively deeper water sediments. Lithic fragments found in the Wilyerpa Formation and basal Tapley Hill Formation, adjacent to other diapirs in the central Flinders Ranges, have been interpreted as diapiric detritus (N. Lemon; pers. comm. 13.1.93).

The Wilyerpa Formation represents the first evidence of a second Sturtian glaciation in the Adelaide Geosyncline (Coats, 1981). At Oraparinna, medium and coarse-grained felspathic sandstone of the Loves Mine Range unconformably overlies diapiric breccia or Holowilena Ironstone on the eastern limb of the diapir (Dalgarno and Johnson, 1966). A similar situation occurs at the Worumba Anticline (Preiss, 1986) where the basal unit of the Wilyerpa Formation was referred to as the Warcowie Dolomite Member (Preiss, 1980). At Upalinna, the Wilyerpa Formation represents possible glaciomarine sedimentation deposited in response to a major fall in relative sea level and its base is interpreted as a sequence boundary. The fall in relative sea level is thought to be glacioeustatic in origin, but local tectonics associated with periods of active diapirism are believed to have been a significant factor.

Tapley Hill Formation

A number of members of the Tapley Hill Formation have been differentiated at Upalinna and correspond to units recognized by Dalgarno and Johnson (1966) adjacent to the Oraparinna Diapir. A possible low-angle unconformity exists between the Wilyerpa Formation and Tapley Hill Formation. The Tapley Hill Formation is about 1650 m thick in the study area (Fig. 7).

Tindelpina Shale Member

A thin (<1 m), laminated, buff-weathered limestone occurs at the base of the Tapley Hill Formation. It is interbedded with dark, laminated carbonaceous shale and appears to pass laterally into a lenticular pebbly limestone. The suite of clasts within the pebbly limestone (Sample 6634 RS 198, Appendix 3) is remarkably similar to that found in the Wilyerpa Formation. The Tindelpina Shale Member is in turn overlain by grey-green shale, siltstone and very fine-grained sandstone of the Mount Caernarvon Greywacke Member (Dalgarno and Johnson, 1966).

A combined sequence boundary and transgressive surface at the base of the Tapley Hill Formation may represent a hiatus at the termination of a depositional sequence, prior to subsequent onlap of the succeeding sequence. The basal, laminated and pebbly limestone is interpreted to have been deposited under shallow water conditions when the diapir was exposed. The overlying carbonaceous shale and fine-grained siliciclastics, transitional to the Mount Caernarvon Greywacke Member, were deposited under progressively deeper water conditions as sea level rose rapidly.

Mount Caernarvon Greywacke Member

The Mount Caernarvon Greywacke Member is about 1500 m thick in the study area. It consists of grey-green siltstone and sandstone that exhibit strong cyclicity (Plate 8). Here 3 macro-cycles can be identified, ranging from 350-600 m in thickness (Fig. 7). The uppermost cycle is capped by dolomitic limestone of the Wockerawirra Dolomite Member. The sandstone beds are often massive and become coarser-grained up-section where they commonly display graded bedding and hummocky cross-stratification (Plate 9). Palaeocurrent data, commonly flutes and wave ripples, indicate deeper water conditions to the south-southeast. The Mount Caernarvon Greywacke Member is interpreted to have been deposited in a turbidite and tempestite environment.

Wockerawirra Dolomite Member

The Wockerawirra Dolomite Member is overall upward-shallowing and consists of 2 major regressive cycles (Fig. 7). The lower cycle (Plate 10) grades upward from siltstone and fine-grained sandstone of the Mount Caernarvon Greywacke Member to thin-bedded limestone commonly displaying small-scale hummocky cross-stratification, wave ripples and combined-flow ripples (Plate 11) suggesting deposition at or near storm wave base. Carbonate and oxygen isotope analyses (Appendix 4) also suggest that the carbonates were deposited in a shallow marine environment (Fig. 8). The carbonate lithofacies of the highstand systems tract of the Wonoka Formation (Wilpena Group) in the central and northern Flinders Ranges (von der Borch *et al*, 1988) bear a strong resemblance to the Wockerawirra Dolomite Member.

Sunderland Member

The lower cycle of the Wockerawirra Dolomite Member is overlain by a relatively thin succession of siltstone and fine-grained sandstone. It is assigned to the Sunderland Member of the Tapley Hill Formation (Dalgarno *et al*, 1965). Palaeocurrents from wave ripples suggest a palaeoshoreline striking approximately north-south (Fig. 7). The Sunderland Member passes gradationally upward into an upper cycle (about 30 m thick) of the Wockerawirra Dolomite Member. It is in turn overlain by oolitic limestone with an erosional base, interpreted to mark the base of the Tarcowie Siltstone. Lithofacies of the Sunderland Member are similar to those of the Mount Caernarvon Greywacke Member and were deposited for the most part in a shallow marine environment above storm wave base.

The Tapley Hill Formation is overall upward-shallowing and appears to consist of 4 macro-cycles. Several 5-10 m thick cycles are contained within each macro-cycle. These smaller-scale cycles are referred to as parasequences in the sequence stratigraphic terminology of Van Wagoner *et al*, (1988). The environment of deposition for the Tapley Hill Formation in the central Flinders Ranges is dominantly shallow marine, but sub-wave base sedimentation is interpreted near the base of some of the cycles.

Tarcowie Siltstone

The Tarcowie Siltstone is about 550 m thick (Fig. 9) and consists of oolitic limestone, dolomitic siltstone and fine-grained sandstone. The basal unconformity is marked by oolitic limestone, displaying soft-sediment deformation and large (ca. 5-10 cm) limestone intraclasts derived from the Wockerawirra Dolomite Member, and passing upwards into a 40 m thick succession of sandy oolitic limestone thinly interbedded with mature, off-white and medium-grained sandstone (Plate 12). This succession is assigned here to the Cox Sandstone Member. The sandstone displays wave ripples and soft sediment deformation. The frequency of limestone beds decreases upwards, the unit becoming dominated by siltstone and fine-grained sandstone. These clastic lithofacies, interpreted as ooid shoals and shoreface sands that were possibly deposited in an estuarine environment, were previously mapped as

Sunderland Member of the Tapley Hill Formation by Dalgarno and Johnson (1966). They are now interpreted to represent lateral equivalents of the Cox Sandstone Member of the Tarcowie Siltstone that crop out further south on the BURRA and ORROROO 1:250 000 geological sheets. The base of the Cox Sandstone Member is interpreted to be a sequence boundary.

Stratigraphic correlation of the upper Umberatana Group

Preliminary sequence analysis of the upper Umberatana Group in the Upalinna area has provided a framework for intra-regional chronostratigraphic correlation. Four major sequence boundaries are identified. Each is represented by an unconformity of the Wilyerpa Formation, Tapley Hill Formation, Tarcowie Siltstone and Elatina Formation. Third-order cycles, commonly referred to as depositional sequences (Van Wagoner *et al*, 1988), are bounded by these major unconformities. Higher-frequency cycles within the depositional sequences may be correlative on a basin-wide scale. This approach has been applied to the Neoproterozoic Sandison Subgroup (Table 1) where 4 macro-cycles were interpreted within the highstand systems tract of the Brachina Formation and ABC Range Quartzite (Dyson, 1992a). These cycles were thought to be the result of orbital forcing within the Milankovitch band. A similar pattern of early Palaeozoic sedimentation has been recognized in the lower Kanmantoo Group (Jago, Dyson and Gatehouse, 1992, unpublished data).

The Farina and lower Willochra Subgroups of the Umberatana Group (Table 1) near Upalinna are each characterized by the development of a thick highstand systems tract that is composed of 4 prominent macro-cycles (Fig. 9). Each macro-cycle represents a major transgressive-regressive (T-R) cycle in which a lower transgressive unit is overlain by a much thicker regressive unit. The development of the Wockerawirra Dolomite Member of the Tapley Hill Formation, and the apparent diachronous nature of the oolitic limestone of the Etina Formation can be readily explained in terms of high-frequency cyclicity. Each of these units cap upward-shallowing cycles within a hierarchical scale. They are diachronous but do not coalesce in a basinward direction. Similarly, \`intertonguing' of the Etina and Wilmington Formations (Coats and Preiss, 1987) reflects cyclic development of upward-shallowing Etina lithofacies within the Wilmington Formation. This relationship is best seen in the Marinoan type-section near Adelaide where sandstone units of Marino Arkose, thought to be laterally equivalent in part to oolitic limestone of the Etina Formation, cap 3 macro-cycles. An uppermost fourth macro-cycle, consisting of greyish-green siltstone and fine-grained sandstone, is truncated by the Reynella Siltstone Member of the Elatina Formation (Dyson, 1992b). A section south of the Warrakimbo Diapir in the south-west corner of the PARACHILNA 1:250 000 geological sheet is correlated with the upper Umberatana Group at Upalinna (Fig. 9). The Wilmington Formation at Warrakimbo is easily correlated with the Marinoan type-section because both sections are located along the depositional strike.

The basal oolitic limestone that overlies the unconformity near the top of the Tapley Hill Formation at Upalinna may represent a partial lateral equivalent of the Brighton Limestone further south. The Brighton Limestone intertongues with units above and below (Coats and Preiss, 1987). The gradational nature of its upper and lower boundaries and the fact that it lenses out laterally suggested that it was significantly diachronous. Furthermore, local unconformities are likely to exist and may be expected to pass laterally into transgressive units or correlative conformities. At Warrakimbo, a several metre-thick channelized unit of brecciated limestone overlies stromatolitic Brighton Limestone (Fig. 9). This unit, the base of which may be a sequence boundary, passes gradationally upwards into the Angepena Formation with an accompanying decrease in limestone interbeds. Preiss (1983) showed that the Brighton Limestone crosses the Sturtian-Marinoan boundary. According to Coats and Preiss (1987), no reliable criterion existed for precise location of the Sturtian-Marinoan boundary outside the type area south of Adelaide. This study suggests that the base of the Marinoan may represent a possible sequence boundary and further field work should map and correlate local unconformities at this level from sections on ADELAIDE, COPLEY, OLARY, ORROROO and PARACHILNA.

STRUCTURE

Regional Setting

The central Flinders Ranges is a zone of weakly deformed rocks where gentle domes and basins dominate along with some significant high-angle and strike-slip faults (Preiss, 1990). This region contains most of the diapiric structures in the Adelaide Geosyncline, many but not all coincident with the cores of anticlinal domes. The Blinman, Enorama, Oraparinna and Oratunga diapirs occur along a regional, north-south anticline. The Upalinna Diapir is situated at the southern end of the anticline, about 15 km south of Oraparinna Diapir.

External Structure

The Upalinna Diapir is almost centrally located within a domal anticline defined by bedding of the Umberatana Group with regional dips of 10-20 degrees. The sediments of the Tapley Hill Formation and Wilyerpa Formation are upturned vertically against the diapir. The diapir is a polygonal-shaped structure about 2.5 x 1.5 km in size. The major and minor axes of the diapir trend 330 and 070 degrees respectively, corresponding to the major north-northwest trending anticline that hosts the Oraparinna complex and the less prominent anticline that extends to the east and includes the Yadnapunda Diapir and Martins Well Dome (Fig. 3).

Several faults, mostly of normal displacement, radiate from the margin of the Upalinna Diapir and are associated with a number of small deposits of micaceous haematite. Small strike-slip and reverse faults occur on the eastern and western rims of the diapir. Some faults are coincident with the trend of the two regional anticlines that interfere at Upalinna. Well-developed fractures corresponding to these trends were highlighted from stereo-plot interpretation of a comprehensive fracture data set (Table 2). A strong fracture set striking 040 degrees (Fig. 10) appears to be aligned with a major lineament direction within the G8 structural corridor (O'Driscoll, 1983). More detailed palaeostress reconstructions are often based on analysis of similar macrofracture patterns (Bergerat *et al*, 1992).

The Upalinna Diapir is structurally asymmetrical, being fault-bounded on the western side. A dyke-like extension of carbonate breccia in the north-western corner of the diapir is associated with a prominent fault striking 070 degrees that is connected to another fault passing through the diapir. The latter can be traced into the rim rocks on the eastern side of the diapir (Fig. 5). This fault and related structures, 1-2 km west of the diapiric core, may be an upper level expression of basement-anchored master faults that acted as conduits for brecciated material. The diapir might have been fed from one side, with the other side of the structure being fault-bounded. Reactivation of basement faults has been described elsewhere to result in multiple upward-diverging splay faults, characteristic of flower structures that are rooted in a master fault (Thurston, 1987). Normal faults have also been related to growth of withdrawal synclines (Thurston and Lothamer, 1991). Both features have been identified at Oratunga by Lemon (1985), a small circular body of breccia north of the Oraparinna Diapir. Alternatively, intrusion of diapiric breccia into the rim rocks may have been responsible for the faulting during the Delamerian Orogeny, as suggested for the Arkaba Diapir (Mount, 1983).

Internal Structure

The shape of the Upalinna Diapir is polygonal in plan view. Basic volcanics occur as smaller rafts on the northern and southern sides of the diapir. Larger rafts of limestone and interbedded carbonate/clastic units are up to tens of metres in length and are strongly folded near the core of the diapir. Nearer to the rim, bedding is sub-parallel to the margin of the diapir where sedimentary facing of individual rafts point in both inward and outward directions. Outcrop of the Niggly Gap Beds is best developed on the eastern side of the diapir where small carbonate rafts occur as inclusions in large masses of brecciated greyish-red sandstone (Fig. 6).

The diapir, as exposed at the present land surface, is interpreted as a cross-section through a mushroom-shaped bulb (Fig. 11). Mapping of Callanna Group stratigraphy within the diapir suggests a number of small diapirs were successively intruded into the main diapiric structure. Rafts of carbonate-hosted material near the core have been rotated, resulting in repetition of some layers, a common feature of diapiric structures (Weinberg and Schmeling, 1992). The larger rafts could be analogous to the spines of Talbot and Jackson (1987) that are the result of small-scale diapirs within a larger diapir.

Jackson *et al* (1990) suggested that the polygonal shape of diapirs represents a late stage in diapir development from an initially circular bulb. Its axisymmetric streamlines radiate outward above and inward below. The bulb then matures to a polygonal shape, with its streamlines parallel outward above and parallel inward below in orthorhombic symmetry (Fig. 12). It was believed that the change in pattern could be induced simply by changing the magnitude of the radial velocities, which might be a function of viscosity contrast.
Experimental and mathematical modelling (eg Jackson and Talbot, 1986, 1989; Jackson *et al*, 1990; Koyi, 1988, 1990; Talbot and Jackson, 1987; Ramberg, 1968, 1981) has shown that the ultimate dome shape and its capacity to trap hydrocarbons are strongly controlled by viscosity contrasts between the source layer and its cover (Fig. 13).
Where the ratio m of overburden viscosity to source layer viscosity is greater than or equal to 1, a pronounced mushroom-shaped bulb trailing a downward-facing peripheral lobe develops because of friction between the sinking cover and rising source. If m is considerably greater than l (eg 100-200), the source layers become more mobile relative to the overburden and the simple mushroom structure can evolve to a vortex mushroom structure where the skirt curls inward and upward (Jackson and Talbot, 1989). In this type of structure, internal circulation within a rising diapir may cause layer repetition by vortex - type rolling folds (Talbot and Jackson, 1987). Weinberg and Schmeling (1992) suggested that polydiapirs, composed of domes within domes in triple-layered diapiric successions, can also lead to a repetition of evaporite layers both by upward-facing folds and by downward-facing rolling folds.

Brecciation of the Niggly Gap Beds is interpreted as the result of large-scale dissolution of salt. It is suggested that salt in this unit was responsible for the viscosity contrast that led to diapiric emplacement of Callanna Group sediments. Mount (1983) also suggested that mobility of the source material rather than factors such as density, was the main driving force behind diapirism in the Adelaide Geosyncline. Centrifuge experiments (Jackson and Talbot, 1989; Jackson *et al*, 1988) have shown that diapirs grow asymmetrically because growth of one side is either retarded or accelerated with respect to the other because of variations in thickness, viscosity, density and boundary conditions. Variations in salt content of the Niggly Gap Beds may have resulted in localized acceleration in some parts of the diapir and may explain the distribution pattern of this unit in Fig. 11.

IMPLICATIONS OF MODEL FOR HYDROCARBON EXPLORATION AND DIAPIRISM IN THE FLINDERS RANGES

The diapiric structure at Upalinna is interpreted to consist of a number of smaller diapirs that evolved within a larger body. If the mushroom model/ polydiapir interpretation is correct, then it may apply more widely to diapirism in the Flinders Ranges. Diapirs are effective traps for hydrocarbons and the mushroom/polydiapir model also has important implications for hydrocarbon exploration in and adjacent to these structures.

The capacity of a diapir to trap hydrocarbons is strongly dependent on the dome shape, which is in turn a function of viscosity contrast between the source layer and its cover. Where a source layer is inclined, for example at the edge of a basin or the updip side of salt withdrawal (eg Lemon, 1985). diapirs may preferentially overhang the downdip side. These overhangs would also be effective traps. If steepening of strata is encountered just below strata with regional dip and some distance from the diapir, it would suggest that the post-diapir stage had been reached. This is the most favourable level for a overhang to form and is an attractive level at which to deflect the drillhole toward the dome to test for an overhang trap.

The post-diapir stage can be recognized by two features:

1. The level at which dip of the surrounding strata is equal to the regional dip marks the point where the rate of withdrawal in the rim syncline has declined to zero (Jackson and Galloway, 1984). This level commonly coincides with the level of maximum overhang.

2. The level above which sedimentary units in the tertiary peripheral sink do not thicken toward the diapir (Fig. 14B) also indicates cessation of

withdrawal from beneath the sink.

Gas can accumulate in the residual high between two adjacent withdrawal basins. A number of potential situations exist in the section from Yadnapunda Diapir and passing through the Martins Well Dome to the Bibliando Dome. However, in the Gulf Coast, abundant hydrocarbons have been trapped closed to salt diapirs. This suggests that either petroleum migrated very early, before the structure had grown significantly, or lateral migration is subordinate to vertical migration around domes (Jackson and Galloway, 1984). In this example, hydrocarbons migrated up the flanks of the dome vertically, perhaps exploiting the fractured aureole around a salt stock, until trapped at higher levels.

CONCLUSIONS

The Upalinna Diapir displays features commonly associated with piercement structures, such as a polygonal plan view, brecciated sediments of evaporitic affinity, upturning of sediments at the margin of the diapir and radial faults.

The diapiric structure at Upalinna is interpreted to consist of a number of smaller diapirs that evolved within a larger body. The proposed mushroom model/polydiapir interpretation may also be applicable to other diapirs in the Flinders Ranges.

The internal and external structures associated with mushroom diapirs and polydiapirs are effective traps for hydrocarbons.

Sequence stratigraphy of Umberatana Group sediments has provided a framework for intra-regional chronostratigraphic correlation. The development of Marinoan sequence boundaries in the central and northern Flinders Ranges may have been affected by periods of active diapirism concomitant with sedimentation.

RECOMMENDATIONS

Recent mapping of the Upalinna Diapir suggests that a number of aspects warrant further investigation:

1. Application of the mushroom diapir model to other diapirs of the Adelaide Geosyncline eg Yadnapunda Diapir 15 km northeast of Upalinna.
2. Mapping between Upalinna, Martins Well, Bibliando and Worumba to supplement gravity and magnetic surveys.
3. Sequence analysis of the upper Umberatana Group on an intra-regional basis.

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APPENDIX 1

Petrographic despcriptions, Upalinna core complex.

APPENDIX 2

Petrographic descriptions, Upalinna rim complex.

APPENDIX 3

Chemical analyses, Upalinna core complex.

APPENDIX 4

Stable isotope analyses, Upalinna rim complex.

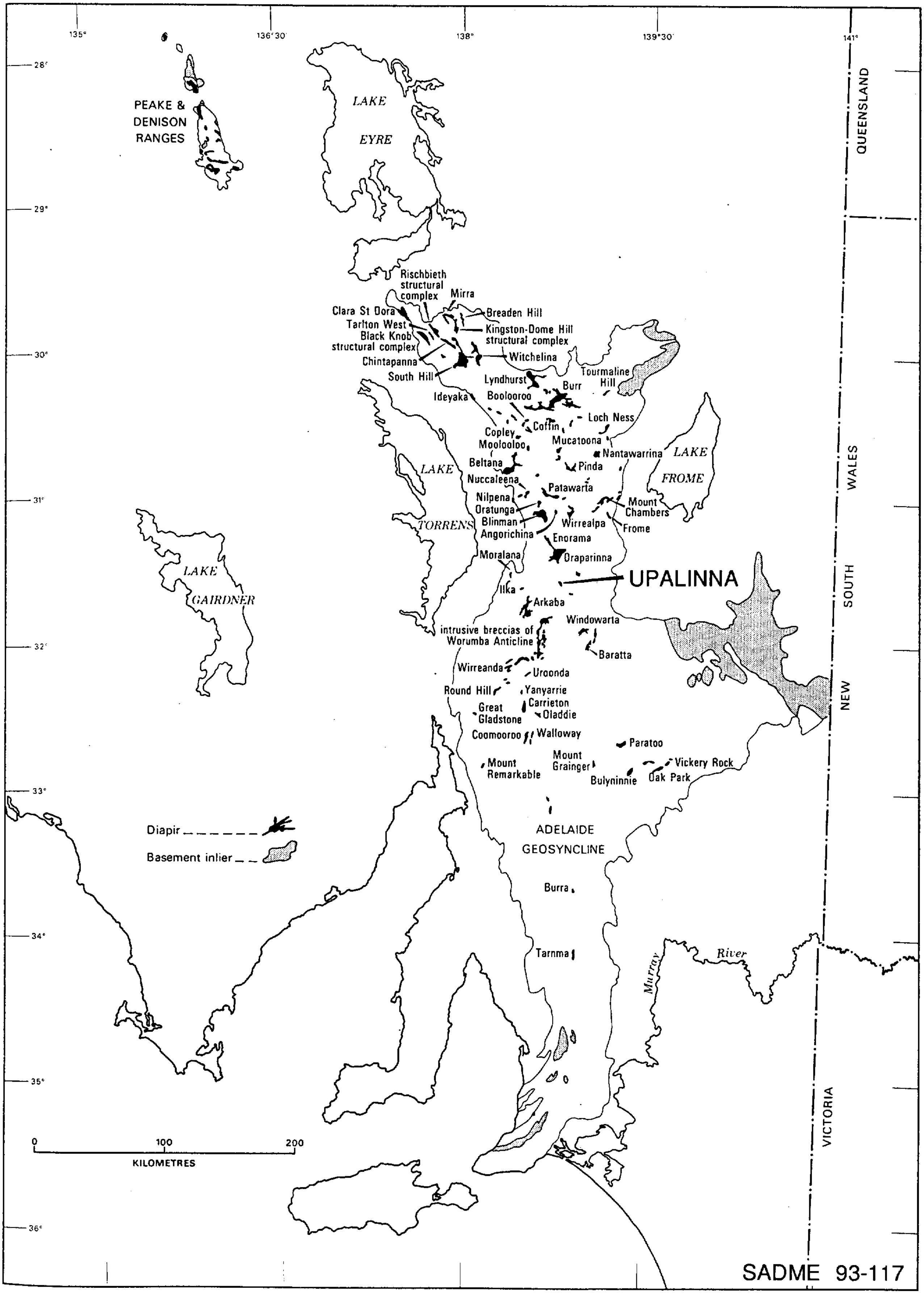

Figure 1. Diapirs and zones of disrupted Callanna Group of the Adelaide Geosyncline (after Preiss, 1987).

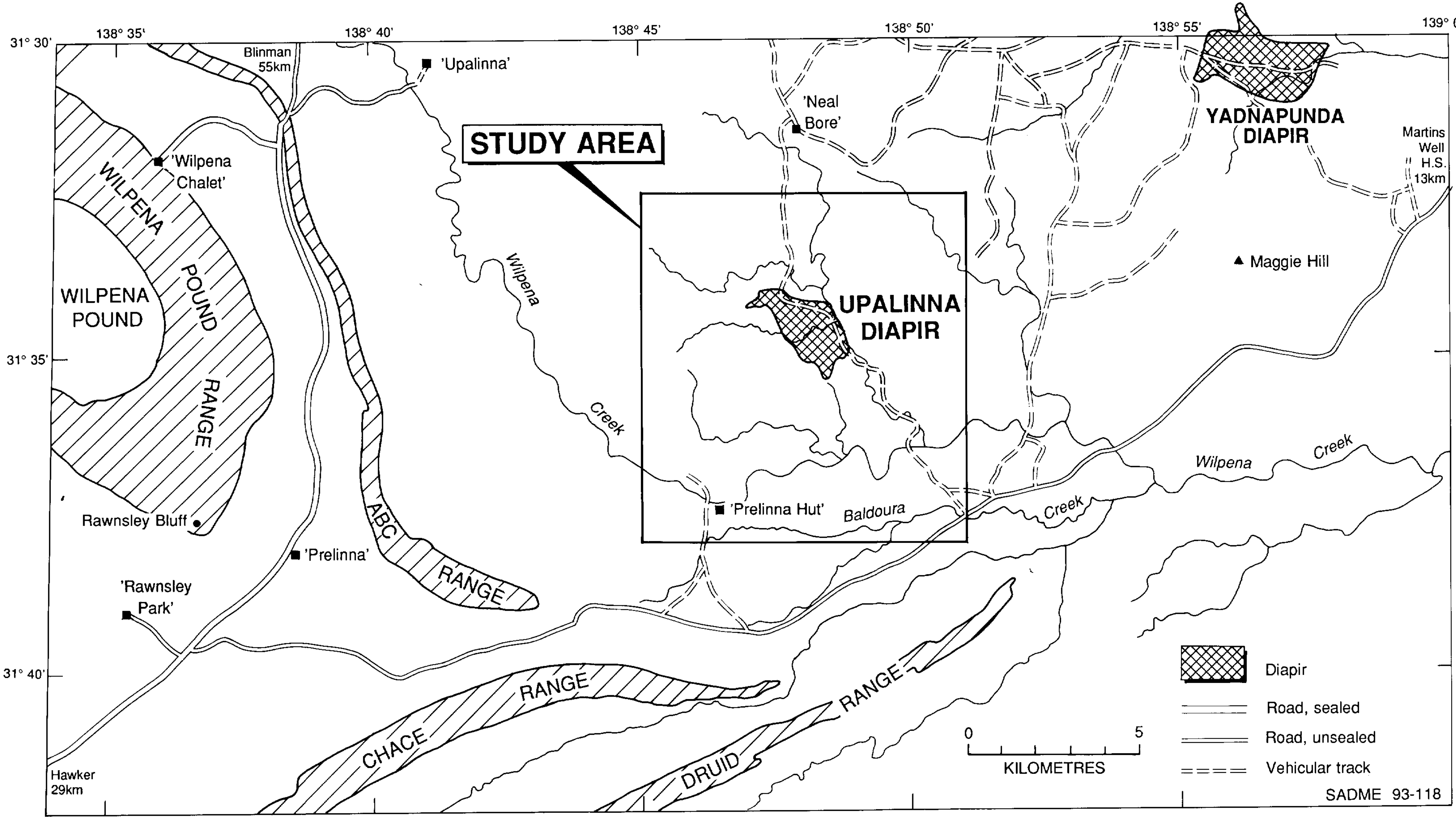

Figure 2. Locality map of the study area and the Upalinna Diapir.

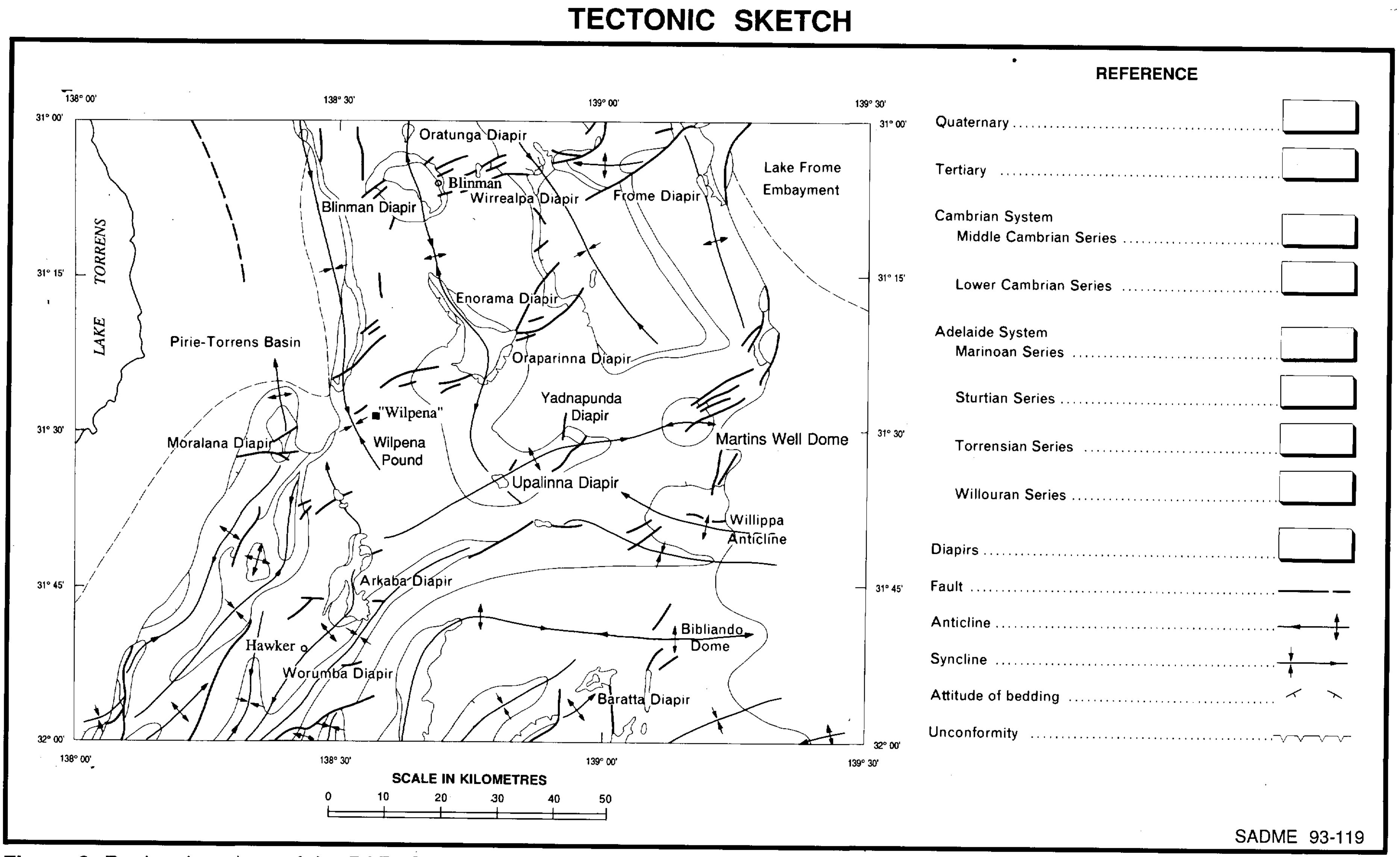

Figure 3. Regional geology of the PARACHILNA 1:250 000 map sheet, showing major structural trends (after Dalgarno and Johnson, 1966).

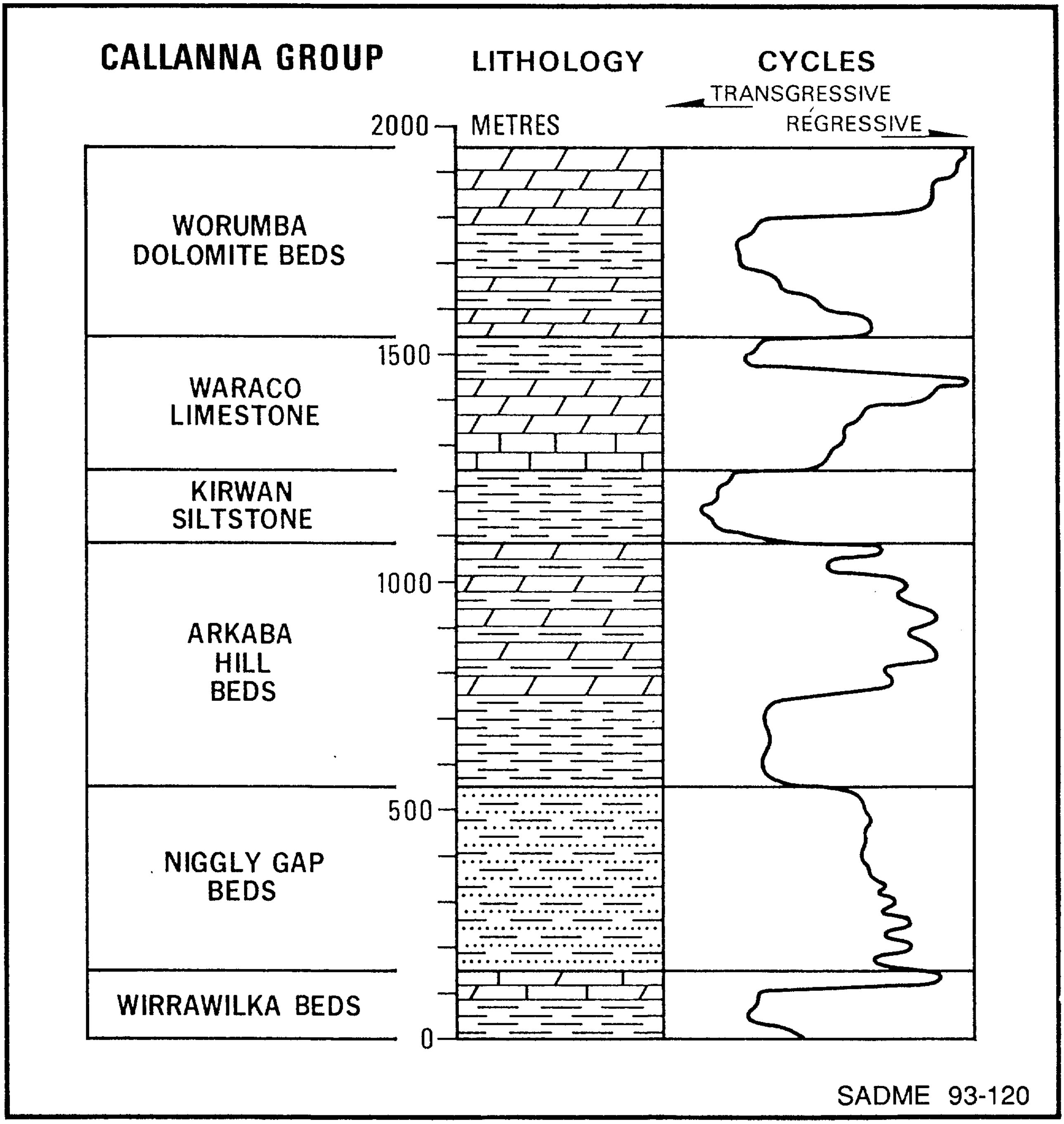

Figure 4. Stratigraphy of the Callanna Group in the central Flinders Ranges (after Preiss, 1985).

GEOLOGY OF THE UPALINNA DIAPIR

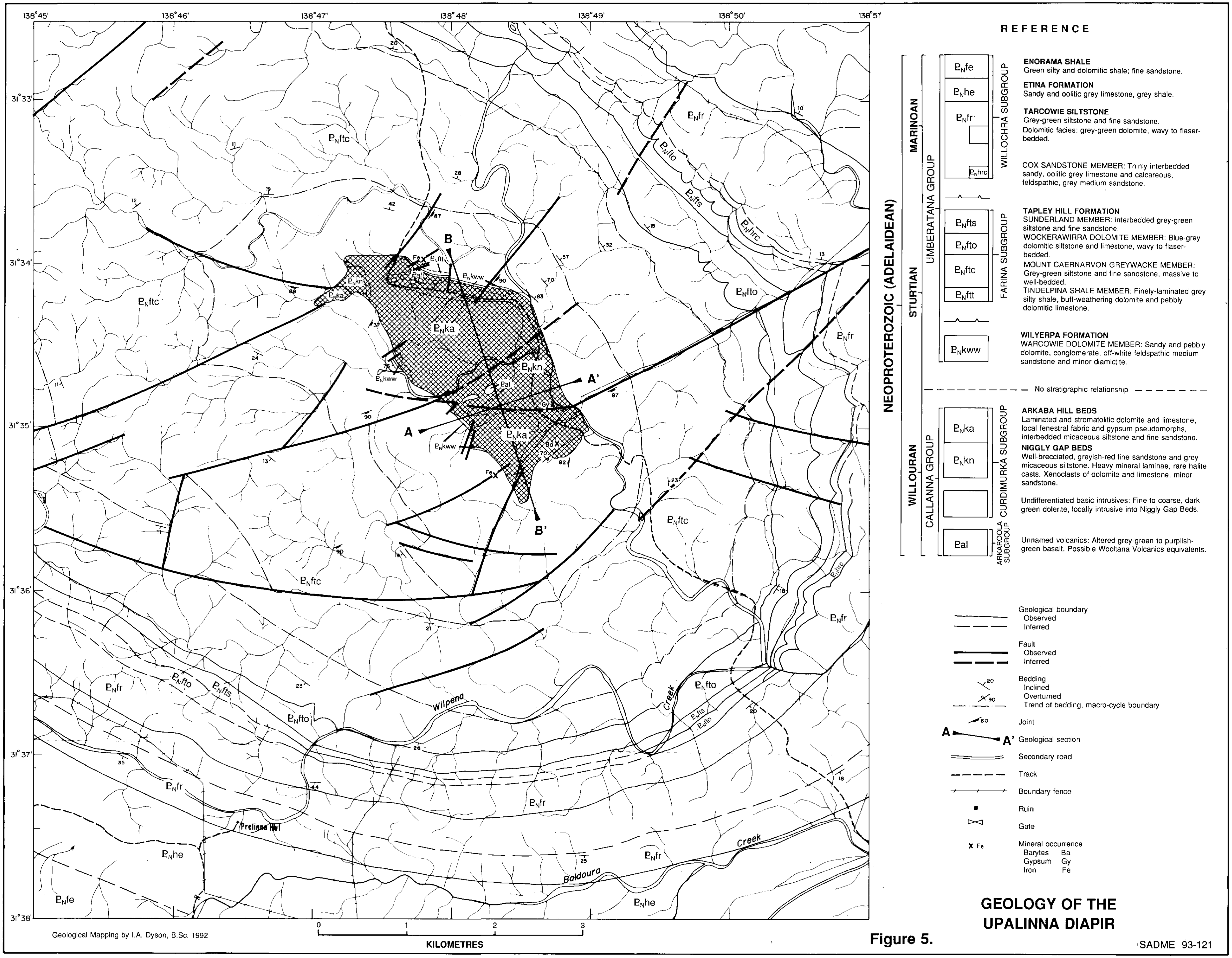

Figure 5.

DETAILED SECTION OF WILYERPA FORMATION UPALINNA DIAPIR

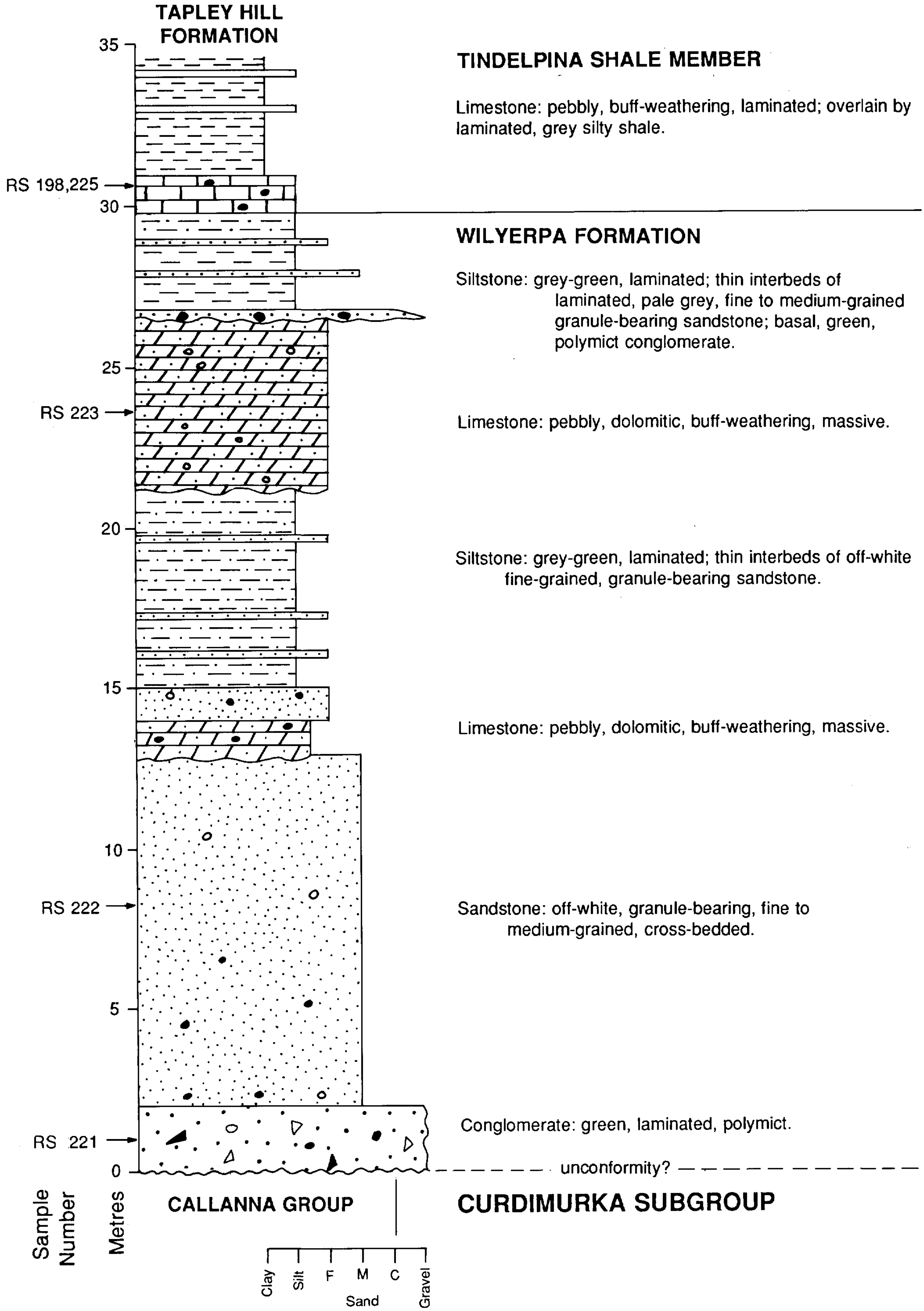

Figure 6.

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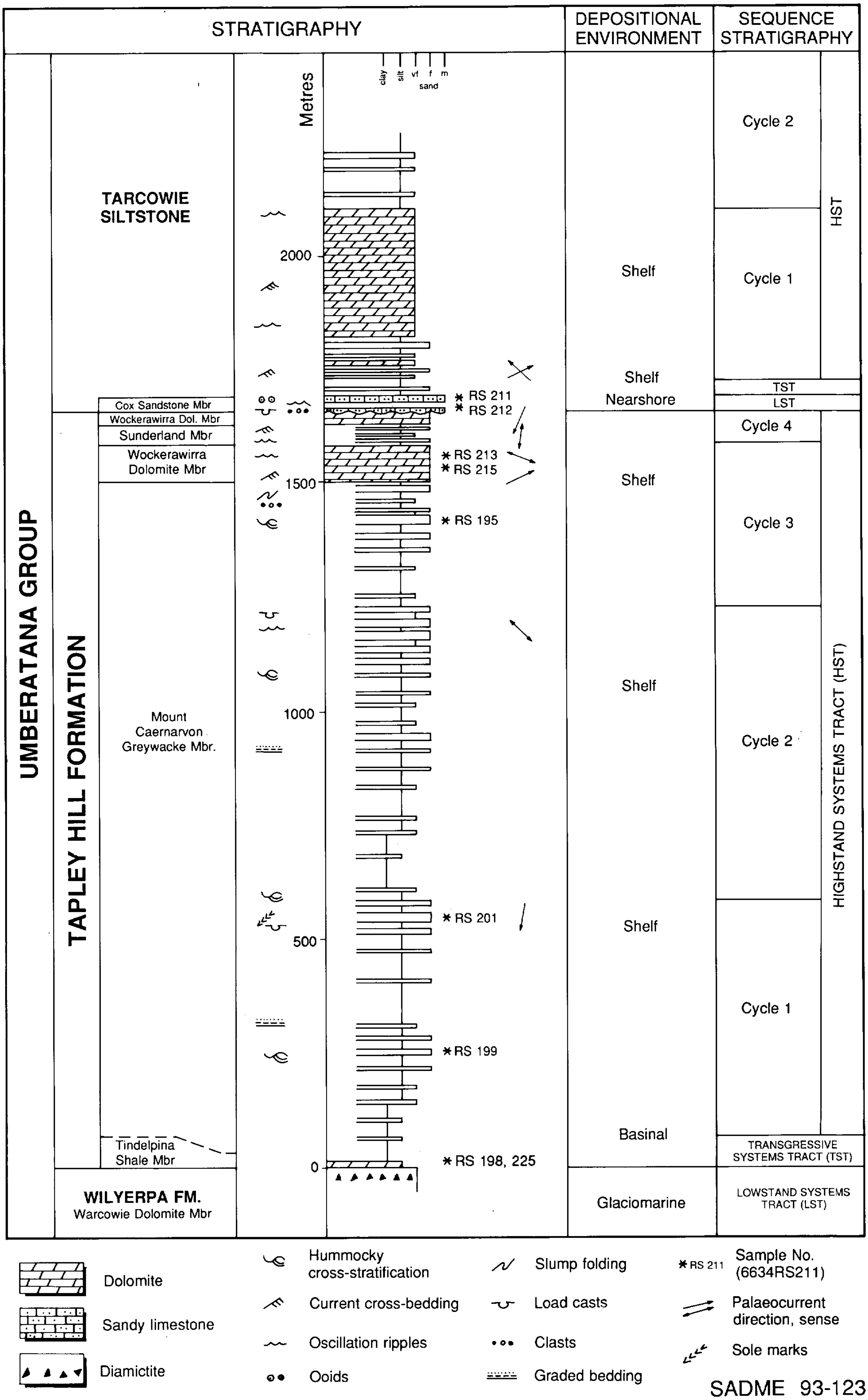

Figure 7. Stratigraphy of the Tapley Hill Formation and lower Tarcowie Siltstone.

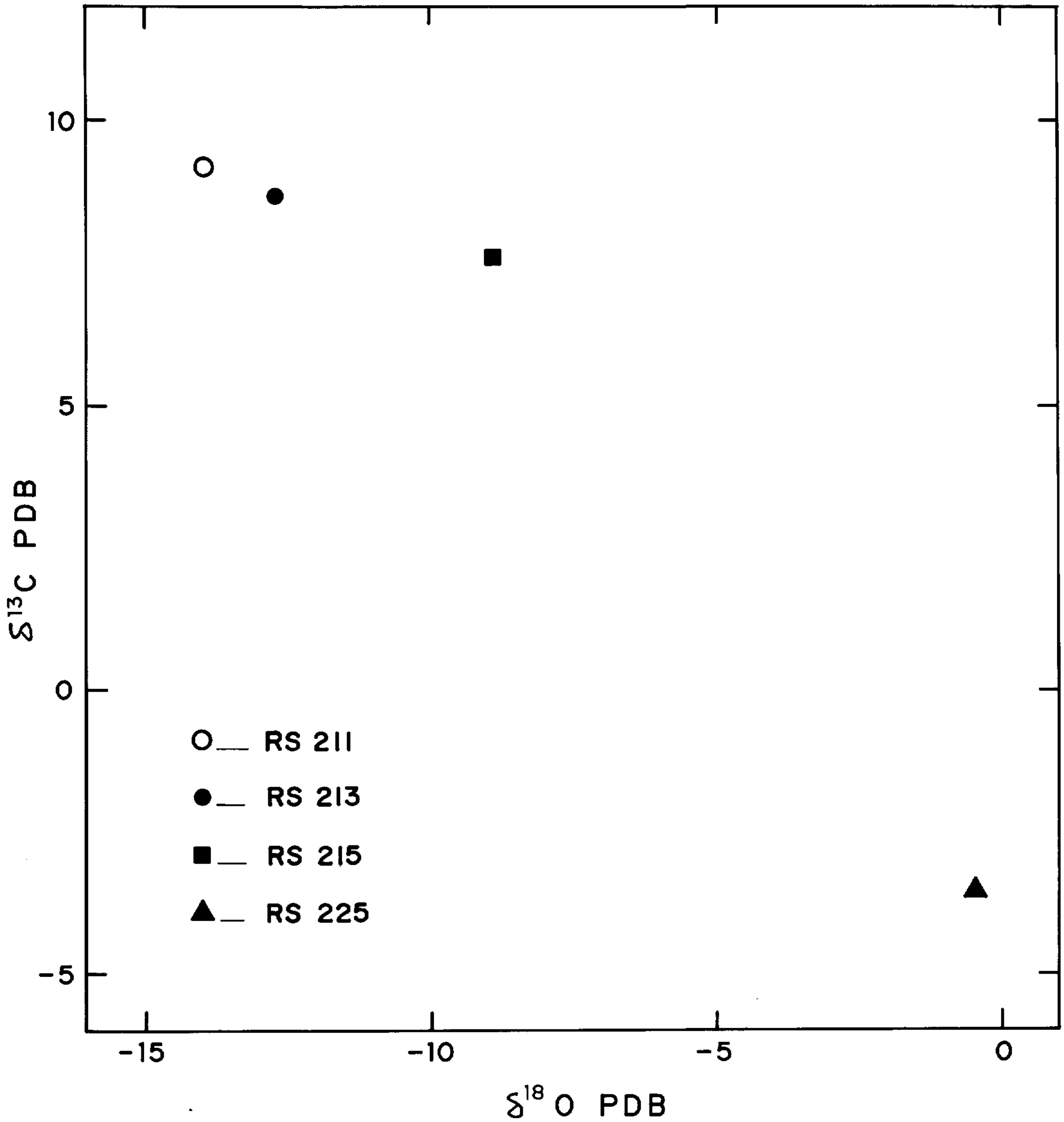

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Figure 8. Carbon and oxygen isotope analyses from selected carbonates in the Umberatana Group. Stratigraphy of samples shown in Figure 7.

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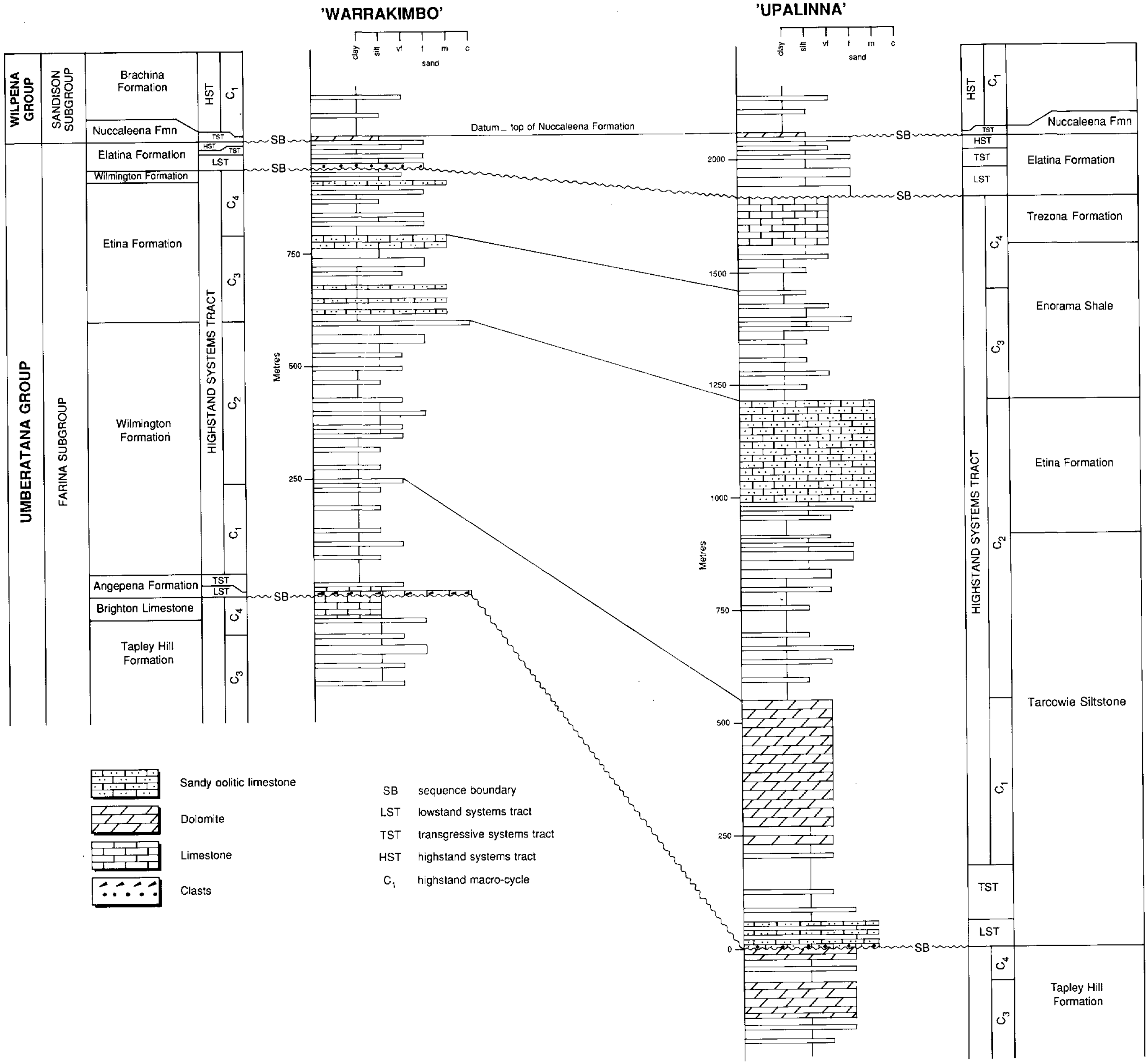

Figure 9. Correlation of the upper Umberatana Group from measured sections at Warrakimbo and Upalinna.

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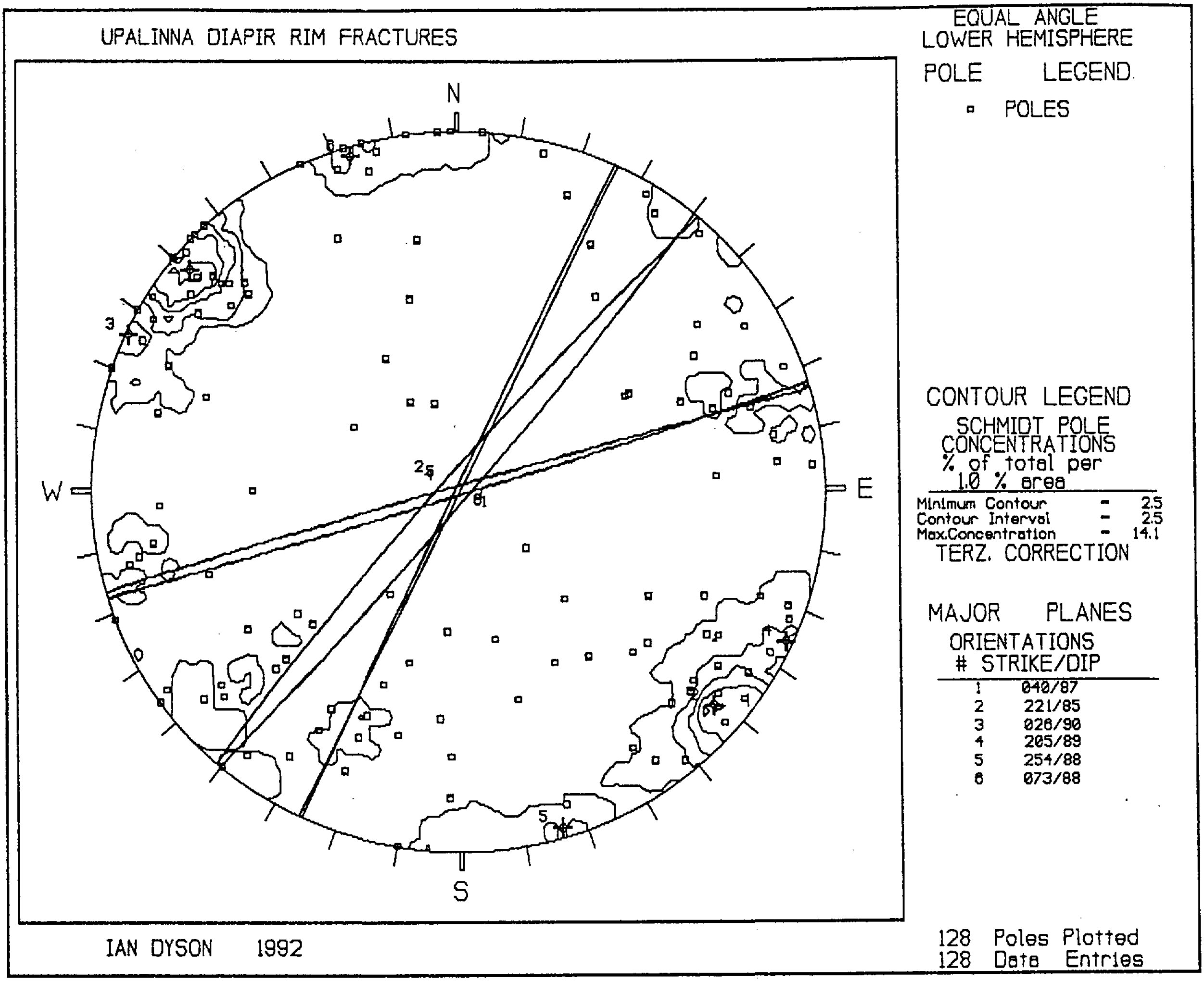

Figure 10.

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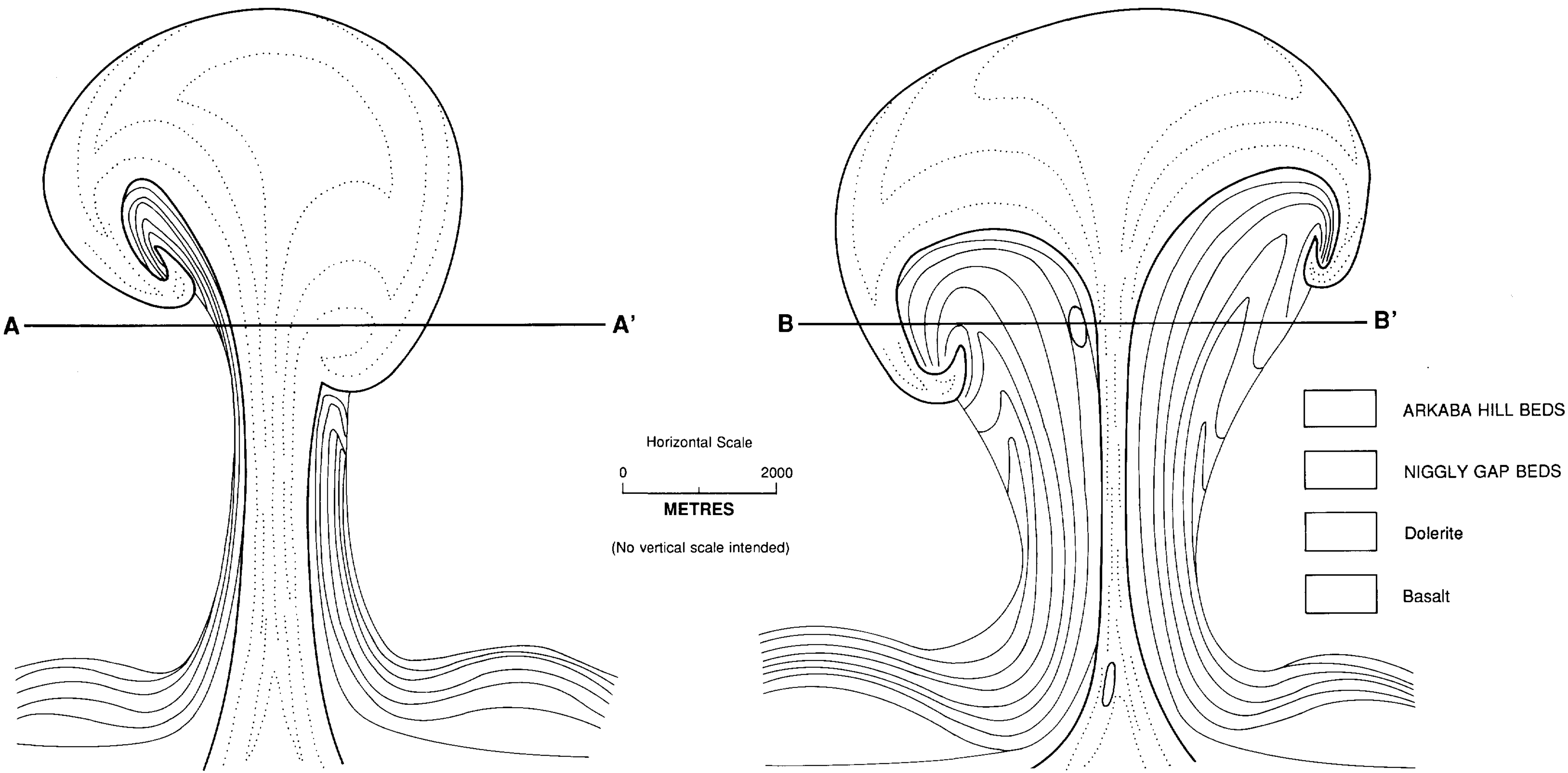

Figure 11. Vertical sections through the mushroom model of the Upalinna Diapir.

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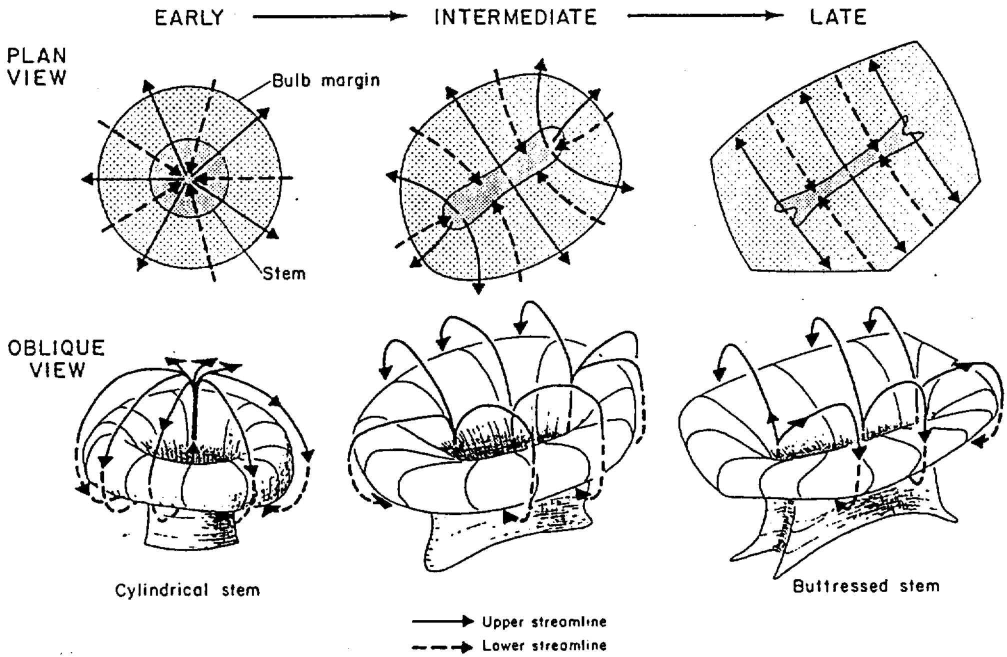

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Figure 12. Evolution of an axisymmetric mushroom diapir into a polygonal mushroom diapir (after Jackson *et al,* 1990).

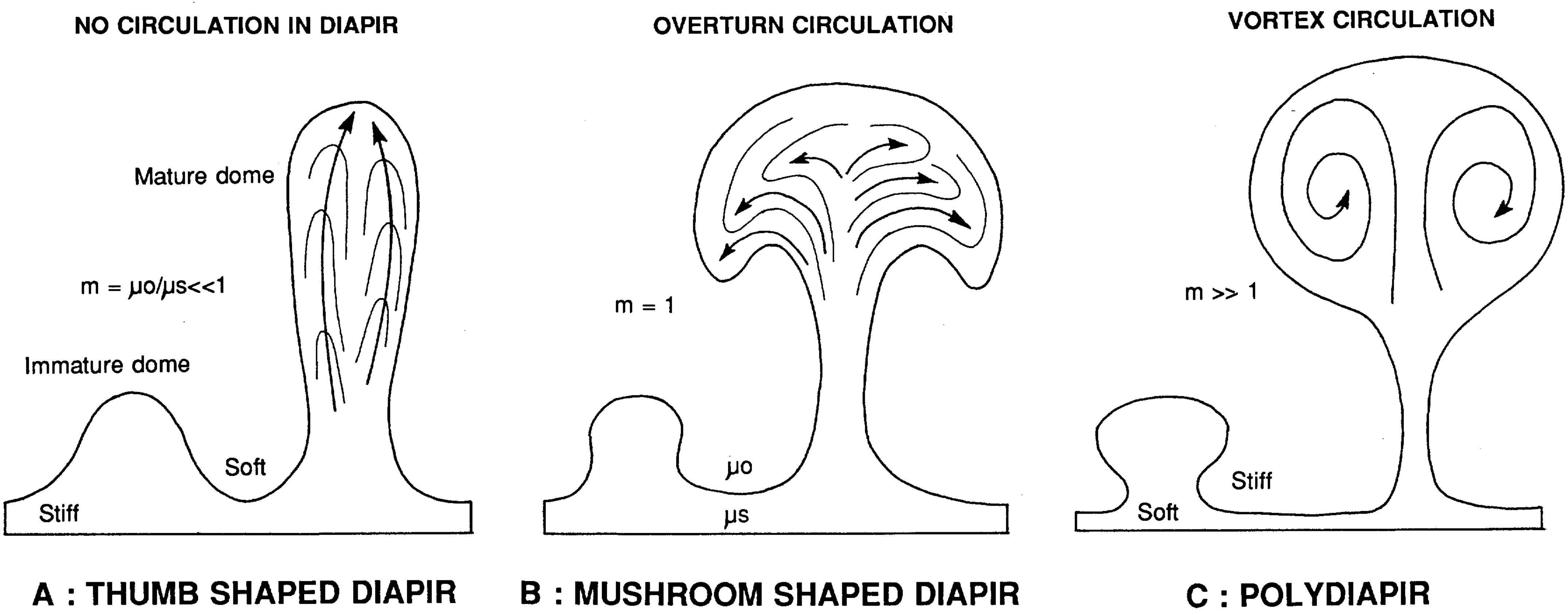

Figure 13. Schematic effects of viscosity contrast on shapes of immature and mature domes (after Jackson and Galloway, 1984; Jackson and Talbot, 1986).

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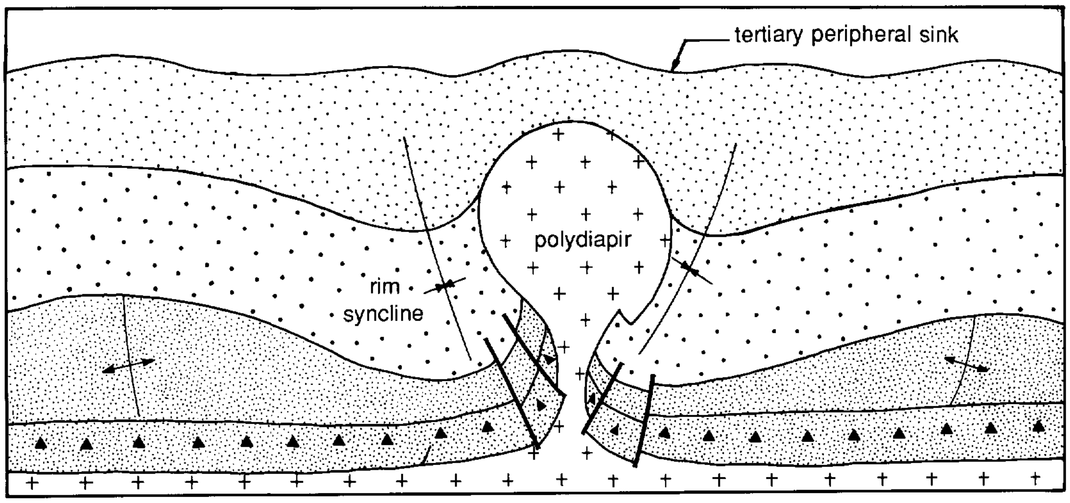
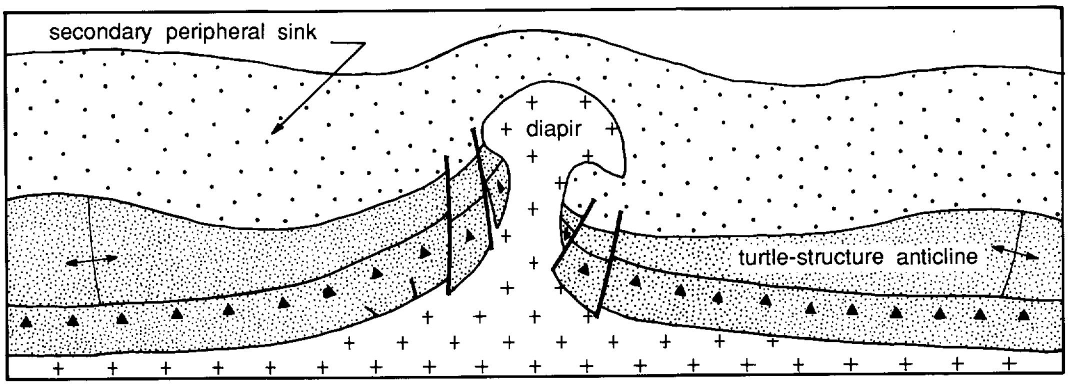
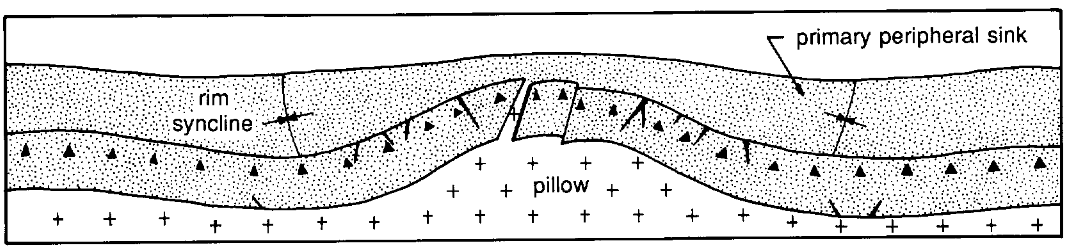


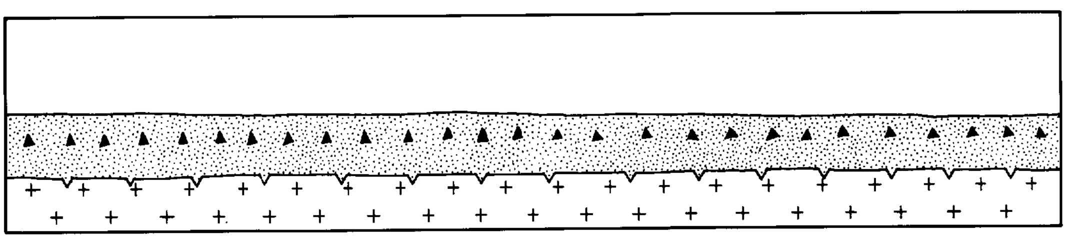
E Development of polydiapir as diapir continues to rise relative to surrounding strata.



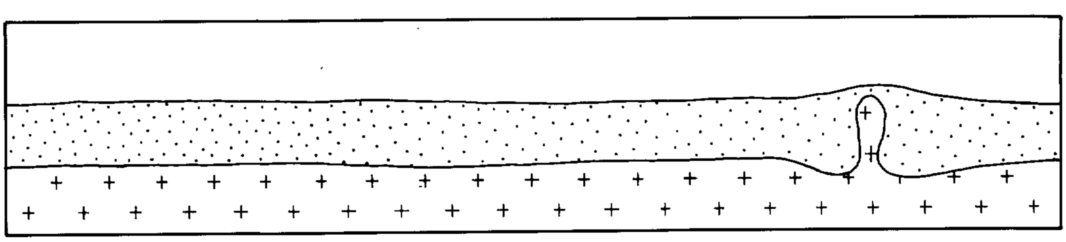
D Pillow grows towards diapir stage and inverts to become a turtle-structure anticline.



C Pillow formed by sedimentary loading and regional compression. Deposition of sediments in peripheral sink.



B Erosion of Burra Group sediments. Deposition of Umberatana Group sediments commences.



A Deposition of Callana Group evaporites and possible early diapirism into Burra Group sediments of unknown thickness.

SADME 93-130

Figure 14. Structural and sedimentary evolution of the Upalinna Diapir and surrounding sediments.