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Stratigraphy, Sedimentology and Tectonic Evolution of the El Sherana and Edith River Groups, Northern Territory, Australia. Record 1991/108.

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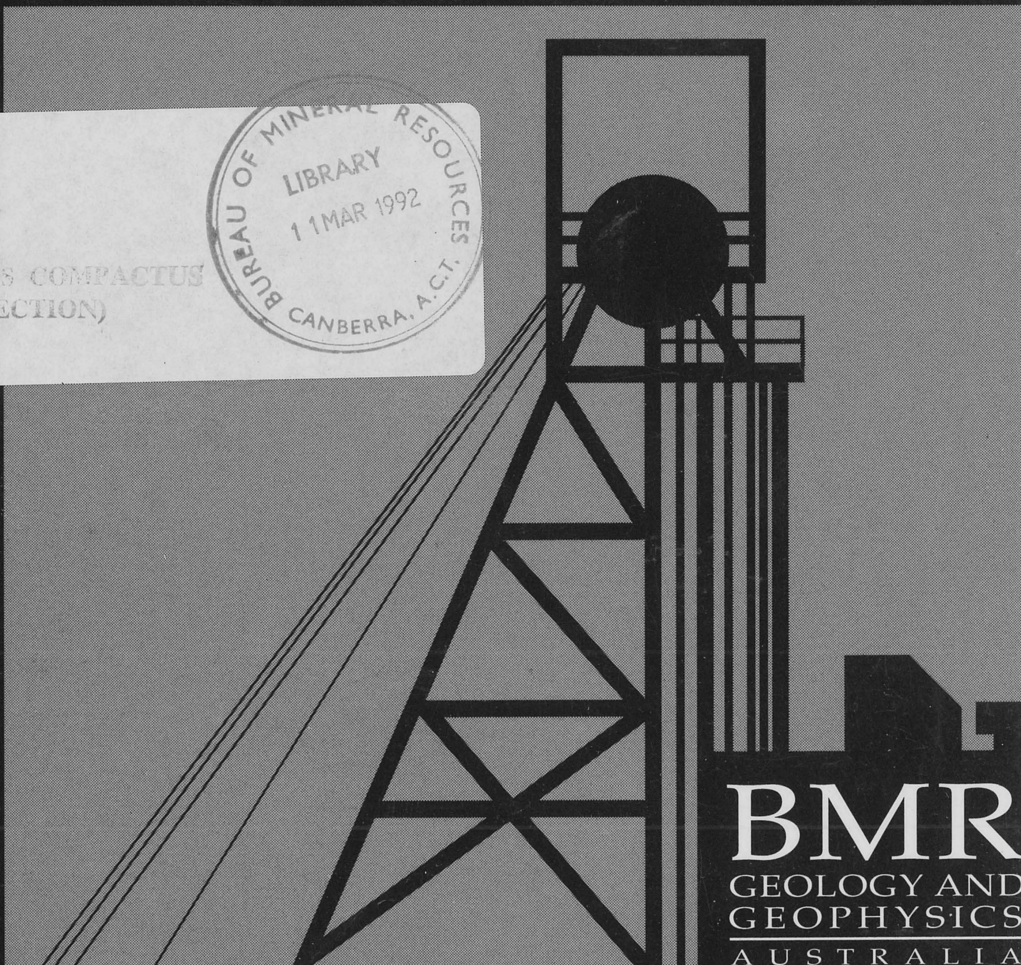

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Stratigraphy, Sedimentology and Tectonic Evolution of the El Sherana and Edith River Groups, Northern Territory, Australia. Record 1991/108.

A contribution to the BMR Kakadu Conservation Zone Project 1987-1992

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This report was prepared by Mr S.Julio Friedmann whilst acting as contractor to the Bureau of Mineral Resources, Geology and Geophysics, for the BMR South Alligator Conservation Zone project in 1989. It is the actual report as prepared by the contractor with no modifications to the text. The work presented in this report was carried out under the supervision of Professor John P. Grotzinger of Massachusetts Institute of Technology, Cambridge, Massachusetts, U.S.A., and has been submitted as partial fulfilment of the degree of Master of Science at Massachusetts Institute of Technology.

The terms of the contract were to undertake detailed facies and stratigraphic mapping in and adjacent to the South Alligator Conservation Zone. The resulting 1: 10 000 scale map and map commentary is included in an appendix to the report.

L. Wyborn

Kakadu Project Manager

1987 - 1991.

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STRATIGRAPHY, SEDIMENTOLOGY AND TECTONIC EVOLUTION OF THE 1.86 Ga EL SHERANA AND EDITH RIVER GROUPS, NORTHERN TERRITORY, AUSTRALIA

by S. Julio Friedmann

ABSTRACT

The 1.86 Ga El Sherana/Edith River Basin of Northern Territory, Australia formed during a period of documented world-wide orogenesis. The basin stratigraphy overlies Wilson cycle sediments of the Pine Creek Orogen, the final stages of which resulted in foreland basin sedimentation and deformation, metamorphism, and uplift of the entire early Proterozoic sedimentary prism. The El Sherana and Edith River Groups consist of braid-plain sediments, ignimbrites and felsic volcanics, and lacustrine turbidites. These units pinch-out against antecedent valley-and-ridge topography, the geometry of which is chiefly controlled by structures in the underlying Pine Creek Supergroup.

All members of the El Sherana and Edith River Groups are bounded by erosional disconformities. These are documented by reversals in paleocurrent trends and by depocenter migration, syntectonic sedimentation, erosional removal of stratigraphy, and erosional paleovalleys with sedimentologically distinct fill. One episode of syntectonic sedimentation is preserved in a small strike-slip basin exhumed in the center of the study area. A tectonic origin is suggested for unconformity generation.

The El Sherana/Edith River stratigraphy developed during orogenesis to the north. Basin subsidence began within only several million years of foreland deposition, compressional deformation, and metamorphism in the underlying Pine Creek Supergroup. Observed synsedimentary faults within the basin are of strike-slip and normal type. Due to the uncertain location and geometry of the initial basin margins, it is uncertain what the immediate mechanism for basin subsidence was.

There are striking similarities between events in the Pine Creek Inlier and northern Australia and events in northwest Canada from ~2.0-1.65 Ga. This observation prompts a tentative correlation.

INTRODUCTION

The end of the Early Proterozoic, from 2.0-1.8 Ga, was a period of global orogenic activity characterized by the assemblage of micro-continents into larger blocks (Etheridge et al., 1986; Hoffman, 1990). The Pine Creek orogen, Northern Territory, Australia, is an inlier from this period containing sediments from a full orogenic cycle. Deposition of the El Sherana and Edith River Groups (Needham et al., 1980, 1988; Stuart Smith et al., 1980, 1988) immediately followed unroofing of the Pine Creek Orogen. They are exposed in the South Alligator Valley (Fig. 1), an area of economically significant mineral deposits, chiefly uranium, with the recent discovery of economic Au-P.G.E.

The origin of the El Sherana/Edith River basin is difficult to assess, since its margins are hidden and the present geometry of the basin is probably not representative its original size or shape. It is thus difficult to accurately predict the local geology and to understand the regional tectono-stratigraphic framework. By determining the stratigraphy of the basin and by mapping contacts, however, one can characterize the processes which dominated basin formation. In addition, palaeocurrent analysis, petrography, and detailed sedimentological studies provide new constraints on timing of faulting, provenance of sediments, depositional environments, and tectonic style. Contributions of this project could include a detailed look at a volcanic-sedimentary basin during an intriguing period in Earth history, further constraints on mineralization in the South Alligator Valley, and evaluation of basin formation models.

Data presented in this paper are the result of three months in the field and several months laboratory work. The results are part of the Bureau of Mineral Resources ongoing resource assessment of the Kakadu Stage 3 Conservation Zone. The paper begins with discussion of the stratigraphy and sedimentology of the Pine Creek Supergroup and the El Sherana and Edith River Groups, followed by petrographic analyses of the El Sherana/Edith River sediments, a tectonic overview, interpretation, and conclusions regarding the basin as a whole.

Pine Creek Supergroup

The Pine Creek Supergroup is a new term proposed for the sequence of low-grade metasedimentary rocks which serve as basement for the El Sherana and Edith River Groups in the South Alligator Valley and are present in other parts of the orogen. It is convenient to refer to this sequence with one term, which reflects a history of successive rifting, thermal subsidence, and foreland basin evolution. This term is strictly an informal designation and has not undergone review for acceptance into accepted stratigraphic nomenclature.

Previous Work

The Pine Creek Stratigraphy is well described and summarized in Needham et al. (1988) and Stuart Smith et al. (1988) as the following groups: the Namoona Group, the Mount Partridge Group, the South Alligator Group, and the Finniss River Group. Needham et. al. (1980) and Etheridge et al. (1986) interpret these units to represent discrete tectonic depositional regimes as interpreted from the dominant lithofacies. The Namoona and Mount Partridge Groups, composed chiefly of interbedded meta-siltstones, dolomitic sandstones, and coarse quartz sandstones and conglomerates, represent continental rifting. The South Alligator Group consists of fine siliciclastics and minor banded ironstone, graphitic siltstone, and tuff; it represents sedimentation during thermal contraction of extended lithosphere. The Finniss River Group, synorogenic feldspatholithic sandstones and siltstones, records sedimentation in a convergent foreland basin. All of these groups and their respective members crop out within the study area. Needham et al. (1985) and Stuart-Smith et al. (1988) interpret the Mount Partridge Group and South Alligator Group as relatively shallow-water facies and the Finniss River Group as distal turbidites.

The Koolpin Formation: Observations and Discussion

The predominant stratigraphic unit of the Pine Creek Supergroup developed in the study area is the Koolpin Formation, the lower unit of the South Alligator Group. It consists of finely interbedded hematitic siltstone and chert. It can be subdivided into several units: a basal sequence of chert or jasper and iron siltstone, with bed thicknesses of several centimeters; an interval of interbedded fine sandstones and siltstones, typically highly cleaved and altered; and a felsic volcanic member several meters thick with rare quartz phenocrysts approximately one millimeter in size. It is capped by the Gerowie Tuff, a felsic crystal tuff which acts as a regional marker horizon.

One can subdivide the basal cherty member of the Koolpin into stratal packages as a function of chert bed thickness and continuity (R. Valenta, pers. comm., 1989). One interval is characterized by millimeter-scale lamination of chert and iron siltstone continuous for hundreds of meters. Another interval below the felsic volcanic unit and above the siltstone member contains nodular chert nodules several centimeters across which define a single horizon within iron-rich siltstone. Another interval is dominated by equal quantity of chert and siltstone with beds several centimeters thick.

The frequency and degree of tight, isoclinal folding at all scales within the Koolpin Formation and overlying units suggests significant shortening with respect to the underlying Mount Partridge Group. One documented thrust occurs north of the study area within the Mundogie 1:100,000 scale map sheet (Stuart-Smith et al., 1984) in which Mundogie Sandstone of the Mount Partridge Group is thrust above Koolpin Formation, using the Koolpin as a detachment. Future work could further differentiate between all chert and hematitic siltstone units within the Koolpin Formation based on the small scale bedding habit of the chert. This would provide the tools necessary to recognize minor or major thrust faults of pre El-Sherana age which are likely to exist (R. Valenta, pers. comm. 1989). Deformation in the Pine Creek Supergroup is discussed under Tectonic History below.

STRATIGRAPHY AND SEDIMENTOLOGY

The El Sherana and Edith River Groups (fig. 2) overlie Early Proterozoic (~2.1-1.85 Ga) Pine Creek Supergroup and underlie the middle Proterozoic (~1.65 Ga) Kombolgie Sandstone of the Katherine River Group. The El Sherana Group consists of three units: the Coronation Sandstone, the Pul Pul Rhyolite, and the Big Sunday Formation. The Edith River Group is made up of the Kurrundie Sandstone and the Plum Tree Volcanics. Each of these five units is separated by an erosional unconformity named after the unit which overlies it. Due to our research emphasis, the Plum Tree Volcanics are not considered here; descriptions are presented in Needham et al., (1988).

The authors' stratigraphy appears in figures 2 and 3. Figure 3 is a fence diagram compiled from mapping and measured sections. All major stratigraphic contacts were walked out along strike to observe the critical stratigraphic relationships. The labelled measured sections provide thickness control.

Previous Work

Walpole et al. (1968) first synthesized the regional stratigraphy and recognized the units discussed here. The Edith River Group was mapped as part of the Katherine River Group and the Kurrundie and Plum Tree as members of the Kombolgie Formation. At the same time, the El Sherana Group was mapped as the Edith River Volcanics.

Stuart-Smith et al. (1988) and Needham et.al. (1988) revised the stratigraphy of Walpole et al. Their interpretation is shown in (fig. 2a). They separated the El Sherana Group and Edith River Group from the overlying Kombolgie Sandstone and each other, outlining the key stratigraphy mentioned above. They also identified a major unconformity between the El Sherana and Edith River Groups, which they attributed to the Maud Creek Event.

The current study further refines the stratigraphic relationships within and between the El Sherana and Edith River Groups.

El Sherana Group

Coronation Unconformity

The lowermost contact between the Pine Creek Supergroup and the El Sherana/Edith River Groups is the Coronation Unconformity. Units of the El Sherana and Edith River Groups lap out against steeply dipping paleotopography along this contact. Resistant units in the Pine Creek Supergroup, such as Koolpin Formation cherty ironstone or Mundogie sandstone quartz arenites, form resistant ridges while less resistant units, like the Finniss River Group phyllites, form deep paleo-lows. This valley-and-ridge topography parallels the regional northwest strike of structural elements in the Pine Creek Supergroup, and is locally exhumed such that one may walk out paleovalley margins for several hundreds of meters. Relief along paleovalleys is typically tens of meters, though locally paleorelief can be several hundred meters.

Before development of this unconformity, Pine Creek Supergroup sediments underwent burial, greenschist-grade metamorphism, deformation, and uplift (Stuart-Smith et al., 1980). The Gerowie Tuff, a crystal tuff roughly in the middle of the South Alligator Group, is well constrained in age at 1885 ± 2 Ma , while the Pul Pul Rhyolite is recently dated at 1870 ± 5 Ma (BMR unpub. data). This could provide, as a conservative estimate, a 15 m.y. interval for deposition of the Pine Creek flysch package, burial, metamorphism, deformation, and uplift.

Locally along the Coronation Unconformity, there is a siliceous, hematitic, phosphatic breccia known as the Scinto breccia. It is best developed within a kilometer southeast of Saddle Ridge (fig. 1), though most occurrences of Scinto breccia are not stratigraphic breccias but rather altered fault gouge. Preliminary optical petrology for the fault rocks and discussion of interpretations can be found below under petrography.

Coronation Sandstone

Facies: In most places, the Coronation Sandstone is typically < 100 m in thickness, although it locally exceeds 600 m (as at section 4, fig. 3). It has an irregular geometry, changing as much as 400 m over several kilometers and pinching out locally against antecedent topography (fig. 3). It contains several interbedded mafic and felsic volcanic flows which act as prominent marker horizons.

There are several facies in the basal Coronation Sandstone. The coarsest is a massively bedded, clast-supported, imbricated-cobble conglomerate (fig. 4a). Deposits are lensoidal and pinch out laterally against paleotopography on a scale of .5 km. Beds are typically 1-5 m thick, though commonly amalgamated forming sequences up to 44 m. Cobbles are well-rounded to rounded with mean maximum clast size of 38.5 cm and the largest clast at 55 cm. Another basal facies contains.planar bedded, decimeter-scale interbedded fine to coarse sandstones and matrix- and clast-supported conglomerates, occasionally imbricated. Sandstones range from poorly sorted, medium-sized to coarse, massively bedded sequences to fine- to medium-grained, planar-laminated deposits. Local, centimeter- to meter-scale scours are filled with either trough cross-bedded or planar-bedded sandstone. Lastly, there is a planar-crossbedded facies which contains clast-supported, imbricated, rounded-pebble conglomerate grading to and interbedded with planar-crossbedded pebbly sandstone. Beds are typically ~ 1 m thick, ranging from 10 cm to ~ 5 m. Numerous scour surfaces with as much as 4 m relief cut across bedding within the sequence (fig. 5); these surfaces are commonly overlain by a lag of coarse imbricated clasts which grades abruptly into planar-crossbedded pebbly sandstone. This facies has a mean maximum clast size of 49 cm, with blocks of Koolpin Formation shale as large as 70 cm long. The polymictic clast variations among the various lithotypes can be seen in Table 1.

This basal assemblage is incised and overlain by coarse to pebbly trough-crossbedded sandstone with a maximum observed thickness of 75 m. These deposits are relatively continuous and can be mapped and walked along strike for over 10 km. Individual troughs are 30 to 150 cm thick, 2 to 10 m in length (fig. 4c), and often have a coarse lag at their base; mean maximum clast size is 19 cm, with the largest 30 cm. Grain size is generally 1 to 2 mm in diameter with few pebbles. This facies is compositionally better sorted than the basal facies, with monocrystalline quartz and chert as the predominant framework grains.

There are minor intervals of fine sediment cropping out only in the area of the section #4 (fig. 1), where an atypically thick section of Coronation Sandstone has been preserved. Here, decimeter- to meter-sized beds of very fine to medium sandstone containing current ripples are interbedded with 2 to 3 m intervals of laminated mudstone. In all other study areas, this facies is absent, and preserved only as rare intraclasts.

Paleocurrent measurements were taken predominantly from exhumed troughs with fewer taken from planar tabular cross-sets. Predominant paleodrainage flowed to the northwest with low dispersion (fig. 6).

Interpretation: The facies of the Coronation Sandstone are most consistent with those of medial braided river systems (Miall, 1977; Cant, 1978). Most of the conglomerates are clast-supported, imbricated-clast cobble conglomerates indicating channel or bar-avalanche deposition. Paleocurrents (fig. 6) are unimodal with low dispersion. Matrix-supported conglomerates are rare, with no evidence for debris-flow deposits. The paucity of fine sand and the lack of mud suggests a lack of overbank deposits, which could relate either to slow subsidence rates or removal of fine detritus due to removal by scouring (Cant, 1978). This is especially true before the advent of land plants, which stabilized banks and altered the dominant bedload and runoff (Schumm, 1968; Cotter, 1978). The observations suggest a mature braid plain depositional environment (Cant, 1978; McCormick and Grotzinger, 1990) rather than an alluvial fan model which would be characterized by high paleocurrent dispersion and debris flow deposits (Rust and Koster, 1984).

Given the size of planar tabular bedforms (minimum of two meters height) and size of exhumed troughs (often ten or fifteen meters in length with one meter preserved relief), the minimum water depth at time of deposition was roughly 6 m (Middleton and Southard, 1984), with a likelihood for considerably deeper water. This suggests a large river system of considerable length which in turn implies a basin larger than the outcrop reaches of the South Alligator Valley. This is consistent with the lack of preserved basin margins or marginal facies. It is therefore likely that the true aerial extent of the Coronation Sandstone paleovalley is greater than present exposure would indicate. Persistent deep water flow and a lack of fines also suggest that the paleoclimate of deposition was humid. Although the facies assemblages are partly explained by an abundant sand supply and the absence of land plants (Cotter, 1978; Andrews-Speed, 1986), this does not explain the vertical persistence of large bedforms requiring deep flow. McCormick and Grotzinger (1990) use similar criteria to make a humid paleoenvironmental interpretation, in contrast to ancient deposits containing abundant mud and debris flow deposition typical of semi-arid or arid environments (Winston, 1978, 1986).

Volcanics: The volcanics of the Coronation Sandstone are typically highly altered and contain hematite, amorphous or microcrystaline silica, chlorite, and sericite. This makes field classification difficult. Two units, one felsic and one mafic, are continuous over several kilometers and relatively unaltered. The felsic volcanic unit is a 4 to 6.5 m thick rhyolite containing quartz and potassium feldspar phenocrysts. It lacks pyroclastic fabrics such as fiamme or lapilli and may be a hypabyssal sill. The mafic unit, a basalt up to 40 m thick, contains amygdules of chert or calcite up to 10 m below the present top. The basalt occurs high in the section, and can be found to rest directly on paleohighs defined by erosional relief on older units. It should be stressed, however, that the volcanics are volumetrically small despite being excellent marker horizons.

Pul Pul Rhyolite Unconformity

A major erosional surface below the Pul Pul Rhyolite removes as much as 100 m of Coronation Sandstone stratigraphy. The units down to and including the basalt horizon are cut out (fig. 3) and filled with a variety of local facies.

A distinct unit which occurs along this horizon is a clast-supported conglomerate, <8 m in maximum thickness, composed predominantly of basalt clasts (Table 1, fig.7a). The basalt clasts are largely angular, whereas other clast lithotypes are rounded to well rounded. The basalt is similar to the marker volcanic within the Coronation Sandstone, which is erosionally absent in locations containing the basalt-clast conglomerate. The conglomerate also contains many clasts of coarse, sub-angular to rounded sandstone, which are interpreted as being derived in part from the Coronation Sandstone. This facies laps out against either Coronation Sandstone or the metasedimentary basement and is overlain by the Pul Pul Rhyolite.

At El Sherana (fig. 1), there is evidence for growth faulting with syntectonic sedimentation which post-dates deposition of the Coronation Sandstone and pre-dates extrusion of the Pul Pul Rhyolite (fig. 8). A horizon of Coronation Sandstone and underlying basement were down-faulted ~50 m and both basement and Coronation Sandstone exhibits drag folding. A succession of very coarse, matrix-supported conglomerates and coarse, poorly sorted sandstones, some containing basalt clasts, were deposited along the fault margin footwall. This event took place, however, before the deposition of the basalt-clast conglomerate horizon described above, which disconformably overlies both this package and the Coronation Sandstone.

Deposition, tectonism, and erosion along the Pul Pul Unconformity, therefore, may significantly postdate deposition of the Coronation Sandstone. Erosion may relate to readjustment of the regional base level, to basin tectonism, and to the extrusion of the Pul Pul Rhyolite.

Pul Pul Rhyolite

Facies: The Pul Pul Rhyolite is a succession of amalgamated felsic volcanics and interbedded volcaniclastics at least several hundred meters thick which rests on Coronation Sandstone, basalt-clast conglomerate, and Pine Creek Supergroup basement highs (fig. 3). There are two predominant facies in the study area; an ignimbrite flow and an upper quartz-feldspar porphyry. The base of the Pul Pul Rhyolite is complicated interval ~5 m thick. It incorporates clasts of underlying lithologies (chiefly greywacke, sandstone, and dolerite cobbles) which are all typically well-rounded. The matrix is rhyolitic and contains fiamme which wrap around cobbles and flow breccia. Above this interval is a flow banded sequence containing centimeter-thick layers of devitrified glass. This layer is locally incised and filled with thin beds of volcanic sand and silt.

The ignimbrite flow contains relics of fiamme ~1 cm to 15 cm long (fig. 7b). The fiamme are flattened at the base, and become less flattened towards the top of the flow. Their strikes and dips mimic local paleotopography. The groundmass is dense and vitreous, typically orange-pink, and contains abundant quartz and potassium feldspar phenocrysts. Columnar jointing is common. The flow(s) is at least 100 m thick, with its thickness varying chiefly as a function of antecedent topography.

The overlying quartz-feldspar porphyry is at least 130 m thick, typically lavender in color, and contains abundant alkali feldspar and quartz phenocrysts > 1 mm in size. The contact between the ignimbrite and the quartz-feldspar porphyry is sharp. The basal portion of the porphyry does not contain fragments of the ignimbrite, nor are the platy clasts obvious exhumed fiamme. It does, however, contains chips of angular lithic fragments, most commonly pale green and platy (fig. 7c,d), typically several cm in size; these are most abundant at the base. The porphyry commonly exhibits a white-mottled discoloration which nucleates about potassium feldspars and platy lithic fragments (fig. 7d).

Interpretation: Due to its presence above the Pul Pul Unconformity, and the reversal of paleocurrent data associated with the Big Sunday Formation (fig. 6), the extrusion of the Pul Pul Rhyolite is here genetically linked to the Pul Pul Unconformity and the growth of the Big Sunday deposystem. The contact between the ignimbrite flow and the quartz-feldspar porphyry is taken as the best available datum for reconstruction (fig. 3).

Although commonly volcanic successions thicken away from their vents (Cas and Wright 1988), the southeast-thickening geometry of the Pul Pul Rhyolite is probably at least in part related to uplift, erosion, and base level change in the north accompanying sedimentation in the Big Sunday Formation (see Generation of Unconformities below). At present, the location of the Pul Pul vent is unconstrained.

Big Sunday Unconformity

The top of the Pul Pul Rhyolite is deeply incised, with local paleo-valleys of 40 m or more filled with imbricated, clast-supported conglomerates (fig. 3, 10). In most of the study area, the valley fills are grouped with the overlying Kurrundie Sandstone, making that contact part of the Edith River Unconformity. To the southeast, however, the Big Sunday Formation sits above the Pul Pul Rhyolite and in turn is disconformably overlain by the Kurrundie Sandstone.

An incised valley crops out southeast of the study area along the unconformity. The valley fill facies consist of interbedded rhyolite flows, epiclastic and quartz-rich sandstones and conglomerates, and peperites, which are not found at any other location in the region. The rhyolite flows occur in beds ~ 1 m thick and are ignimbritic and aphanitic. One horizon contains abundant pumice fragments which grade laterally into a dense, aphanitic feldspar porphyry across several meters. Some flows include many well rounded cobbles in a volcanic matrix. The conglomerates are clast-supported and texturally mature. Clasts are rounded to well-rounded and are predominantly composed of vein quartz, dolerite, and felsic volcanic fragments. The sandstones are both compositionally and texturally immature. The peperites consist of wispy patches of felsic volcanic resting in a matrix of immature sand, with coarse grains collecting along one edge of a felsic patch (fig. 9). These deposits are similar to other sub-aqueous, shallow water extrusions (e.g., Withe and Busby- Spera, 1987).

New dating on this particular valley fill sequence (Jagodzinski, 1992) suggests that this particular package and the overlying strata are considerably younger (~1830 Ma) than the El Sherana succession (~1870 Ma). The implications of the new dates are discussed below.

This valley fill succession is probably linked genetically to the extrusion of the Pul Pul Rhyolite. It appears to be disconformably overlain by the Big Sunday Formation; however, the contact between the valley fill and the Big Sunday Formation is not actually exposed. Assuming that the extrusion of the Pul Pul Rhyolite occurred in a geological instant, this unconformity is likely a consequence of post-eruptive erosion rather than tectonism.

Big Sunday Formation

Facies: The Big Sunday Formation is a succession of tuffs, tuffaceous siltstones, greywackes, and sandstone in excess of 140 m. Although a complete section was not measured, the section presented (appendix A6) represents the largest continuous and correlatable exposure of the total thickness. The chief facies of the Big Sunday consist of tuffs and tuffaceous siltstones and include as well fine- to coarse-grained, massive- to planar-bedded feldspathic greywacke.

The Big Sunday has been correlated to the 2200 m thick Tollis Formation to the south by Needham and Stuart-Smith (1985) on stratigraphic and lithologic grounds (fig. 12). We feel that the Tollis Formation is likely to be older than the Big Sunday and probably correlates to the Finniss River Group of the Pine Creek Supergroup (figs. 1, 2b) for reasons discussed below under petrography.

Tuffaceous sediment, either pyroclastic or epiclastic, is the chief component of Big Sunday Formation fine-grained rocks, although it often contains a component of quartz-rich silt and detrital mica. Planar laminated, sometimes cleaved tuffs dominate the lower 76 m of the section. Locally, meter-scale intervals dominated by Bouma-sequence structures are present within the tuffs. Commonly, only parts of Bouma sequences are preserved, predominantly T_{c-e}, with increasingly abundant T_{b-e}, T_{a-c} or just T_{a-b} towards the top of the section. Beds are frequently amalgamated. Because tuffaceous material of uniform grain size dominates the lower sequence, there may be no grain size variation between or within some turbidites, i.e., Tb-e have the same grain size. Upper bedding surfaces are often exposed and show exhumed climbing ripples. At the base of the section, planar lamination alone is common. Typically, turbidite intervals lie between thick intervals of undisturbed, finely laminated tuffaceous shales. Rarely, an undulose, low-angle cross-stratification is developed higher in the section, occasionally with fully exhumed hummocks and swales.

Massive feldspathic greywackes are common in the upper half of the measured section. These represent T_a turbidites, as indicated by the occasional preservation of T_{a-b} and T_{a-c}. Bed thickness increases towards the top of the sequence from < 10 cm to over one meter; grain size also increases from very fine to coarse. Many beds fine upward, but their contact with tuffs is always an abrupt transition. Some fine-grained greywacke beds contain intraclasts.

Paleocurrent orientation points southeast with low dispersion (fig. 6). Measurements came from exhumed ripple trains and climbing ripples exposed in three dimensions.

Interpretation: The dominance of classic turbidites (Walker 1984, 1978) strongly suggests that the bulk of the Big Sunday Formation is subaqueous. The stratigraphic position of the Big Sunday Formation between subaerially deposited sandstones and the restricted geography of the deposits suggest that they might be lacustrine. The sequence matches descriptions of deltaic turbidites (Lunegard et al., 1985), submarine fan facies (Normark, 1978), and lacustrine turbidites (Link, 1982). These depositional environments are difficult to distinguish, and insufficient cross-basin and strike-parallel work exists to document independently either geometry. The occurrence of HCS high in the section, coarsening- and thickening-upwards packages, plus the increasing abundance of Bouma bc and Bouma abc structures, suggests overall shallowing upwards or increased sedimentary supply (Walker, 1978).

This unit is not found with the study area, and we have only studied it above the volcanic succession which may be younger than the El Sherana succession. If it is true that the Big Sunday is really only found in this context and location, and that E. Jagodzinski's new dates and interpretations are true, then this unit is not a member of the El Sherana Group and there may in fact be no Big Sunday Formation at all.

Edith River Group

The Kurrundie Unconformity

The Kurrundie Sandstone overlies the Pul Pul Rhyolite, the Big Sunday Formation, and the Pine Creek Supergroup along the Kurrundie Unconformity. Stuart-Smith et al. (1988) describe angular discordance between the Big Sunday Formation and the Kurrundie Sandstone along this contact. This discordance is not developed within the study area. Rather, one finds the Kurrundie Sandstone deposited in paleovalleys cut into the Pul Pul Rhyolite (fig. 10a).

We interpret the unconformity to be a product of some tectonic event which may be related to development of the Palette Sub-basin. The genesis of the Kurrundie Unconformity is discussed with the Palette system below as well as in the tectonic history chapter.

Kurrundie Sandstone

These sandstones were deposited above the Big Sunday Formation south of the study area and directly on the Pul Pul Rhyolite above the Kurrundie Unconformity within the study area. It is a relatively thick (> 300 m) succession of siliciclastic sediments capped by the Plum Tree volcanics and/or disconformably overlain by the platform cover sandstone of the Katherine River Group.

The Kurrundie Sandstone is pervasively iron-stained, ranging from a dark red-purple color to *liesegang* bands. This staining, although characteristic of the Kurrundie Sandstone, is not strictly diagnostic; *liesegang* banding occurs in the Coronation Sandstone, as well as the overlying Kombolgie Sandstone and even in portions of the Pul Pul Rhyolite.

Facies: The Kurrundie Sandstone displays many facies, including a cobble-boulder, channel-fill conglomerate; coarse- to fine-grained planar laminated sandstone; coarse- to fine-grained trough-crossbedded sandstone; planar-laminated siltstones/shales; and quartz-pebble conglomerate.

The cobble-boulder conglomerate (fig. 10b) has a clast-supported framework of rounded to well rounded, imbricated clasts composed predominantly of Pul Pul Rhyolite, with a maximum mean clast size as large as 43.3 cm (Table 1). One bed is dominated by clasts of Pul Pul Rhyolite breccia (fig. 10b; refer to Palette Sub-basin stratigraphy and fig. 11a). Beds are typically several meters thick and are interbedded with trough cross-bedded or planar-bedded sandstones, usually < 1 m in thickness (fig. 10a). Sandstone bodies rest in erosional scours on the conglomerate and are laterally discontinuous. This sandstone, as well as the matrix for the conglomerate, is composed mostly of lithic fragments.

Interbedded with the conglomerates are decimeter- to meter-scale lenses of coarse- to fine-grained planar-laminated lithic to quartz arenite. These are gradually replaced with fine- to coarse-grained trough-crossbedded lithic to quartz arenite towards the top of the conglomerates. This facies then continues for at least 40 m above the massive conglomerates. Troughs can be as large as four meters long, but are generally less than one meter long and 20 cm in relief (fig. 10c). In the coarsest sediment, rounded pebbles line the bases of individual troughs.

Siltstones, shales, and fine lithic to quartz arenites rest abruptly above an interval of trough-crossbedded sandstone, though they ultimately grade upward into thin trough-crossbedded sandstone. The shales are quartz-rich and are interbedded with planar-laminated lenses of fine quartz sand several centimeters thick.

The upper section is a conglomeratic sequence dominated by well rounded clasts of vein quartz 2-5 cm in size. Planar- and trough-crossbedded pebble sandstone and imbricated conglomerate are interbedded and grade between each other, with bed thickness ~ 30 - 150 cm. This sand is the most compositionally mature of the Kurrundie Sandstone samples (fig. 12).

Interpretation: A braid-plain environment is consistent with all facies except for the boulder conglomerates. The conglomerates, like those of the Coronation Sandstone, suggest a valley-fill environment of deposition based on imbrication, clast size and rounding, clast-supported fabric, and lateral discontinuity.

The rather thick (> 40 m) interval of fine siliciclastics probably represents a change in sediment supply. The abruptness of the transition from sand to shale suggests an episodic change in basin equilibrium, which then gradually returned to a more proximal braidplain environment. The root cause of such a shift could be tectonic (e.g. Burbank and Talling, 1991; Talling, 1991)

Palette Sub-basin

The Palette Sub-basin (fig. 1) is an exhumed outlier on the Scinto Plateau. It contains a number of facies (fig. 11) which suggest a depositional system not present in either the El Sherana or Edith River Groups. Rather, they represent a distinct tectonic environment within the larger succession and provide clear evidence for syntectonic sedimentation after the extrusion of the Pul Pul Rhyolite. The structure of the Palette sub-basin (fig. 13, 14) adds supporting evidence for many of the sedimentological interpretations.

Facies: The facies of Palette (fig. 11) are indicative of high-energy tractional transport and abundant mass wasting. They include rock avalanche breccias; massive to imbricated boulder-cobble conglomerates; matrix-supported conglomeratic breccias; and fine-medium grained sandstones containing ripples, planar bedding, and small troughs.

The rock avalanche breccia sheets (figs. 11a, b) consist of clasts of Pul Pul Rhyolite. Clasts are angular, and the sparse matrix comprises mostly Pul Pul Rhyolite debris with occasional pockets of fine-medium sandstone. There is no clear bedding; minor beds of planar-laminated, fine-medium sandstone are present between breccia sheets. These are distinct from fine-medium grained sandstone dikes which locally cut breccia sheets, rarely with fitted fabrics (fig 11b), evidence of early cementation. The present mineralogy of the cement is hematite, though the original cement could have been phosphate, carbonate, or even ferricrete.

There are several varieties of conglomerate, divisible by clast composition, rounding, and mean maximum clast size (Table 1, figs. 11c, d). Each deposit is incised and overlain by either another conglomerate or a lens of lithic sandstone; the bounding surfaces may have as much as four meters of local relief (fig. 11d). The basal conglomerates are massive to imbricated, boulder- to cobble-, polymictic, and clast supported; their matrix is medium to fine quartz sand. All other conglomerates are matrix-supported, and clasts range from angular to rounded. Those near the base of the succession tend to lack bedding, sorting, and clast imbrication. The largest clasts show the most rounding.

Well sorted, rounded to well rounded, fine to medium quartz arenites are interbedded with and incise the conglomerates (fig. 11d,e). Planar lamination and trough crossbeds are predominant lower in the sequence; higher in the section climbing ripples appear and then dominate. Mud drapes (< 1 cm thick) separate many beds; drapes have abundant desiccation cracks and form molds of oscillation ripples. Grain size and composition of the arenites (fig. 12) do not vary as a function of stratigraphic position and remain strikingly uniform throughout the sub-basin.

Towards the top of the sequence, conglomerates disappear altogether. The fine to medium sandstones do not continue to scour into underlying beds, but rather have sharp planar bases (fig. 11e). The quartz arenite laps against and ultimately overlies all primary growth faults, thus indicating when fault motion ceased (fig. 14). In at least one case a growth fault reactivated and folded the overlying sandstones (fig. 11f); these were in turn overlain by later flat-lying quartz arenites (fig. 11e).

Interpretation: The facies of the Palette Sub-basin are indicative of high-energy deposition, in particular the breccia sheets and conglomerates. The breccia sheets exhibit many characteristics of air-fall sedimentary breccias (Shreve, 1968, Yarnold and Lombard, 1989). The structures of the quartz sandstones are characteristic of upper flow regime transport (Middleton & Southard, 1984), with the exception of the oscillation ripples and desiccated mud. These probably represent waning flow and local, short-lived ponding. This assemblage of structures probably represents a system of alluvial fans (Rust and Koster, 1984; Winston, 1978) derived from and proximal to the margins of the sub-basin.

Since the fine to medium quartz arenites overlap all growth faults (figs. 13, 14), they must have derived from a different source than the debris-flow conglomerates and compositionally immature basal sandstones; also, the latter two lithotypes do not occur above the margins of the growth faults. This supposition is supported by the high maturity of the quartz sandstone (fig. 12) in contrast to the compositionally and texturally immature conglomerates, as well as by similarities between Palette sand and sand in other lithologies.

Figures 13 and 14 shows an interpretation of the sequence of events in the Palette sub-basin. This interpretation is very well constrained by outcrop scale observation, mapping of stratigraphic and structural relationships, and by composition and association of basin facies. The local tectonic environment resulted in great local relief, high-energy facies, and compositional variance. Sense of stratigraphic throw is usually well constrained, such as the reversal of stratigraphic throw along steep faults (fig. 13). Relative timings of fault motion, however, are typically unconstrained (fig. 13) though locally constrained by overlapping strata (fig. 14).

Due to the degree of offset, abundance of syn-sedimentary faulting, and active margin facies, the development of the Palette sub-basin probably relates to a large-scale regional tectonic event. The outstanding question of the Palette sequence is its age of deposition and hence relation to the rest of the El Sherana/Edith River sequence. It must have developed after the deposition of the Pul Pul Rhyolite, yet its minimum age is poorly constrained since it has no regionally recognizable stratigraphic cap.

We here group the Palette facies with the Kurrundie Sandstone based on the following arguments. First, the Kurrundie Sandstone contains clasts of Pul Pul Rhyolite rock avalanche breccia near Freezing gorge (fig. 10b). Next, there is no evidence of the Edith River Group having been once deposited and then removed, either in the form of preserved stratigraphy or clasts elsewhere in the region. Last, the Palette sub-basin probably opened due to some basin-wide tectonic event which may be correlated to that which deformed the El Sherana group and reversed the basin gradient creating the Edith River Unconformity. The disparity between facies of Palette and the Kurrundie Sandstone successions could be attributed to the different hydraulic conditions created by the tectonic setting. Another possibility is that the Palette sub-basin represents the earliest deposition of the Kurrundie Sandstone; this is consistent with the presence of rock avalanche breccia clasts in the lower Kurrundie at Freezing Gorge.

An alternative scenario would set basin development syn- or post-Kombolgie. Evidence for this model is the maturity of Palette sub-basin sand (fig 12).

Kombolgie Unconformity

The El Sherana and Edith River successions are overlain by the Kombolgie Sandstone (Stuart-Smith et al., 1988), a thick regional cap of meter-scale quartzose sandstones. The contact between the Kombolgie is an angular unconformity with 20-30° of angular discordance. Locally along the base of the Kombolgie are lenses of boulder conglomerate and breccia. These deposits are always poorly sorted, texturally immature, and composed almost exclusively of the lithology on which they lie. Deposition of the Kombolgie sandstone postdates open folding and planation of the underlying Edith River Group.

Summary

Distinctions between the stratigraphy of Needham et al. (1988) and the present interpretation as summarized in fig. 2. The present interpretation chiefly differs in the recognition of demonstrable and mappable unconformities which separate chronostratigraphic blocks. In addition, lithologic packages such as the Coronation sandstone are refined in terms of recognition of key event deposits and both facies- and time-dependent subdivisions of larger stratigraphic blocks. This reduces uncertainty with respect to the volume and range of volcanic and fine siliciclastic material in the section. Finally, the true original extent and geometry of the El Sherana/Edith River basin is poorly constrained due to erosion associated with unconformities, lack of preserved margins or marginal facies, and burial under later platform cover.

PETROGRAPHY

Over one hundred samples were studied petrographically using a polarizing light microscope. Fifteen total point counts are presented in Appendix B, as well as key petrographic descriptions. The counts consider both present mineralogy and original composition of framework grains and, where possible, matrix.

Previous Work

Together, P. Stuart-Smith, S. Needham, and L. Bagas collected and described over one hundred samples for the Stow 1:100,000 map (L. Wyborn, pers. comm.). Those are brief petrographic descriptions to characterize representative rock types, not detailed analyses. In addition, Needham et al. (1988) include six point counts of 1000 points each from the Tollis Formation, their stratigraphic correlative of the Big Sunday Formation. Figure 12 includes the mean of these counts for comparison. Valenta (1991) included several petrographic descriptions from the El Sherana and Edith River Groups.

Needham et al. (1980) and Stuart-Smith et al. (1988) concluded that the El Sherana and Edith River Groups are unmetamorphosed. Contrary to their field and petrographic descriptions, optical analyses by G. Warren (pers. comm.) and Jagodzinski (1992) argue for lower greenschist metamorphism of these units based on the presence of chlorite and epidote replacement textures in thin section.

Geochemical data from this stratigraphic interval is a presented in Etheridge et al. (1986) and Wyborn (1988). Based on a variety of geochemical evidence, L. Wyborn (1988) concluded that El Sherana and Edith River Group volcanics along with many other regional igneous rocks were derived from infracrustal sources. Zircons from the Pul Pul Rhyolite (Page, 1988) are highly discordant and have proved difficult to date. The Pul Pul Rhyolite shows considerable regional variation in composition as a function of hydrothermal alteration (R. Page and L. Wyborn, pers. comm.).

Methods

In order to improve accuracy of point counting, all sandstones and volcanics were stained for plagioclase and K-feldspar. After preparing samples as thin sections, we gave half of each slide a bath in dilute HF for approximately 10 seconds before staining. Staining was otherwise similar to Friedman (1967). This extremity of surface etching proved necessary, as the samples did not initially accept the stain, particularly the sedimentary lithologies. Half baths were given to provide a control for degree of acid etching and staining effectiveness. Unfortunately, due to the high degree of weathering and hydrothermal alteration proper identification and differentiation of lithic fragments and feldspars still proved difficult.

The 15 point counts included 275-350 points per slide. To achieve 95% accuracy, a sample will lie within 2s of compositional assessments, varying from 0-100%, when within a range of 3-12% (Van der Plas and Tobi, 1965). This calculation assumes no further uncertainties; however, due to the advanced state of hydrothermal alteration and weathering in most specimens, there was occasionally considerable uncertainty in grain recognition.

Dorsey (1985) assumes an uncertainty several percent greater than Van der Plas and Tobi (1965) to attain 95% confidence level for compositional estimates due to the likelihood of errors in grain identification. Following her reasoning, we assign a slightly greater uncertainty in compositional estimates, 10-20%, due to the advanced stage of alteration. It is worth noting, however, that the estimates of quartz composition are likely to be closer to the 3-12% statistical deviation due to their relatively pristine and unaltered condition and ease of recognition. None of these error ellipses are shown on the ternary plots (fig. 12)

Coronation Sandstone

Siliciclastics. The Coronation Sandstone ranges in composition from quartz to lithic sandstone. Lithic fragments are mostly reserved as polycrystalline quartz and chert, with uncommon volcanic, sedimentary, and metasedimentary fragments. Alteration of volcanic fragments will be discussed below with the Pul Pul Rhyolite. Feldspars are typically completely altered; the chief mechanisms are clay mineral replacement and vacuolization. It is therefore rather difficult to distinguish between K-spar and plagioclase populations in most circumstances.

Other minerals are also uncommon. Of these, the most prevalent are detrital micas, mostly chlorite then muscovite. Micas are considered to be detrital only when they exhibit deformation and fracture attributable solely to compaction, e.g., folding about a framework grain with a sharp contact between grains, or transport. It is therefore likely that some fraction of the phyllosilicate population which was not counted as detrital may be so. Other heavy grains, including sphene and epidote, appear throughout the section. Although often in a state of alteration, epidote grains can be quite pristine (fig. 15a,j).

The framework grains are bound chiefly by grain suturing and syntaxial overgrowths of quartz. Other matrix and cement is in the form of late-stage amorphous silica, probably chert. Much interstitial material is altered or replaced with high- and low-birefringent phyllosilicate minerals. These high-birefringence types include authigenic white micas including illite and chlorite both white and green, and the low-birefringence varieties are probably smectite and mixed-layer clays. Authigenic mineral size ranges from several microns to several hundred microns. Very large masses occur both as books and randomly oriented crystal aggregates which cut across the boundaries of framework grains. Chlorite also occurs within quartz as well, commonly as vermicular chlorite or as a thin blanket over portions of grains rather than as true replacement.

Due to alteration, it is difficult to determine if earlier matrix or cements were important or common. However, there are rare patches of well preserved phosphate cements. Phosphate is suggested based on birefringence and crystal habit, which is akin to wavellite. The cement can have a coarse, bladed habit, which may be primary or secondary, or a multilaminate, colliform habit (c.f. Southgate, 1986), consisting of laminae composed of isopachous fibres (fig. 15b,c). In addition, one can observe that the cement has included small quartz grains within fibrous bundles. Quartz grains have pristine, unaltered boundaries, in contrast to small, high-birefringence clays which cut across relict fibrous bundles irregularly. This suggests that the authigenic minerals replace phosphate.

Volcanics. Most volcanics in the Coronation Sandstone are altered beyond recognition both in outcrop and under the microscope. The predominant replacement minerals are hematite and silica, and are probably related to both devitrification of groundmass and hydrothermal alteration associated with faulting and perhaps mineralization. The most important volcanic, both volumetrically and stratigraphically, is the thick amygdaloidal basalt horizon described above. In thin section, none of the original minerals remains; but in relatively pristine samples, mineral pseudomorphs are preserved, chiefly silica after plagioclase laths. In addition, silica pseudomorphs after fibrous rinds are common. Present amygdule fill consists of chert or calcite.

The rhyolite which lies below the basalt horizon near Saddle Ridge (fig. 3, Appendix Ac) is also relatively fresh. However, its petrography is essentially identical to the Pul Pul Rhyolite quartz feldspar porphyry described below, and will not be elaborated upon here.

Conclusions. Detrital chlorite, muscovite, sphene, and epidote combined with the chert and metamorphic rock fragments and extremely low feldspar populations are most consistent with a provenance of underlying greenschist grade metasediments in the Pine Creek Supergroup. At the same time, the presence of detrital metamorphics argues against regional metamorphism or deep burial involving the Coronation Sandstone. Diagenesis involved precipitation of quartz cement overgrowths with minor pressure solution and suturing effects, with the possibility of early phoscretes. The generation of clays and other phyllosilicates is likely to be a function of relatively recent deep weathering, consistent with the assemblage of illite and chlorite (Hoeve et al., 1980).

The volcanics form a compositional array which is best described as bimodal volcanism. This is part of the Barramundi orogenic association (Etheridge et al. 1986). Fabrics preserved as silica pseudomorphs in the mafic suite may represent groundmass dissolution and zeolite encrustation. Another alternative consistent with pseudomorph habit is that rinds may represent palagonitization of mafic glass (Fisher and Schminke, 1984).

Pul Pul Rhyolite

Mineralogical changes have largely obliterated microtextures in the Pul Pul Rhyolite. The present ground mass has inverted to two dominant textures, one microcrystalline and one relatively coarse (fig. 15d,e). The microcrystalline fabric strongly resembles chert yet has slightly lower relief. These are interpreted as a devitrification fabric.

Fresh feldspars in the Pul Pul Rhyolite are extremely rare. Most have undergone complete replacement by clay minerals, and the rest are partially altered and replaced. Although the majority of quartz phenocrysts are fresh, many have undergone vacuolization, embayment, and partial dissolution. Lithic fragments, dominantly slates and phyllites with minor polycrystalline quartz, show occasional carbonate replacement as well, though this could be attributed to pre-detrital metamorphism.

Despite considerable alteration in the Pul Pul Rhyolite, rocks within the study area showed no evidence of metamorphism. There are, however, minerals of metamorphic assemblages within the Pul Pul Phyolite outside the study area, in the incised valley fill sequence along the Big Sunday Unconformity. Clasts from conglomerates in the area show extensive metamorphism in clasts (fig. 15f,g). These include chlorite greenschists with chlorite pseudomorphs after plagioclase, well rounded detrital epidote, and several populations of plagioclase; others include detrital microcline and felsic volcanic fragments. Clasts are uniformly well rounded except for plagioclase. All detrital fragments lie in a siliceous matrix which shows no sign of metamorphism or alteration other than minor local development of authigenic clays. Given the unstable nature of volcanic glass, it would have been highly susceptible to even low-grade metamorphism. This suggests that metamorphic assemblages found within rocks of that stratigraphic level do not require metamorphism, but may be incorporated framework constituents.

Jagodzinski (1992) describes metamorphism in the volcanics outside the study area based on the assemblage and fabrics of replacement minerals. Thus our interpretations differ strongly from hers.

In conclusion, metamorphic clasts may have been incorporated into the Pul Pul Rhyolite either from the surface as detritus or at depth as xenocrysts and xenoliths. The former is suggested by high frequency of the metamorphic minerals and clasts and supported by the observation of similar processes in the Coronation Sandstone.

Big Sunday Formation

The Big Sunday Formation consists of tuffs and tuffaceous silts to feldspatholithic sandstones and greywackes. These are the only rocks in the El Sherana/Edith River Groups to contain significant percentages of feldspars.

The tuffs have a microcrystalline matrix, and phenocrysts typically are < 50 mm in size. Quartz phenocrysts are angular, show unit extinction, and are fresh. No feldspars are visible in thin section, though staining turns the groundmass bright yellow. There are fine-grained clay pseudomorphs after feldspar, probably sericite, which in unaltered samples is distinct from the groundmass. Phenocrysts comprise < 5% total volume. Small round to angular cherty masses are fairly common, and are likely to represent devitrification of glassy tephra. Micas are common, though their small size and great abundance suggest they are later replacements.

Tuffs and tuffaceous siltstones are difficult to differentiate in outcrop and are best sorted by optical petrographic analysis. Quartz-rich laminae over 100 mm thick are common in tuffaceous siltstone, and may comprise as much as 40% bulk composition.

The feldspatholithic sandstones and greywackes contain abundant grains medium size or larger, and first occur roughly half-way up the section. The grains are dominantly quartz and feldspar, both potassium and plagioclase (fig. 15h,i). Quartz grains are fresh, though some have vermicular chlorite and corroded boundaries. There is on average more potassium feldspar than plagioclase, and subequal portions of quartz to feldspar with quartz slightly more common. Matrix volume is high even in the sandstones, and is predominantly siliceous and unaltered. Again, the predominant alteration is low-temperature chlorite and illite. Detrital chlorite is quite common; detrital muscovite is less so. Detrital and authigenic chlorites in part can be distinguished in these units by refractive indexes and birefringence (Albee, 1962), which are high for the detrital fractions and very low, below plagioclase, for authigenic fractions which are often mixed with vermiculite (Deer, Howie, and Zussman, 1976). There are also infrequent detrital epidote grains.

Chlorite replacement is ubiquitous in all Big Sunday Formation units, resulting in a green color to most beds in outcrop. This contrasts with the Tollis Formation, the stratigraphic correlative of the Big Sunday, in which both matrix and grains are relatively unaffected by chlorite alteration and feldspars are fresh. Chlorite chiefly replaces matrix, especially tuffaceous matrix, though it can be seen to cut into and across grain boundaries.

Conclusions. The Big Sunday Formation has undergone alteration which may be low-temperature and low-pressure replacement. Low refractive index chlorite indicates a high-silica, low-iron composition (Albee, 1962), and this is often the case with authigenic chlorites (Velde, 1977), which show an iron enrichment trend increasing with depth. The iron content is also a function of brine chemistry and climate temperature (Velde, 1977), yet metamorphic chlorites show consistently higher iron fractions than authigenic chlorites (Albee, 1962).

Upward in the section, the tuffs become enriched with respect to quartz, and fresh feldspars and detrital mica become volumetrically important. Early tuffs, therefore, may represent pure ash composition, with an increasing component of Pul Pul Rhyolite epiclastic material upwards. In addition, the advent of coarse detritus, increasing volume of feldspars, and introduction of detrital heavies probably correspond to uplift and erosion below the Pul Pul Rhyolite to metamorphosed Pine Creek Supergroup farther to the north. This is consistent with paleocurrent data, geometry of unconformities, petrography from the valley-fill sequence along the Big Sunday Unconformity described above, and the absence of Coronation Sandstone and ultimately Pul Pul Rhyolite far north of the study area.

Kurrundie Sandstone

In general, the Kurrundie Sandstone is similar to the Coronation Sandstone both compositionally and texturally in outcrop and thin section. The chief compositional differences are the relative abundance of felsic volcanic lithic fragments (Table 1, fig. 12, fig.15j). There are no observed phosphate cements. Hematite staining and *liesegang* banding are not strongly developed petrographically. Heavy minerals, especially micas, are fresher in the Kurrundie than in the Coronation Sandstone (fig. 15j). In short, there is no petrographic evidence to indicate a provenance or depositional environment drastically different from that of the Coronation Sandstone except for large percentages of felsic volcanic fragments sourced at least in part from the Pul Pul Rhyolite.

The sandstones of the Palette sub-basin are very well sorted hydraulically and compositionally (fig. 12). They contain quartz in excess of 95% bulk composition. In contrast, breccia units and fanglomerates are locally sourced and poorly sorted.

Discussion

Fig. 12 presents three ternary diagrams after Dickinson and Suczek (1979) which include the 15 point counts as well as counts from the Tollis Formation presented in Needham et al. (1988). There are no compositional trends within individual units. Total Q*L*F was not plotted, as it is a gauge of susceptibility to porosity occlusion; the Qm*Lt*F diagram is considered here to represent grain composition most accurately as it plots the total lithic fragment population versus quartz and feldspar (Dickinson and Suczek, 1979)

The units tend to cluster in relatively discrete groups. The Big Sunday Formation is most distinct from the other groups due to the large feldspar component. The Coronation and Kurrundie Sandstones fall within the same general field for all three diagrams. The Palette sub-basin sandstones, in contrast, containing greater compositional maturity than any other sediments in the El Sherana and Edith River Groups. It is possible, therefore, that the Palette sub-basin has a separate provenance as a function of timing of basin formation or paleogeography. All samples plot within the fields of either recycled orogen or continental block provenances, which is consistent with the regional environment which sourced these sediments.

The Tollis Formation mean from Needham et al. (1988) was plotted on the diagrams to compare with the other sediments. The Big Sunday Formation and Tollis Formation are qualitatively discrete in fig. 12, suggesting that they had different provenances. This agrees with the stratigraphic evidence for local sourcing of the Big Sunday Formation from the Pul Pul Rhyolite during active volcanism in two ways. The Pul Pul would provide a source for fresh feldspar and quartz phenocrysts. What is probably the dominant effect, however, is that the Big Sunday Formation would be more susceptible to alteration based on the high tuff or volcanic content, and on these grounds lithic volcanic fragments might be very difficult to recognize.

The Tollis Formation is rich in volcanic lithic fragments but is less altered than the Big Sunday Formation. In addition, the Tollis Formation is thicker than the Big Sunday Formation by at least a factor of five and contains significant argillite. Finally, the Tollis Formation is penetratively deformed by tight folds while the Big Sunday Formation is undeformed. This evidence does not necessarily refute the stratigraphic evidence for correlation; nonetheless, the Big Sunday Formation and Tollis Formation may represent two geographically distinct basins, both of which antedate deposition of the Kurrundie Sandstone, and formed within similar tectonic circumstances. Further studies of the Tollis Formation may shed light on this problem.

Scinto Breccia

This chemically complex unit is identified in the field as a breccia which is highly siliceous, hematitic, and in which the host lithology is indeterminable due to extreme replacement. Most previous examinations of the Scinto breccia have suggested that this lithology represents a weathering horizon or saprolite which formed above carbonate in the Pine Creek Supergroup and lies below the Coronation Sandstone (Walpole et al., 1968; Stuart Smith et al., 1988). New evidence presented here supports field observations that several outcrops of Scinto breccia formed as tectonic breccias rather than unconformity breccias.

Outcrop/hand sample scale observations. There are several places within the study area in which well developed Scinto Breccia is exposed. Most outcrops are siliceous, sub-vertical ridges which stand in relief to the earlier metasediments. However, one can often find stratigraphic offset across these ridges. In several places, such as near the Palette mine, one can walk along horizons of El Sherana Group sandstone or volcanics directly into these ridges. This demonstrates that ridges of Scinto Breccia are stratigraphically discordant with respect to their hosts and strongly suggests that these locations represent tectonic or fault breccias rather than unconformity breccias.

Chemical zonation can be observed along faults characterized by Scinto Breccia. Closest to the fault, both silica and hematite replacement are strong. Farther from the fault surface, silicification weakens and disappears, such that only hematite replacement and veining have altered the host; farther again, the host lithology is unaltered. This zonation is typically developed on the scale of decimeters to meters. In the host, veins with quartz cement lining have a late-stage fill of hematite. Additionally wavelite (S. Needham, pers. comm.) is formed as an additional phase interior to the hematite.

Locally one may find angular, platy clasts within breccia bodies. These clasts are oblate rectangles in cross section, typically composed of milky white, vitreous chert. Silica usually has replaced the host completely In clasts showing only partial replacement, relict crystal compromise boundaries are preserved as an uneven, jagged boundary which runs along the meridian of the clast, roughly bisecting the plate. In less altered clasts, silica replacement grades into unaltered, interlocking quartz palisades. One scenario for clast genesis involves the existence of quartz veins which became rectangular, platy clasts as the host rock fractured.

Both host and veins then underwent silica replacement. Similar observations and interpretation were made by Valenta (1991).

As discussed above with respect to the Coronation Unconformity, there are exposures of Scinto Breccia which may be unconformity related. The type location for this lithology is southeast and below the Saddle Ridge mine. Here, a broad, horizontal lens of Scinto Breccia can be found above an exposure of carbonate in the South Alligator Group. The unit is siliceous, hematitic, phosphatic, and the original composition of the host lithology is indistinguishable. One can not, however, actually demonstrate unequivocally at this location that Scinto Breccia lies below unaltered Coronation Sandstone, and may be a zone of tectonic or hydrothermal breccia.

Optical petrography. Development of Scinto Breccia involved a series of replacements and cements. Through cement stratigraphy we determined relative timing of hydrothermal events. These events all took place after the initial silicification of the host rocks, as all cement phases nucleate on either silicified host or later cements. It should be noted again that all mineral identification preceded solely from optical petrography.

Figure 16 shows a sequence of six successive mineralizing events under plain and polarized light. The first-stage mineral is a blocky phosphate cement which nucleates directly on the host. The second phase is apatite, with euhedral crystals nucleating on the earlier phosphate or on a silica base. These two stages are only locally developed. After apatite, quartz fills all vughs with large crystals with no fine crystal precursors. It is possible that more than one quartz precipitation event took place back-to-back based on slight optical discordance across cryptic surfaces within what otherwise appear to be single crystals. In many vughs or fractures, this is the last phase recorded.

The fourth-stage mineral is coarse, platy or bladed hematite. Single crystals can be as large as 500 mm. The fifth mineral phase is a late-stage phosphate cement, probably wavelite, which occludes remaining pore space, engulfing hematite laths which show local mild dissolution. The sixth phase develops as fine acicular needles. Its optical properties unfortunately are not observable at a scale to pose a compositional interpretation. In other veins, needles cut across quartz grain boundaries and nucleate on hematite laths. The fifth and sixth phases are not seen cutting each other, and may be contemporaneous.

Conclusions. Based on both outcrop and petrographic observations, we propose following scenario for paragenesis of Scinto Breccia. There may be additional events, chemical or tectonic, which have not been properly demonstrated.

The first stage is the formation of Scinto Breccia *sensu stricto*, namely as a hematitic, siliceous, phosphatic unconformity breccia. This would by definition occur at the base of the Coronation Sandstone and must predate later occurrences which cut the El Sherana Group. At Coronation Hill, Scinto Breccia affects the Kurrundie Sandstone, yet due to the uncertain timing of the Palette sub-basin, one can assert neither that Palette sub-basin postdates the Kurrundie Sandstone nor that there must be at least two temporally and geographically distinct occurrences of Scinto Breccia.

The following events are suggested to have been important in the timing of Scinto Breccia development. Enough fracturing must have occurred during initial tectonic brecciation to create veins of quartz with an interior specular hematite fill. Next, brecciation continued, either hydrothermal or tectonic, with continued silica and hematite alteration. These may have all been contemporaneous, or any pair of them contemporaneous provided brecciation is one of the first pair. Last, the series of cementation described above postdated that all of these, with wavelite as the last phase to form both in outcrop and in thin section. This invokes then at least two episodes of silica replacement followed by hematite.

It is unclear how the genesis of Scinto Breccia relates to mineralization. Silicification and hematite replacement are both hydrothermal phenomena, both acidic and oxidizing. This would be in agreement with the rough model proposed by Valenta (1991), as a couplet to the basic, reducing, mineralizing fluid system and seems to be born out in several locations, including El Sherana, Saddle Ridge, Palette, and Coronation Hill. The prediction that zones of desilicification would occur below zoned of silicification has not yet been demonstrated in outcrop, however, and might be amended such that zones of desilicification and silicification are coupled in some other geometry. Continued work on the mineral paragenesis of the Scinto is strongly recommended to better understand local and regional hydrothermal geochemistry.

TECTONIC HISTORY

Previous Work

Regional mapping, geochemistry, and geochronology conducted by the Bureau of Mineral Resources set the framework for tectonic interpretation of the South Alligator Valley. Needham et al. (1980, 1988) recognize deformation and metamorphism in the Pine Creek Supergroup and relate it to regional compression related to the Nimbuwah Event. In the study area, deformation involved lower-greenschist-grade metamorphism of Pine Creek Supergroup sediments, although regional metamorphism related to Nimbuwah orogeny reached amphibolite grade. Shortening was chiefly observed as northwest-trending isoclinal folds in the Pine Creek Supergroup and northwest-trending subvertical faults, several kilometers long. Needham et al. (1988) concluded that movement along these faults began before El Sherana Group sedimentation based on stratigraphic thickness variations across the South Alligator Valley. The faults were considered to represent chiefly strike-slip displacement based on sub-vertical dips. Valenta (1991) supports their conclusions, finding S-C foliations and fault lineations which suggest dextral displacement. He suggests that these faults may be as long as 20 km and attributes differences in deformational style across the faults partly to rheological changes from the Mount Partridge Group to the Koolpin Formation and to pre- El Sherana Group age faulting proposed in Stuart-Smith et al. (1980).

Needham et al. (1980) consider the Mount Partridge-Koolpin contact to be an angular unconformity where exposed. Johnston (1984) examined regional structure related to Pine Creek orogenesis and concluded that thrust faulting could play an important role in regional faulting. He considered that the Koolpin Formation acts as a regional décollement. Valenta (1991) conducted structural studies in the South Alligator Valley with an emphasis on the areas of great deformation and U- and/or Au-PGE mineralization. He recognized four deformational styles, one of which is pervasive northwest-trending isoclinal folds. Valenta (1991) suggests that these areas relate to either restraining or releasing oversteps associated with strike-slip motion along these faults. Within this model, he describes El Sherana as restraining bend, the Scinto Plateau as an extensional duplex, and Coronation Hill as a rhombic syntectonic basin at a releasing overstep. Based on stratigraphic grounds, he suggests ~ 10 km offset along the major northwest faults before deposition of the Coronation Sandstone and less offset, ~3-5 km post- El Sherana and pre- Kombolgie time. In addition, he catalogued the dominant geometries of the South Alligator Valley into north-trending strike-slip or extensional faults, east-trending strike-slip or compressional faults, and northwest-trending dominantly strike-slip faults.

The earlier Nimbuwah Event (Needham et al., 1980; Stuart-Smith et al., 1980) is the end of a complete orogenic cycle and is part of the regional Barramundi orogeny (Etheridge et al., 1986). Burial, metamorphism, and deformation throughout the Pine Creek Supergroup is linked to the intrusion of orogenic batholiths several hundred kilometers to the northeast of the study area (Needham et al., 1988, Wyborn 1988). Page and Wilson (1988) used U-Pb zircon techniques to date Nimbuwah granulites and granitoids at 1886 ± 5 Ma to 1.866 ± 8 Ga.

The Gerowie Tuff in the South Alligator Group yields an age of 1.885 ± 2 Ga (Needham et al., 1988), setting a maximum age for El Sherana group sedimentation, including an antecedent interval of significant flysch sedimentation prior to El Sherana deposition. R.W.Page (unpub. data) has dated the Pul Pul Rhyolite near El Sherana (fig.1) at about 1870 Ma. These dates are consistent with published ages both for the Plum Tree Volcanics (1870-1860), which set a minimum age for Edith River Group sedimentation, and the Nimbuwah granulites and granites (1.886± 5 Ga to 1.866± 8 Ga) related to orogenic collision.

Faulting Patterns and Timing

Appendix C is a 1:10,000 scale map of the South Alligator Valley northeast of the South Alligator River. Faults with several recurring geometries cut rocks of the El Sherana and Edith River Groups within the map area. These closely match those described in Valenta (1991). East-trending, moderately dipping reverse faults, with stratigraphic displacements both to the north and south, have the best constrained geometries. These cut Pine Creek Supergroup and El Sherana Group. The Saddle Ridge fault is one of these, as is a reverse fault above and immediately north of Saddle Ridge which appears to cut the Palette sub-basin sediments. The latter fault must be coeval with or postdate Palette sedimentation. A series of north-northeast-trending, southside-up reverse faults cut the El Sherana Group but have not been found to cut the Edith River Group. It is possible that these faults are relatively early and are cut by other faults. Moderately-dipping, north-northeast-trending, southside-down normal faults are common only along the Scinto Plateau (fig.14), and are coeval with Palette sub-basin deposition.

Steeply dipping northwest-trending faults show variable stratigraphic displacement, typically less than 150 m. Stratigraphic (figs. 13,14) and structural (Valenta 1991) data indicate that they are probably strike-slip faults of about one kilometer lateral displacement. These faults cut the Edith River Group, and may cut the Kombolgie Formation. The longest fault on the Appendix C map is the Fisher Fault, two kilometers in length. The new interpretation suggests that there is not one long, through-going fault, but that there is a zone of faulting with small *en echelon* faults of variable displacement and length. In this context, the Rockhole-El Sherana-Palette fault is reinterpreted as a discontinuous series of faults. This style of deformation is relatively common in areas featuring strike-slip faulting (Christie-Blick and Biddle, 1985).

The true length or displacement of the South Alligator fault is unclear as it is typically not exposed nor are both adjacent blocks. We therefore suggest that it may also be made up of several shorter faults.

Generation of Unconformities

As discussed above, the basal contacts of the Coronation Sandstone, Pul Pul Rhyolite, Big Sunday Formation, Kurrundie Sandstone, and Kombolgie Sandstone are regionally developed erosional unconformities. From examination of paleocurrent patterns (fig. 6) and isopach maps (fig. 17) one can see evidence for changes in drainage patterns which were ultimately responsible for erosion of sediment packages.

The Coronation Unconformity resulted from an erosional event in which lower-greenschist-grade Pine Creek Supergroup was uplifted and denuded. This is the largest demonstrable erosion in the South Alligator Valley. This is likely to be syn- to post-tectonic erosion of rocks deformed during Nimbuwah orogenesis. This erosion resulted in the development of topography which paralleled structural trends. Subsequent deposition also paralleled the structural trends (fig. 6), suggesting long-lived paleotopographic control within and outside of the study area.

The isopach map for the Coronation sandstone shows thinning towards the northwest below the Pul Pul Unconformity (fig. 17). This is contrary to observed Coronation age northwestward paleoflow. Therefore, the northwest end of the South Alligator Valley was raised relative to the southeast after deposition of the Coronation Sandstone. Erosion then removed Coronation Sandstone and Pine Creek Supergroup sediment from the northwest and deposited the Big Sunday Formation sediments to the southeast. This model is consistent with petrologic data from the Big Sunday Formation, which contains metamorphic detritus.

The Pul Pul Unconformity is associated with at least one normal growth fault at El Sherana of approximately 70 m throw (fig. 8). It may be that the tectonic pulse responsible for the Pul Pul Unconformity was extensional rather than compressional, with increased subsidence to the southeast. This would then result in thickening of units to the southeast (fig. 17) and paleoflow in the Big Sunday to the southeast (fig. 6).

The Kurrundie Unconformity shows again the opposite trends. Units thicken towards the north and paleocurrents also show northwestward flow. If one places the Palette sub-basin within the Kurrundie member (see above), then significant syn-tectonic sedimentation occurred with the development of the Kurrundie Unconformity. The isopach and paleocurrent data suggest a reversal of the previous trend in sedimentation, with increased subsidence and paleoflow towards the northwest.

Discussion

Appendix C reinterprets the stratigraphic thickness in several locations where fault repetition exaggerated previous estimates of thickness. The two most prominent areas are at the "Hogbacks" near Fisher Creek, and the Monolith (Fig. 1), where previous estimates of thickness for the Coronation Sandstone were ~160 and 140 m respectively (Stuart-Smith et al., 1988; Valenta 1991, fig 31). The present interpretation reduces unit thicknesses to 70 and 60 m respectively, roughly the same stratigraphic thickness from Rockhole to Palette. In addition, thickness changes throughout this interval can be demonstrably attributed to either removal via erosion during generation of unconformities (fig. 17) or pinch-out against antecedent paleohighs (fig. 3). This implies that no synsedimentary block faulting occurred along either the South Alligator fault or the Rochhole-El Sherana-Palette fault during deposition of the Coronation Sandstone. It is also unlikely that any synsedimentary block faulting occurred before Coronation Sandstone deposition as there is no stratigraphic evidence of earlier sedimentation.

The only evidence for post-El Sherana syntectonic sedimentation is preserved in the 4 km^2 Palette sub-basin. The basin has a 3:1 length-to-width aspect ratio, which is typical of many strike-slip basins (Aydin and Nur, 1982). It is bounded by steeply dipping faults (fig.13), shows a migrating depocenter (fig 14), and is dominated by facies indicative of active tectonism (fig. 11). Many faults in the area, particularly the E-W reverse and SSW-NNE normal faults, may be kinematically linked to the longer subvertical faults as antithetic and secondary synthetic shears respectively (Christie-Blick and Biddle, 1985). A strike-slip pull-apart mechanism for Palette extension is consistent with these observations. Similar relations are reported from the Little Sulphur Creek Basins (Nilsen and McLaughlin, 1985).

Despite the likelihood of a local strike-slip origin for the Palette Sub-basin, evidence for major deformation and syntectonic sedimentation typical of transform zones and major strike-slip faults (Crowell, 1974; Crowell and Link, 1982; Steel and Gloppen, 1980; Nilsen and McLaughlin, 1985) is absent in all other parts of the El Sherana/Edith River succession. Consequently, any through-going strike-slip faults in the South Alligator Valley probably are not of significant length or displacement. It is possible that Coronation Hill is also a remnant pull-apart basin, yet faults along which Scinto Breccia has developed cut the uppermost sediments at Coronation Hill. This presents a partial argument that deformation at Coronation Hill may entirely postdate deposition of the Kurrundie Sandstone. Thereby, Palette sedimentation is either contemporaneous with Coronation Hill and Palette sediments are not Kurrundie time equivalents, or deformation at Palette and Coronation Hill was not contemporaneous.

The lack of evidence for pre-El Sherana age faulting revises the estimate for 10 km of translation for this time period (Valenta, 1991). previous displacement estimates were based chiefly on thickness changes across fault contacts; these thicknesses are revised as stated above. Assuming no pre-El Sherana strike-slip deformation, the displacement along any of the northwest-trending faults is likely to be less than 5 km. Since these faults generally show displacement only after deposition of the key El-Sherana lithologies, they are not basement structures reactivated during deposition.

The reversal of paleocurrents (fig. 6) and generation of unconformities linked to tectonic events is witnessed in all tectonic settings. Since the margins of the El Sherana/Edith River basin are not exposed, one cannot determine bounding fault geometries. Also, proximal facies are not preserved, which could have been used to constrain the location or orientation of bounding faults. Moreover, because the generation of unconformities resulted in removal of geographically large portions of the Coronation Sandstone, the original size of the basin is also undetermined. It is therefore difficult to say with any degree of certainty what the actual mechanism of basin subsidence was. We favor either an extensional or trans-tensional setting based largely on the preservation of synsedimentary structures of normal or strike-slip throw.

It is possible that the El Sherana/Edith River basin formed from post-orogenic collapse. Given the timing of basin formation relative to timing of orogenesis described in Page and Williams (1988) and Etheridge et al. (1986), El Sherana sedimentation must have followed Pine Creek orogenesis closely, probably within 15 m.y. A mechanism similar to that proposed for intermontane basins in the Appenines or Carpathians (Malinverno and Ryan, 1986; Burchfiel and Royden, 1991) could account for basin subsidence. This is a particularly appealing model, because these environments are characterized by both regional extension and strike-slip deformation either during or shortly after compression and low-grade-metamorphism (Ghisetti and Vezzani, 1981; Horvath, 1983). The basement to these basins also contains thick flysch sequences without molasse, has undergone low-grade metamorphism, and the early stratigraphy commonly shows volcanism and extension (Malinverno and Ryan, 1986).

Regional and Global Ties

The Barramundi Orogeny (Etheridge et al., 1986) is a period of continental collision in Northern Australia chiefly represented by fold-thrust belts like the Pine Creek Inlier. The Barramundi Orogeny is typified by bimodal volcanism, chiefly mafic, low-grade metamorphism with elevated geotherms, and lack of evidence for formation of oceanic crust or tectonic highlands. In other Barramundi provinces (e.g., Davenport province, Gawler province) an episode of volcanism and subaerial to shallow-water clastic sedimentation occurred in a similar stratigraphic position as the El Sherana and Edith River Groups. Deposition post-dates earlier Wilson cycle sedimentation (thermal subsidence, flysch, fold-thrust deformation) associated with convergence (Blake and Page, 1988; Fanning et al., 1988). The sub-aerial volcanism and sedimentation may post-date deposition by as much as 40 m.y., but may closer in age. It is possible, then, that what Etheridge et al. (1986) interpret as a mantle delamination event may be a pulse of extensional tectonism. This pulse would be either syn- or post-orogenic (e.g. Burchfiel and Royden 1985; 1991) with respect to the assembly of northern Australia.

Wopmay Orogen (Hoffman, 1980; Hoffman and Bowring, 1984), in the northwest corner of the Canadian Shield, displays many of the same characteristics as the Barramundi Orogeny and occurred at roughly the same time as Pine Creek orogenesis (Etheridge et al., 1986). New stratigraphic correlations between Wopmay Orogen and the Kilohigok Basin (Grotzinger, 1989) have revised the dates of orogenesis in Wopmay. Those dates include a crystal tuff date at 1885±3 Ma for the transition from passive margin to foreland basin sedimentation (Bowring and Grotzinger, 1989) marked by the deposition of shales and distal turbidites of the Recluse Group (Hoffman and Bowring, 1984). This overlaps remarkably with the Gerowie Tuff age of 1886±2 Ma, which is also overlain by fine siliciclastics and turbidites in the Finniss River Group. Both sediment cycles are then intruded by a series of mafic sills just prior to deformation, the Morel sills in Wopmay and the Zamu Dolerite in Pine Creek. There is therefore a striking similarity between the two successions in terms of time and style.

After collisional tectonism in Wopmay, there occurred an event of regional transcurrent faulting developed at all scales. Transcurrent faulting was accompanied by sedimentation of the Et Then Group in the Athapuscow basin (Hoffman et al., 1977; Bowring et al., 1984). This was followed by sedimentation of the Hornby Bay Group, part of the Coppermine Homocline (Ross, 1983). The Hornby Bay Group is a 1 km thick sequence, partly of fluvial sandstones, which covers a large portion of the northwestern Canadian shield. Timing of deposition is well constrained by bimodal volcanics dated at 1.663±8 Ga (Bowring and Ross, 1985). Again, this coincides very closely with the deposition of the Katherine River Group, another thick fluvial succession dated with volcanics at ~1650 Ma which overlies the El Sherana/Edith River Groups and much of the Pine Creek Orogen.

There is striking similarity between events and correlative dates in northern Australia and northwestern Canada from roughly 1.9 to 1.6 Ga (Friedmann and Grotzinger, 1989). Figure 18 shows schematically the timing and nature of events in Wopmay Orogen, the Athapuscow Basin, and the Pine Creek Orogen. In each location, a full Wilson cycle of rifting, thermal subsidence, and basin closure occurred, followed by a tectonic episode featuring strike-slip deformation, and later deposition of extensive middle Proterozoic platform-cover sequences. Sedimentation was preserved in the Et Then, Edith River, and El Sherana Groups. Sedimentation may have occurred in Wopmay, but would have since eroded to deeper structural levels. In both the basal Et Then and El Sherana, coarse clastics lap out against antecedent paleohighs, in places with several hundred meters of paleorelief within a lateral distance of less than five kilometers (Hoffman, 1969).

This correlation allows two possible interpretations. The first is a paleo-geographic reconstruction in which northern Australia and northwestern Canada were near each other, at least from ~1.9 to ~1.6 Ga. This would imply such correlations as the Katherine River Group to the Hornby Bay Group, the basal Recluse tuff to the Gerowie tuff, or the Morel Sills to the Zamu Dolerite.

The other explanation involves basin formation models, like that of Dewey (1988), which are related to orogenic activity in general. Since the period of time from 2000 to 1800 Ma is a period of global orogeny, one could expect to find the same pattern of events in many locations regardless of paleogeographic position. Such a conclusion would temporally link Wopmay and Pine Creek by coincidence rather than geography. Either hypothesis can be tested through continued stratigraphic, geochemical, and paleomagnetic research.

Part of the difficulty in linking the two areas is that the two orogens are based on entirely different models. Wopmay has served as the typical example for uniformitarian Alpine-type crustal genesis and mountain building, where northern Australia is one of the surviving cases for "ensialic" orogeny. These differences can be resolved by new application of modern analogues to the two orogens. Compression in both systems may well have taken place side by side, but Wopmay may represent Alpine-style deformation while Pine Creek may represent Pyrenean-style.

The Pyrenees are an orogen which lacks typical arc volcanism and plutonism. In addition, there is no true crystalline hinterland as the core of the Pyrenees is composed of greenschist grade rocks. Nonetheless, significant shortening has occurred on both sides of the orogen with particularly strong deformation in the flyschoid sediments. The Pyrenean foreland also underwent post-collisional strike-slip and extensional deformation shortly after convergence. Thus, in a "cake-and-eat-it-too" scenario, two orogens of radically different deformational styles may coexist with very similar early and post-tectonic histories. In this way, Precambrian continental accretion can take different forms based on different initial conditions, much as the Mediterranean has done over the past 40 Ma (Coward and Deitrich, 1989; LePichon et al., 1988).

CONCLUSIONS

The following conclusions can be drawn concerning the El Sherana/Edith River succession.

1) Sedimentation in the El Sherana and Edith River Groups probably was not controlled by northwest-striking strike-slip faults in the South Alligator Valley. There is little evidence for significant syntectonic sedimentation of that age, and the facies patterns are not characteristic of proximal or predominantly strike-slip environments. Therefore, movement on the South Alligator fault or the Rockhole-El Sherana-Palette fault did not control sedimentation during El Sherana Group deposition. This significantly shortens the movement history of these faults from a maximum of 20 km to 5 km.

2) The Coronation Sandstone reflects sedimentation in a mature river system, uncut by syndepositional faulting, in a valley-and-ridge antecedent topography. The Big Sunday Formation is dominated by turbidites. There are no proximal facies of Coronation or Kurrundie Sandstone preserved in the South Alligator Valley, with the exception of the Palette sub-basin and possibly Coronation Hill. The lack of facies associated with active tectonism suggests that there was little synsedimentary tectonism in the South Alligator Valley.

3) Revised thickness estimates of the El Sherana Group suggest that cumulative thicknesses do not vary much locally but do show significant variations on a more regional scale. Thickness variations are probably a function of paleotopography and erosional events versus not differential subsidence. Unconformities were generated as an erosional response to tectonic pulses.

4) The El Sherana and Edith River succession is dominated by the presence of regionally developed unconformities related to tectonic activity. Tectonism and volcanism may be related to orogenesis in the Nimbuwah region or a temporally linked extensional event.

5) Two events of basin gradient inversion are documented in the paleocurrent record. These events are related to tectonism and the generation of unconformities.

6) Provenance is strongly a function of development of unconformities, and in all circumstances suggests local sourcing. The Big Sunday Formation, in part, has a different provenance than other units and is compositionally controlled by erosion of the Pul Pul Rhyolite.

7) Metamorphism affects neither the El Sherana nor Edith River Groups within the study area. Alterations and replacement can be attributed to hydrothermal alteration or younger weathering. It is possible that similar or correlative rocks within the region underwent metamorphism.

8) The Palette sub-basin and the Scinto Plateau are an exhumed minor strike-slip basin with a depositional environment of active tectonism distinct from the rest of the El Sherana and Edith River Groups. Palette sub-basin age is correlated to the basal Kurrundie Sandstone.

9) The Scinto Breccia is at least in part a fault breccia which cuts El Sherana stratigraphy and locally Edith River stratigraphy. In most locations within the South Alligator Valley it is not a siliceous saprolite. The breccia may record episodes of local silicification related to mineral paragenesis.

10) The present size and geometry of both the El Sherana and Edith River Groups is not representative of the original geometry of the basin. This is based on the lack of proximal facies in the Coronation Sandstone and the Kurrundie Sandstone, unconformity-related erosion, and extensive platform cover.

11) The El Sherana/Edith River basin formed immediately after Pine Creek/Nimbuwah orogenesis. If genetically linked to Nimbuwah orogenesis, then basin formation may be related to post- or syn-orogenic collapse of thickened continental crust.

Recommendations

We make the following recommendations for continued work in the El Sherana/Edith River Groups:

1) The continuation of 1:25,000 scale mapping, particularly from El Sherana to Rockhole and farther north, in the area between Fisher Creek and Koolpin Gorge focusing on Freezing Gorge, east-southeast of the "syncline", and on the southeast side of the South Alligator Valley. Particular attention should be paid to locations of possible syntectonic sedimentation and whether observed faults cut the Kombolgie Formation.

2) Measurement of sections through El Sherana and Edith River lithologies in these locations.

3) Detailed comparison between the Big Sunday Formation and the Tollis Formation to better understand how these formations relate. Paleocurrent, petrographic, and sedimentologic studies should accompany 1;25,000 scale mapping

4) Detailed sedimentological work on the Kurrundie Sandstone to better constrain depositional environments and regional paleocurrent trends. In addition, mapping of the Kurrundie Sandstone-Plum Tree Volcanics contact to assess the possibility of unconformity.

5) 1:5000 scale mapping of Coronation Hill and adjacent areas, to evaluate possible syntectonic sedimentation and constrain timing of deformation.

6) Detailed sedimentological and stratigraphic studies of the Pine Creek Supergroup, in particular the Koolpin Formation.

7) Possible examination of BHP cores to help constrain the sedimentology of sequences in the South Alligator, Mount Partridge, and Namoona Groups.

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Fig. 1 Geological map. Locations for measured sections as follows: (1) Monolith; (2) Stag Creek; (3) Saddle Ridge, (4) the "syncline" east of Koolpin Gorge; (5) the "Hogbacks"area west of Koolpin Gorge. Section (6) is from a waterfall along the South Allligator River. Section (7) and (8) are sections through the Palette Sub-basin on Scinto Plateau. Map adapted from Needham and Stuart-Smith, 1987. Appendix A contains more precise locations form measured sections.

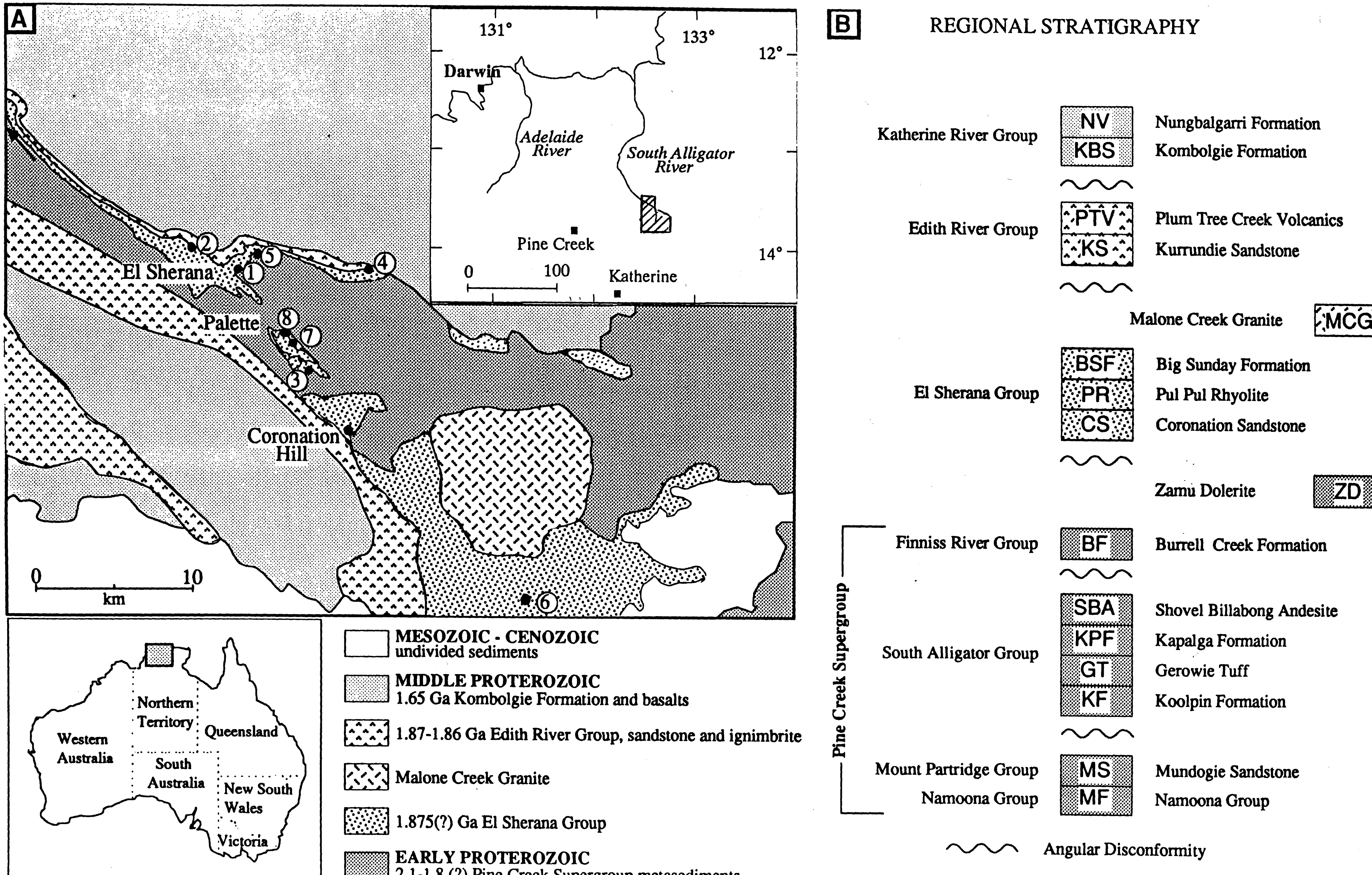

A
131°
133°
12°
14°
Darwin
Adelaide River
South Alligator River
Pine Creek
Katherine
0
100
El Sherana
Palette
Coronation Hill
1
2
3
4
5
6
7
8
0
10
km
Western Australia
Northern Territory
Queensland
South Australia
New South Wales
Victoria
MESOZOIC - CENOZOIC
undivided sediments
MIDDLE PROTEROZOIC
1.65 Ga Kombolgie Formation and basalts
1.87-1.86 Ga Edith River Group, sandstone and ignimbrite
Malone Creek Granite
1.875(?) Ga El Sherana Group
EARLY PROTEROZOIC
2.1-1.8 (?) Pine Creek Supergroup metasediments.
B
REGIONAL STRATIGRAPHY
Katherine River Group
NV
Nungbalgarri Formation
KBS
Kombolgie Formation
Edith River Group
PTV
Plum Tree Creek Volcanics
KS
Kurrundie Sandstone
Malone Creek Granite
MCG
El Sherana Group
BSF
Big Sunday Formation
PR
Pul Pul Rhyolite
CS
Coronation Sandstone
Zamu Dolerite
ZD
Pine Creek Supergroup
Finniss River Group
BF
Burrell Creek Formation
South Alligator Group
SBA
Shovel Billabong Andesite
KPF
Kapalga Formation
GT
Gerowie Tuff
KF
Koolpin Formation
Mount Partridge Group
MS
Mundogie Sandstone
Namoona Group
MF
Namoona Group
Angular Disconformity

Fig 2. The El Sherana/Edith River stratigraphy in two interpretations. Figure 2a is the stratigraphy as presented by Stuart-Smith et al. (1988), figure 2b as presented in this study.

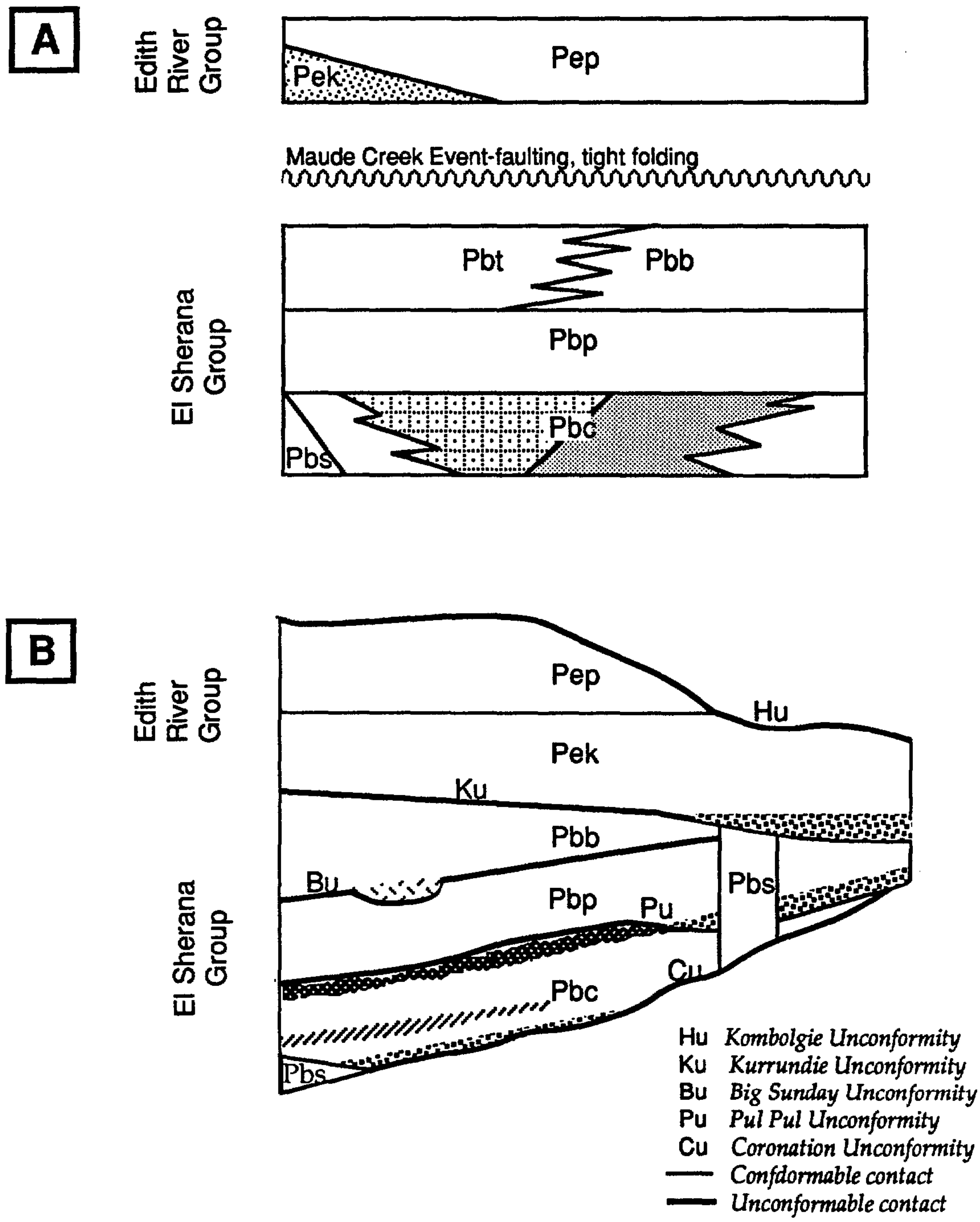
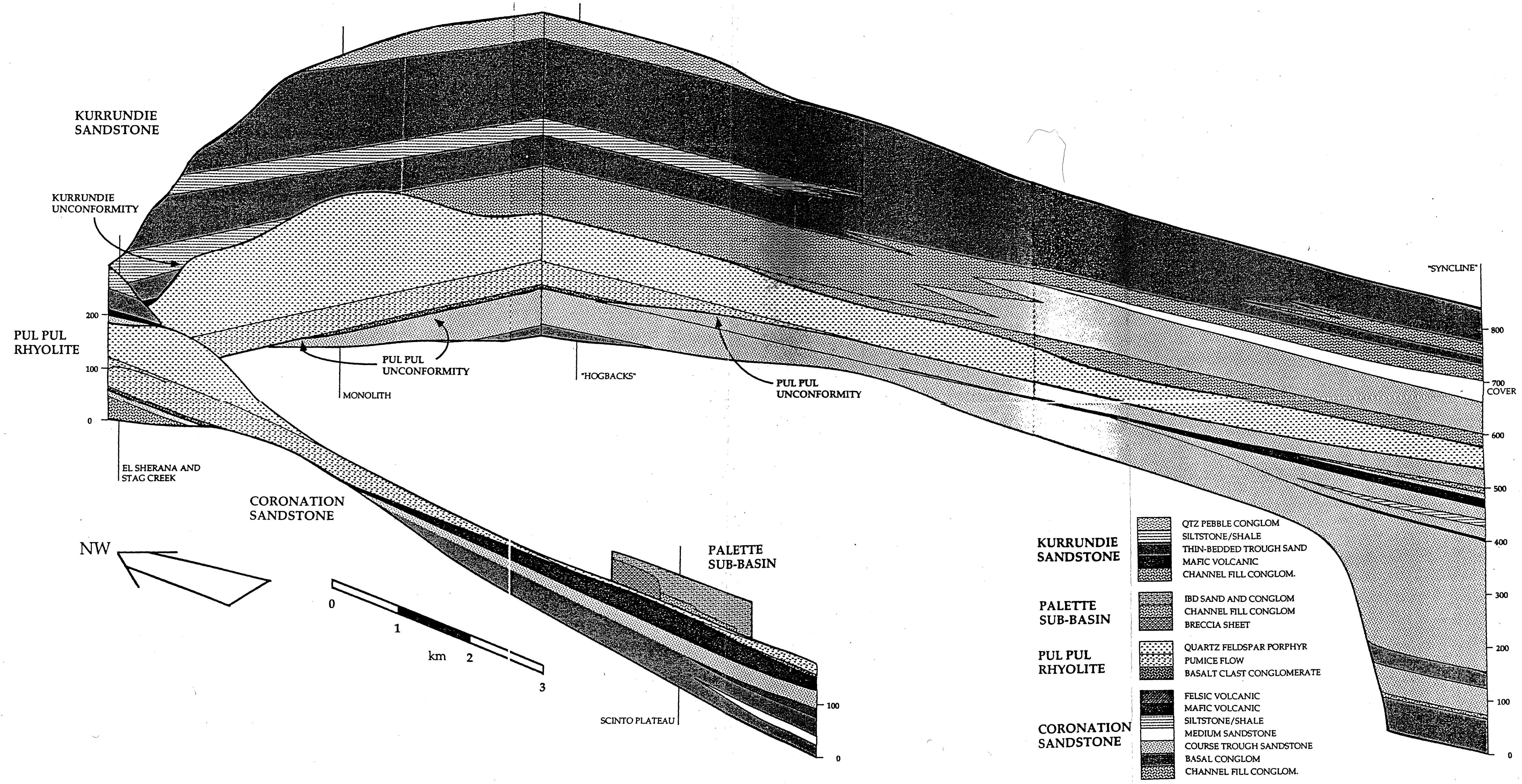

A
Edith River Group
Pep
Pek
Maude Creek Event-faulting, tight folding
El Sherana Group
Pbt
Pbb
Pbp
Pbc
Pbs
B
Edith River Group
Pep
Hu
Pek
Ku
El Sherana Group
Pbb
Bu
Pbp
Pu
Pbs
Cu
Pbc
Pbs
Hu Kombolgie Unconformity
Ku Kurrundie Unconformity
Bu Big Sunday Unconformity
Pu Pul Pul Unconformity
Cu Coronation Unconformity
Confdormable contact
Unconformable contact

Fig 3. Fence diagram of the El Sherana/Edith River stratigraphy pinned locally to detailed measured sections. Major bounding surfaces were walked out in the field where possible.



KURRUNDIE SANDSTONE
KURRUNDIE UNCONFORMITY
PUL PUL RHYOLITE
200
100
0
PUL PUL UNCONFORMITY
MONOLITH
"HOGBACKS"
PUL PUL UNCONFORMITY
"SYNCLINE"
800
700
COVER
600
500
400
300
200
100
0
EL SHERANA AND STAG CREEK
CORONATION SANDSTONE
NW
0
1
km
2
3
PALETTE SUB-BASIN
SCINTO PLATEAU
100
0
KURRUNDIE SANDSTONE
QTZ PEBBLE CONGLOM
SILTSTONE/SHALE
THIN-BEDDED TROUGH SAND
MAFIC VOLCANIC
CHANNEL FILL CONGLOM.
PALETTE SUB-BASIN
IBD SAND AND CONGLOM
CHANNEL FILL CONGLOM
BRECCIA SHEET
PUL PUL RHYOLITE
QUARTZ FELDSPAR PORPHYR
PUMICE FLOW
BASALT CLAST CONGLOMERATE
CORONATION SANDSTONE
FELSIC VOLCANIC
MAFIC VOLCANIC
SILTSTONE/SHALE
MEDIUM SANDSTONE
COURSE TROUGH SANDSTONE
BASAL CONGLOM
CHANNEL FILL CONGLOM.

Fig 4. Facies of the Coronation sandstone. (a) a thick (~4m) deposit of imbricate-boulder conglomerate at Stag Creek (*Gm* facies). (b) planar-crossbedded pebble sandstone (*Sp* facies). (c) large exhumed trough (*St* facies) (hammer for scale).

Fig. 4

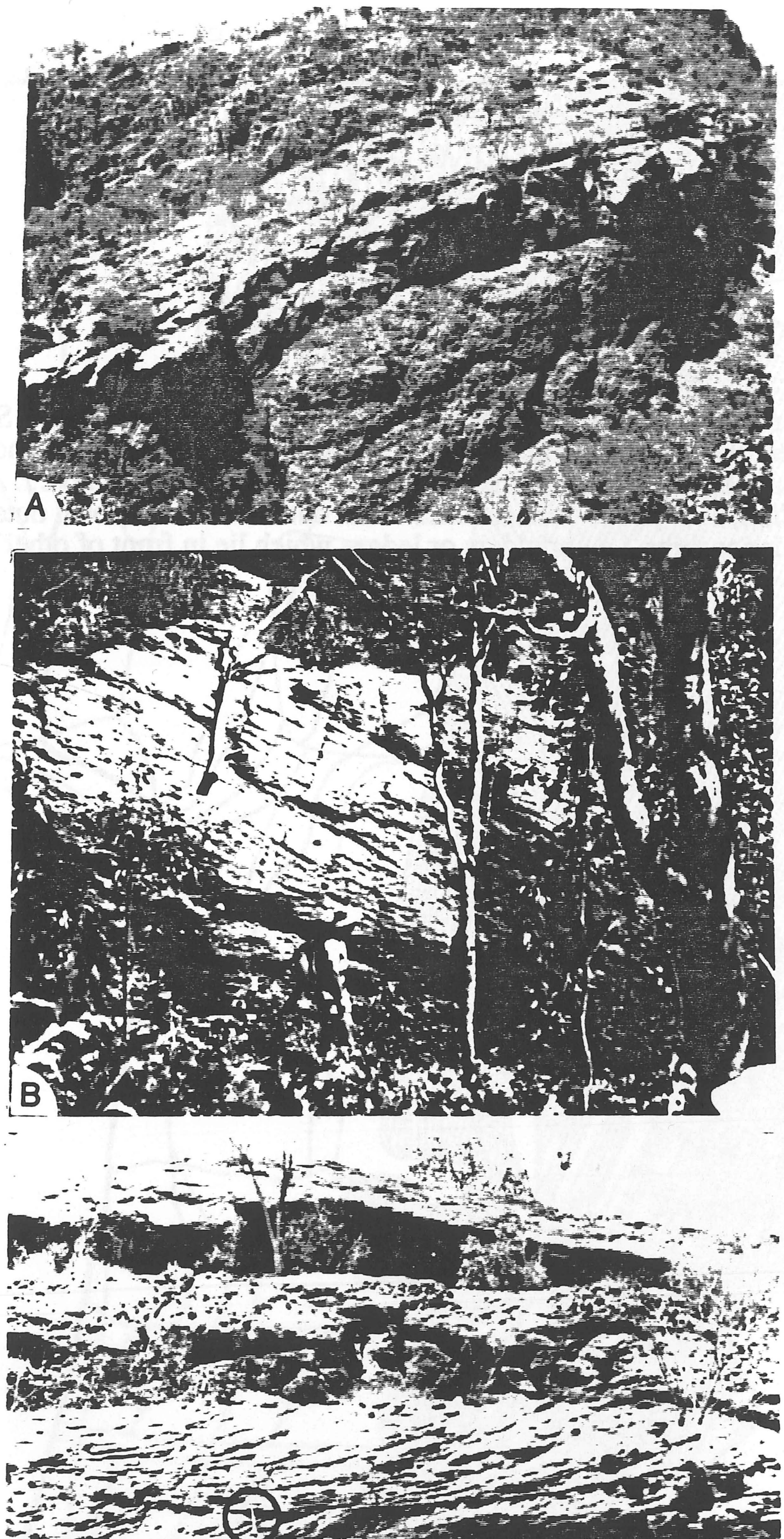
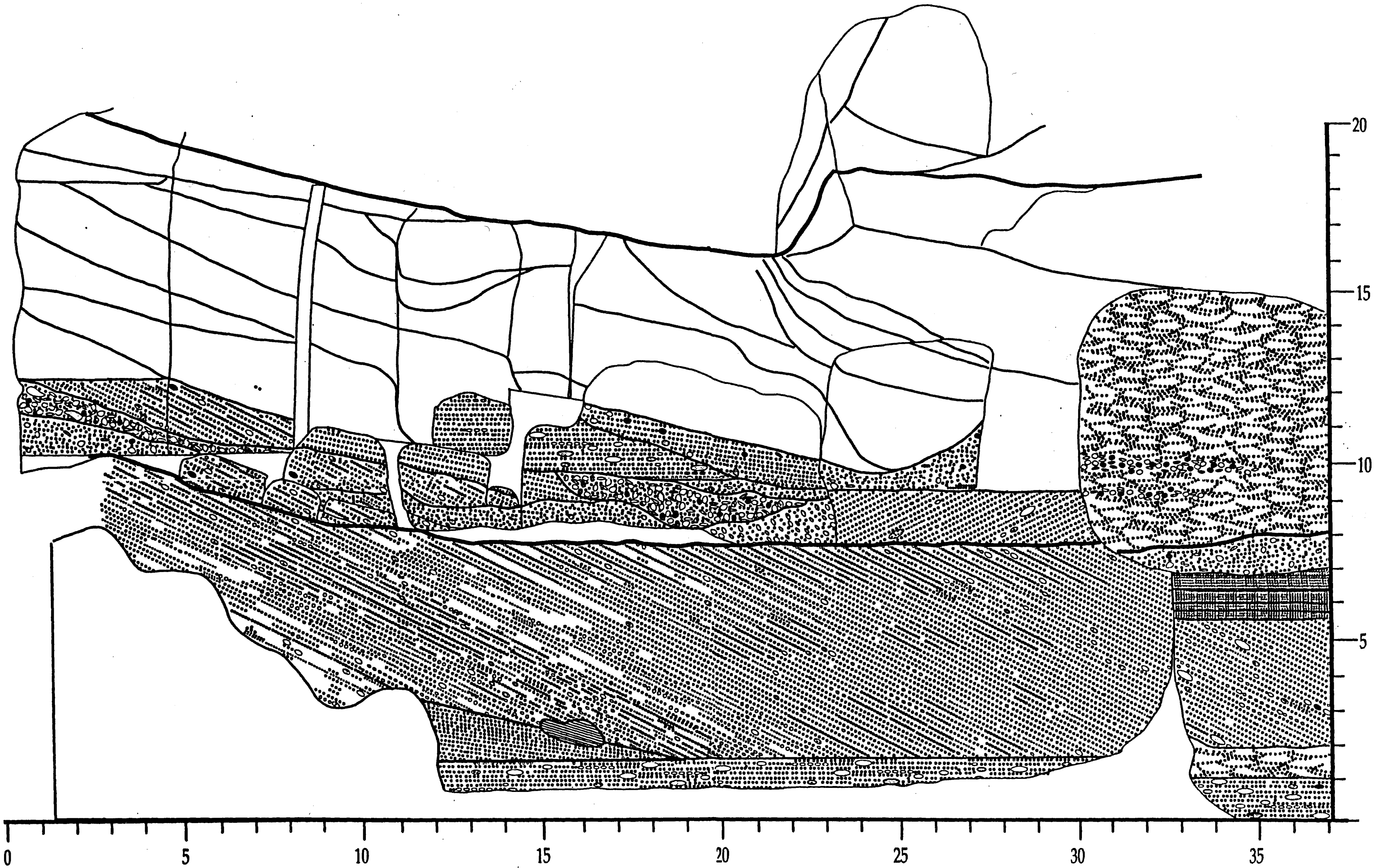


Fig 5. A map of bounding surfaces of a basal exposure of Coronation Sandstone near the Monolith. The bounding surfaces of the thickest line and largest number, e.g. 4, bound the grossest packages of sandstone *(c.f. Allen 1983; Miall, 1987)*. The thinnest lines break out three-dimensional outcrop relationships, i.e., boulders or ledges which lie in front of other exposures.

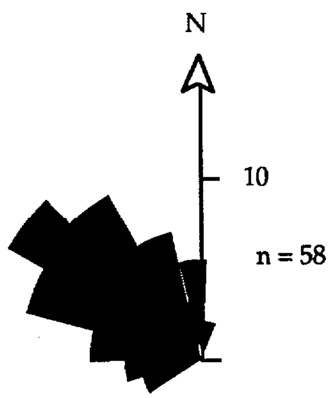


20
15
10
5
0
5
10
15
20
25
30
35

Fig 6. Paleocurrent data from the region, organized in ascending order through the sequence. Note the small dispersion of (a,b,c) vs. the large spread of paleocurrents from (d). The paleocurrent rosettes are scaled by area-proportion and not incremental axis length.

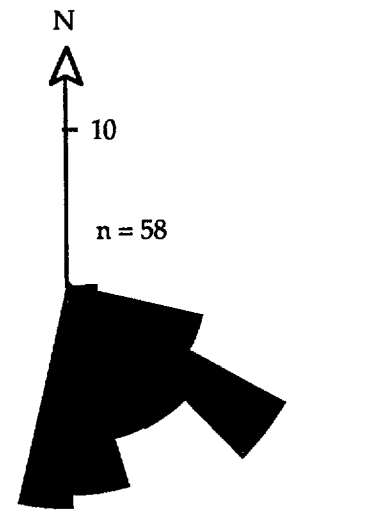
A

CORONATION SANDSTONE
PALEOCURRENTS



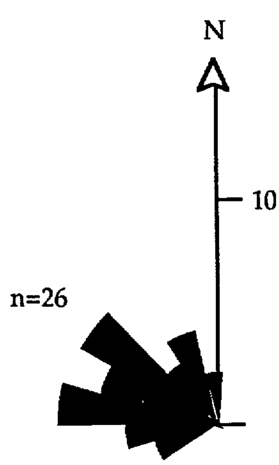
B

BIG SUNDAY FM
PALEOCURRENTS



C

KURRUNDIE
PALEOCURRENTS



D

PALETTE BASIN
PALEOCURRENTS

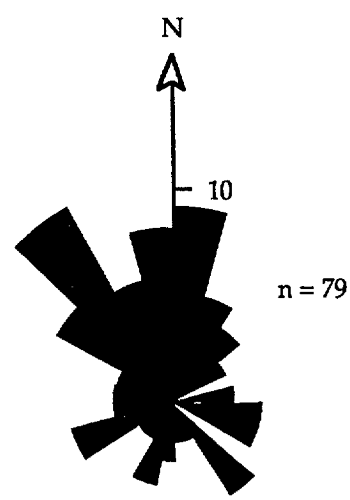


Fig 7. Facies of the Pul Pul Rhyolite. (a) Breccia/conglomerate of Coronation Sandstone basalt in sandy matrix. (b) partly silicified fiamme ignimbrite. (c) quartz-feldspar porphyry with lithic fragments. (d) alteration halo around lithic fragment.

Fig. 7

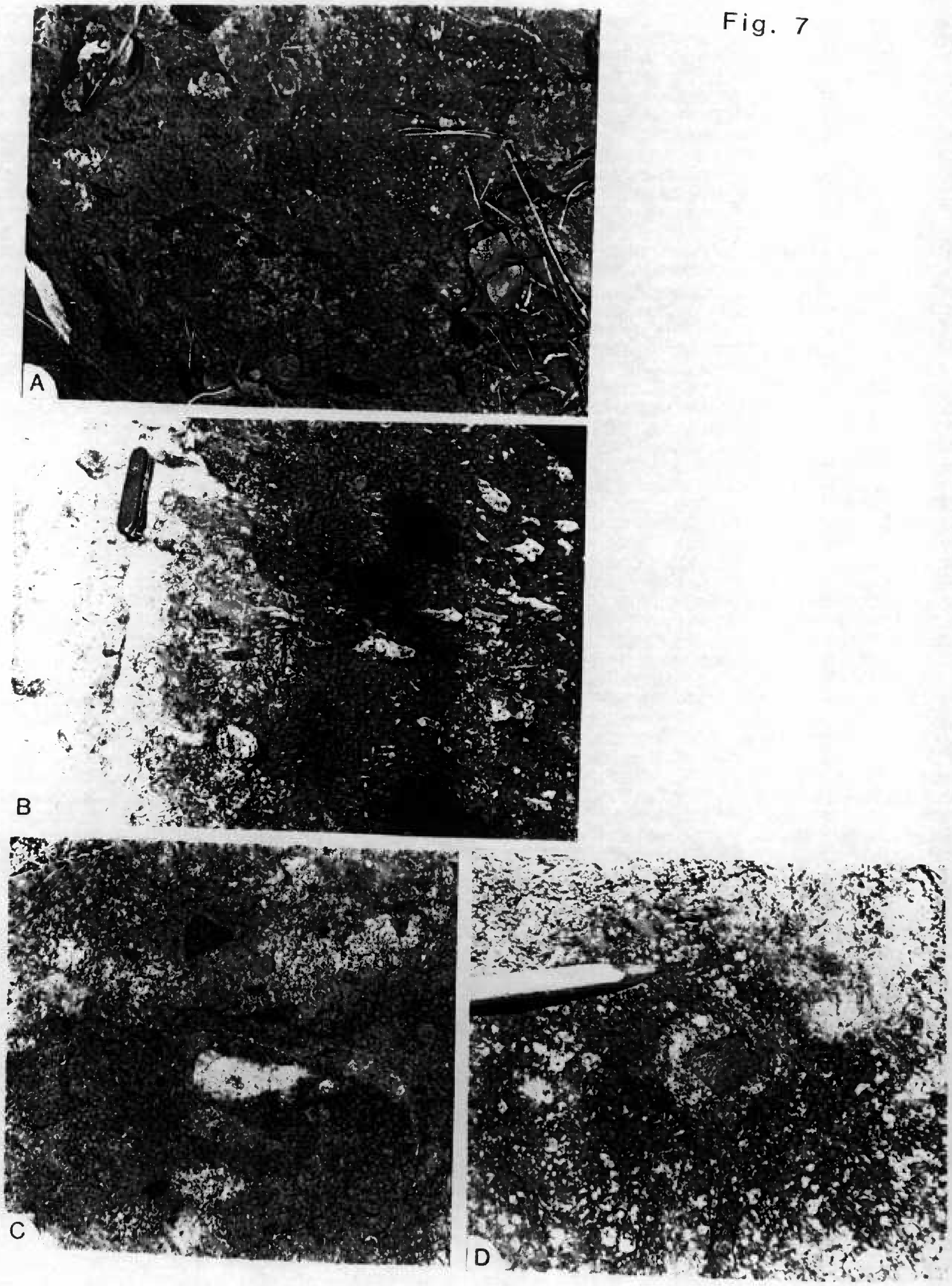


Fig 8. Schematic interpretation of post-Coronation growth faulting at El Sherana. Note the footwall folding. The hatched line shows the lower limit of outcrop exposure. The two photos (one with interpretation drawn on) are taken from and of a ridge directly behind El Sherana.

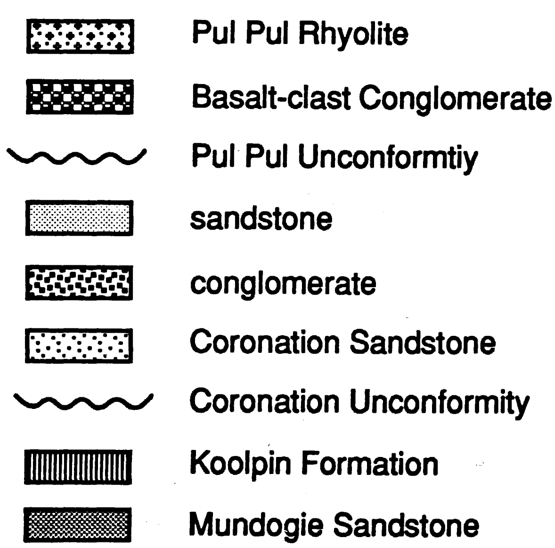


FIGURE 8

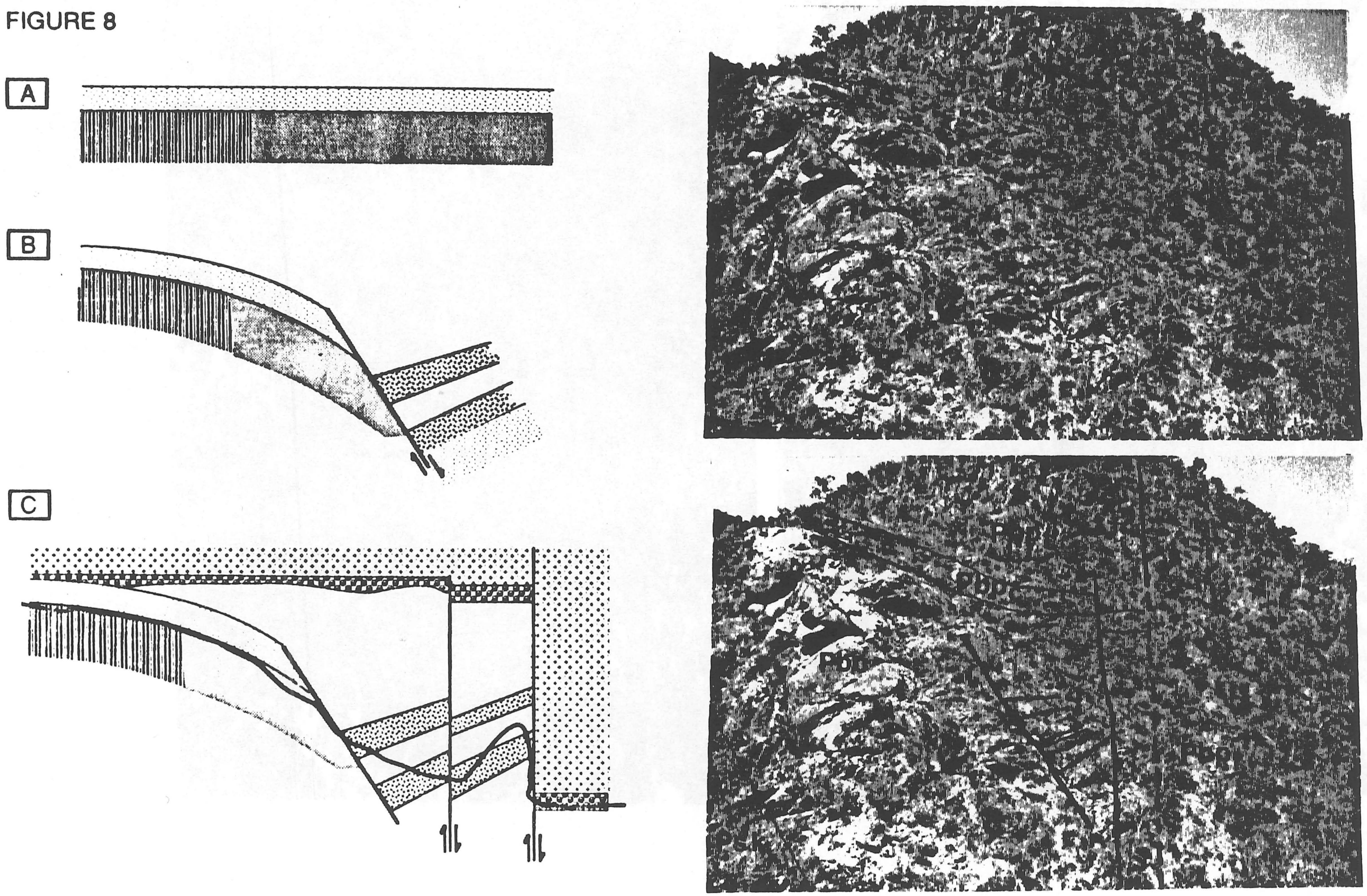


Fig 9. Peperite associated with the Big Sunday Unconformity. Solid-line borders surround individual volcanic elements within the deposit.

Fig. 9

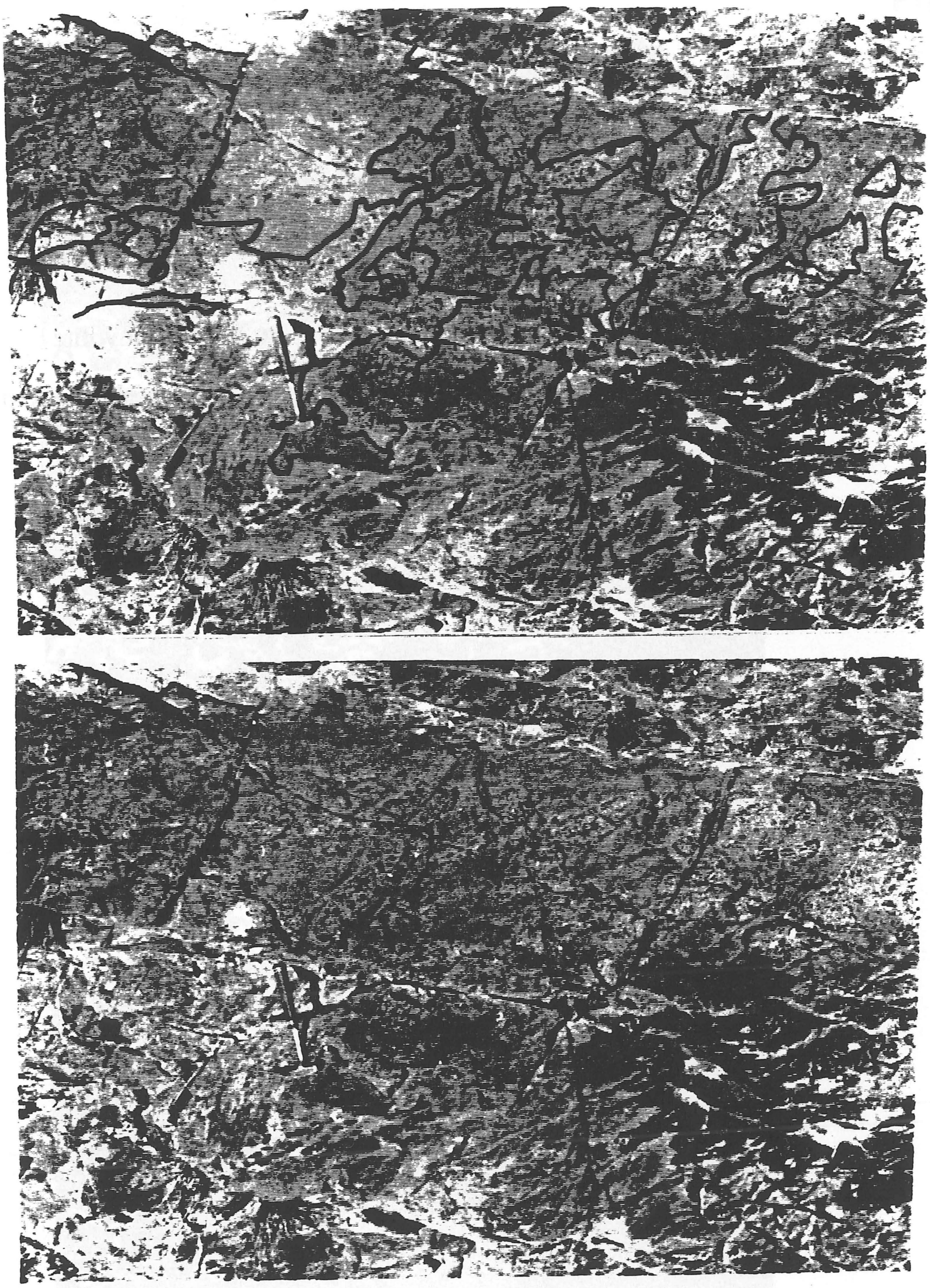


Fig 10. Facies of the Kurrundie Formation. (a) Incision into the Pul Pul Rhyolite overlain by Kurrundie conglomerates and sandstones. (b) Boulder conglomerate containing clasts of Pul Pul Rhyolite Breccia Sheet (photo taken near Fisher). (c)Trough-cross-bedded sandstone (*St* facies)

Fig. 10

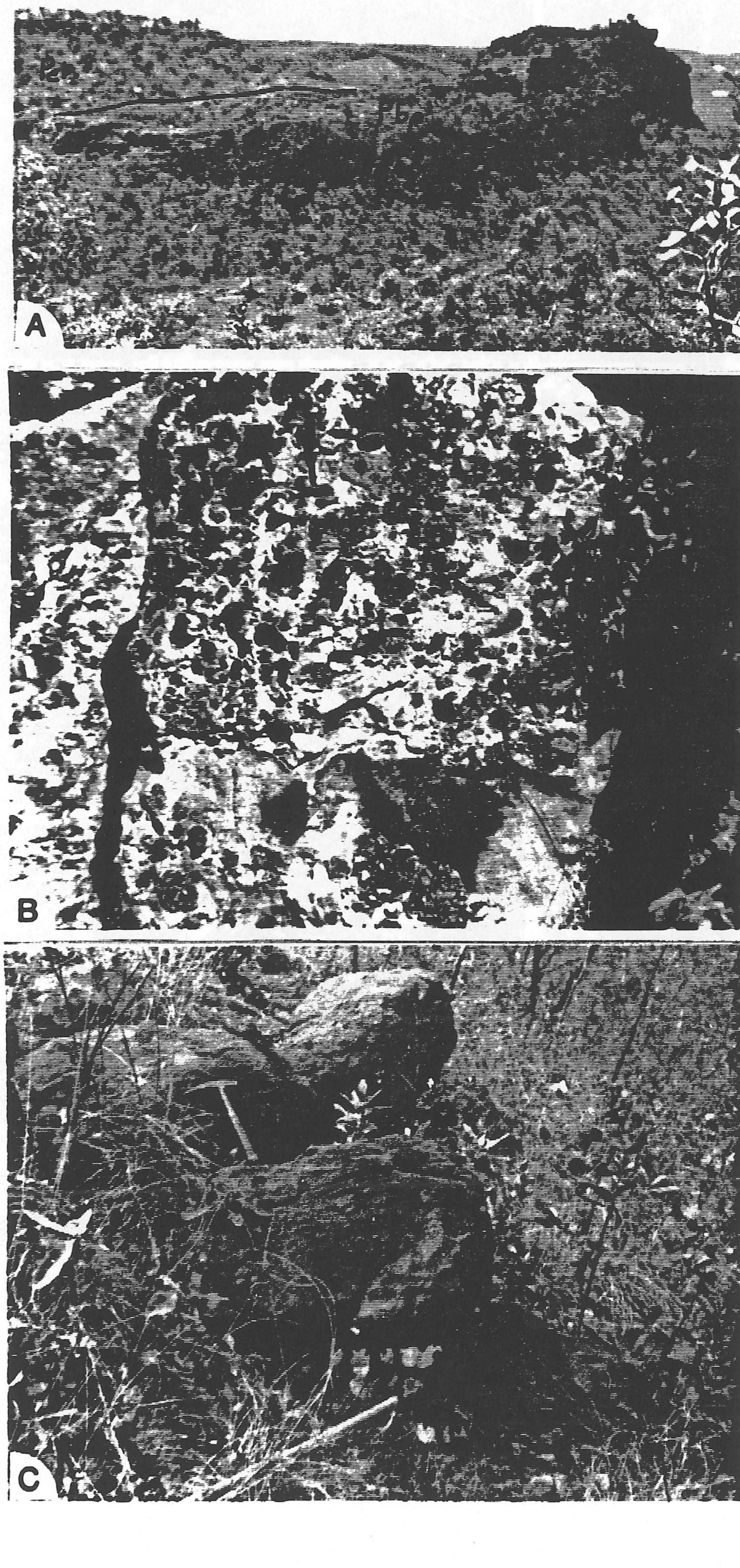


Fig 11. Palette Sub-basin Facies. (a) contact between Pul Pul Rhyolite and overlying Pul Pul Rhyolite breccia sheet; notice fiamme within breccia clasts; (b) sandstone dike filling fracture within Pul Pul Breccia sheet; note fitted fabric; (c) two generations of conglomerates, the lower with large rounded sandstone boulders, the upper interbedded with and incising medium to fine sandstones; (d) incision of sandstones into both generations of conglomerate. Bounding surface has four meters of relief; (e) medium-fine quartz arenites which overlap a growth faulting surface; (f) the same sandstones deformed by a later growth faulting event.

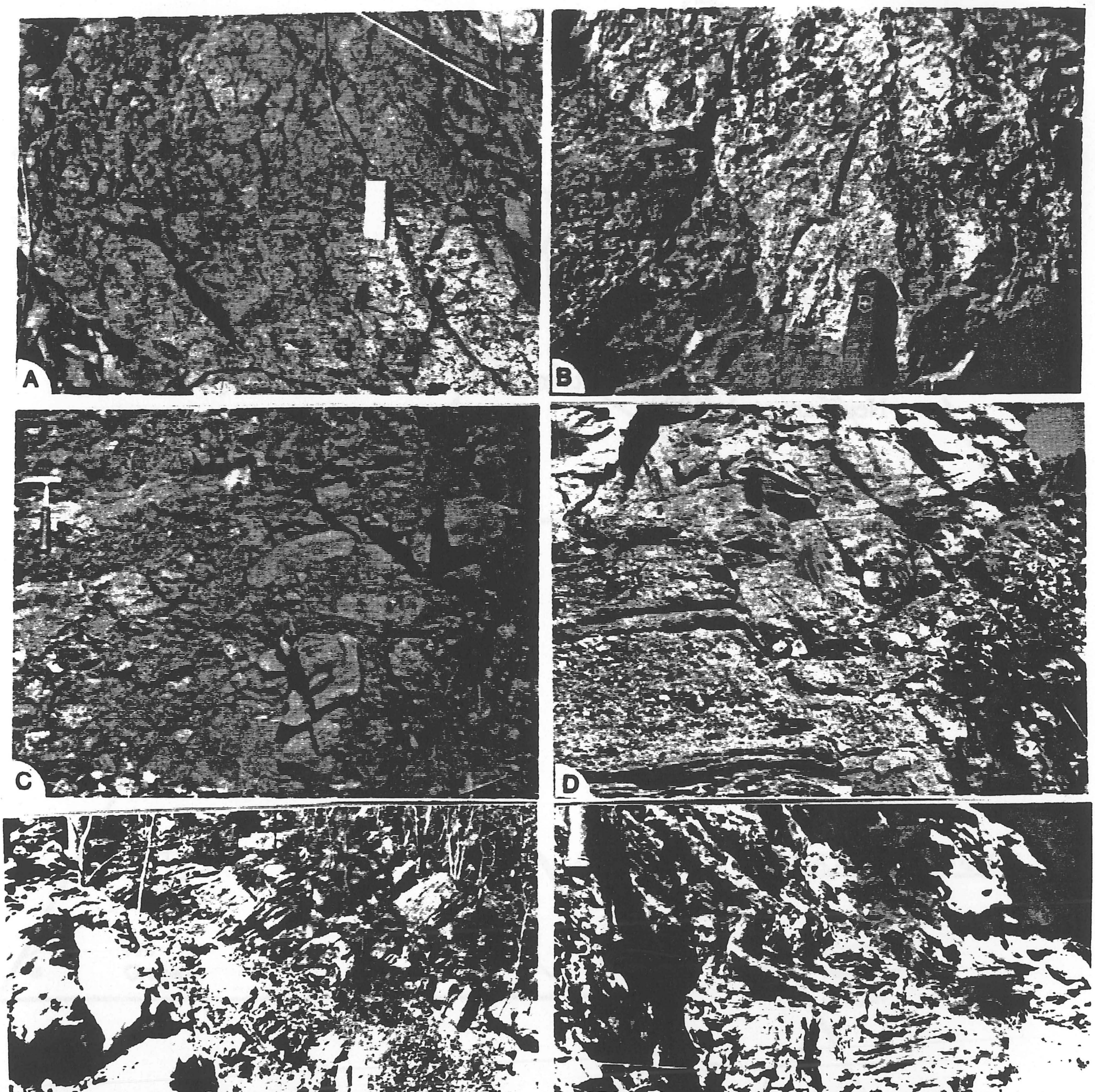
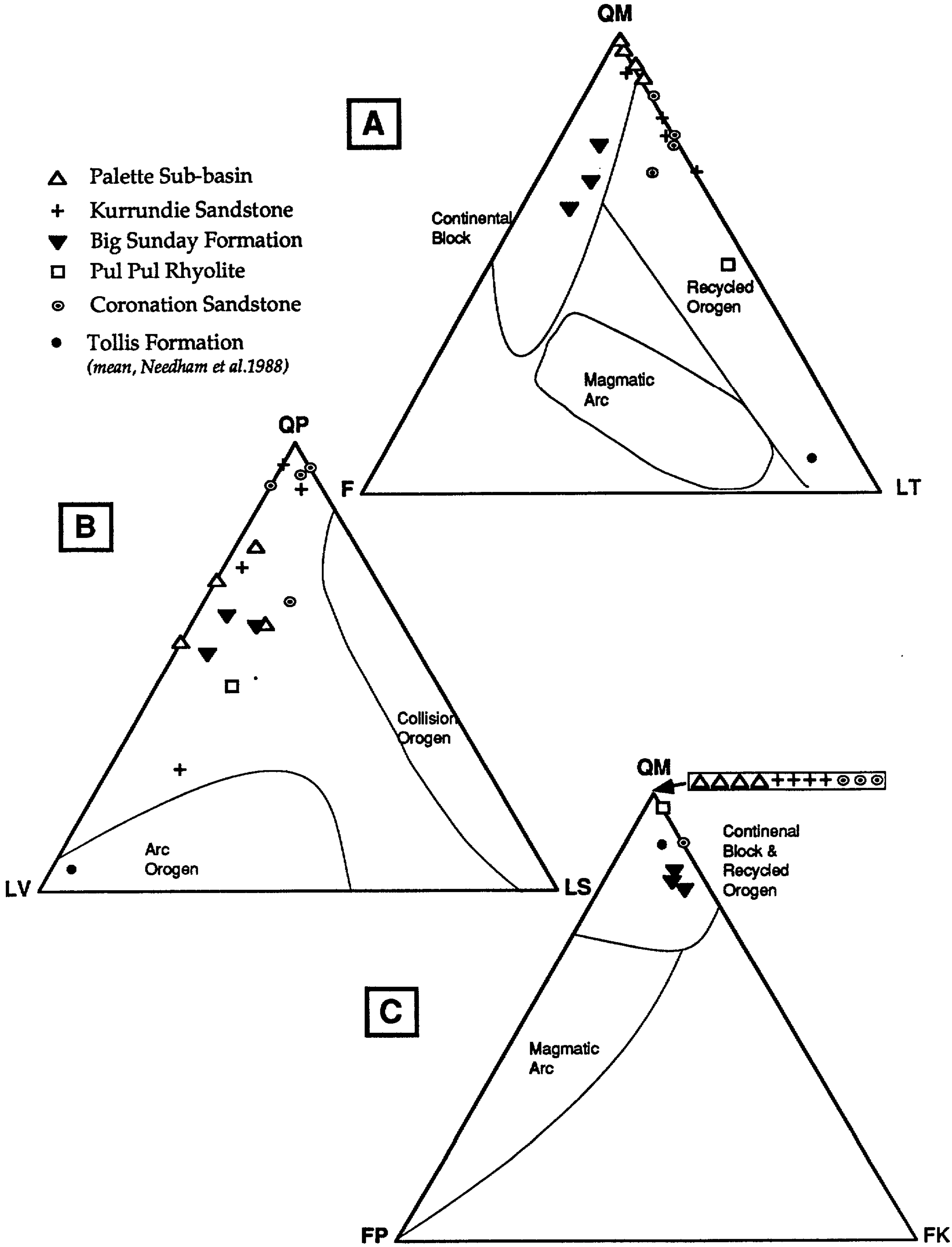


Fig. 11

Fig 12. Provenance Diagrams. Ternary diagrams and fields from Dickinson and Suczek (1979). Σ represents mean of Tollis Formation samples from Needham et al. (1988).



QM
A
Palette Sub-basin
Kurrundie Sandstone
Big Sunday Formation
Pul Pul Rhyolite
Coronation Sandstone
Tollis Formation
(mean, Needham et al.1988)
Continental Block
Recycled Orogen
Magmatic Arc
F
LT
QP
B
Collision Orogen
Arc Orogen
LV
LS
QM
Continenal Block & Recycled Orogen
C
Magmatic Arc
FP
FK

Fig 13. A schematic representation of the interpreted events at Palette. (a) El Sherana Group on Pine Creek Supergroup; view to the southeast (b) initial growth faulting with deposition of Pul Pul breccia sheets; (c) fault reversal with continued growth faulting, with basal conglomerate, incision, deposition of interbedded debris-flow conglomerates and sandstones, and fault scarp onlap and overlap by later sandstones; (d) final faulting and present basin configuration.

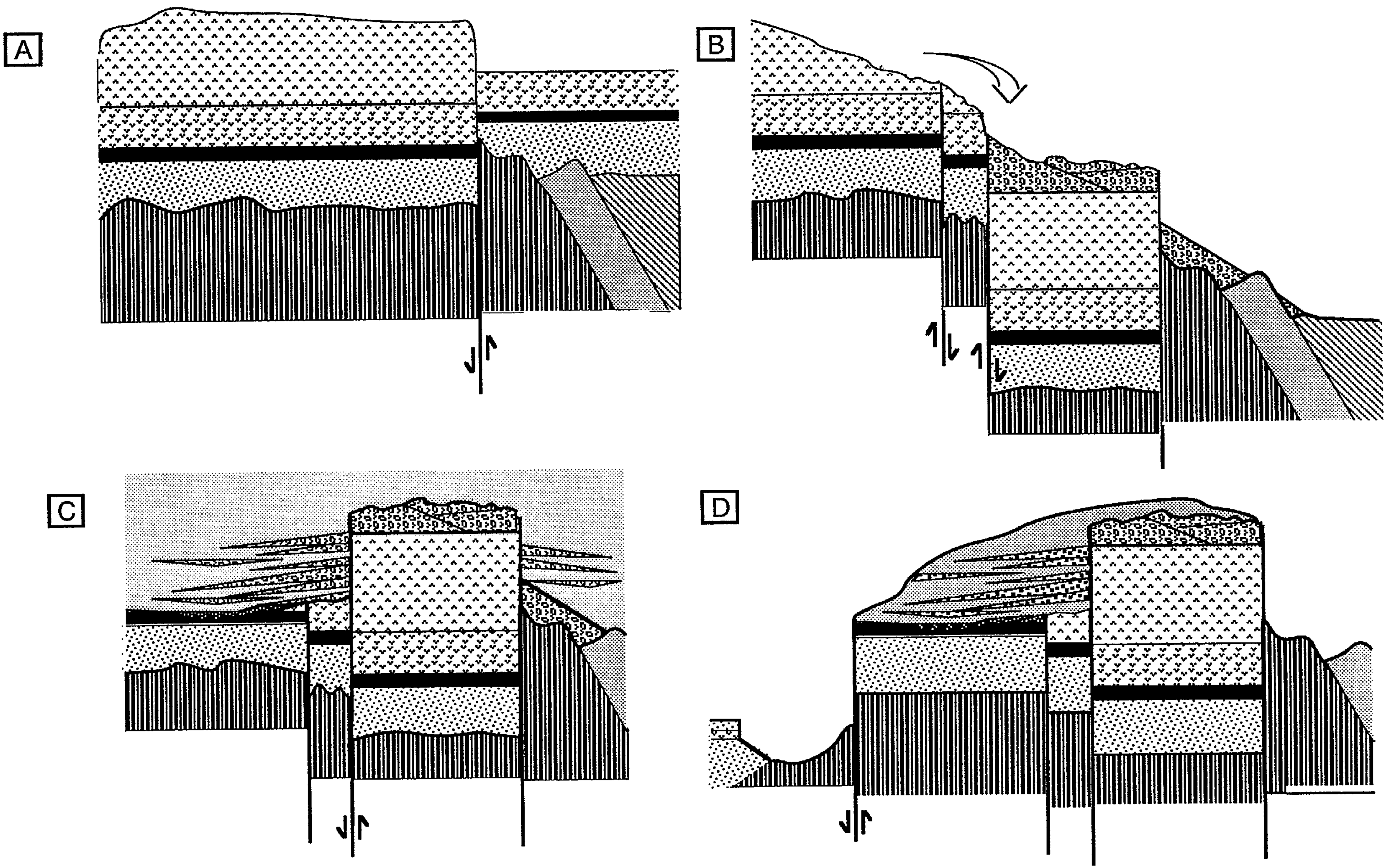
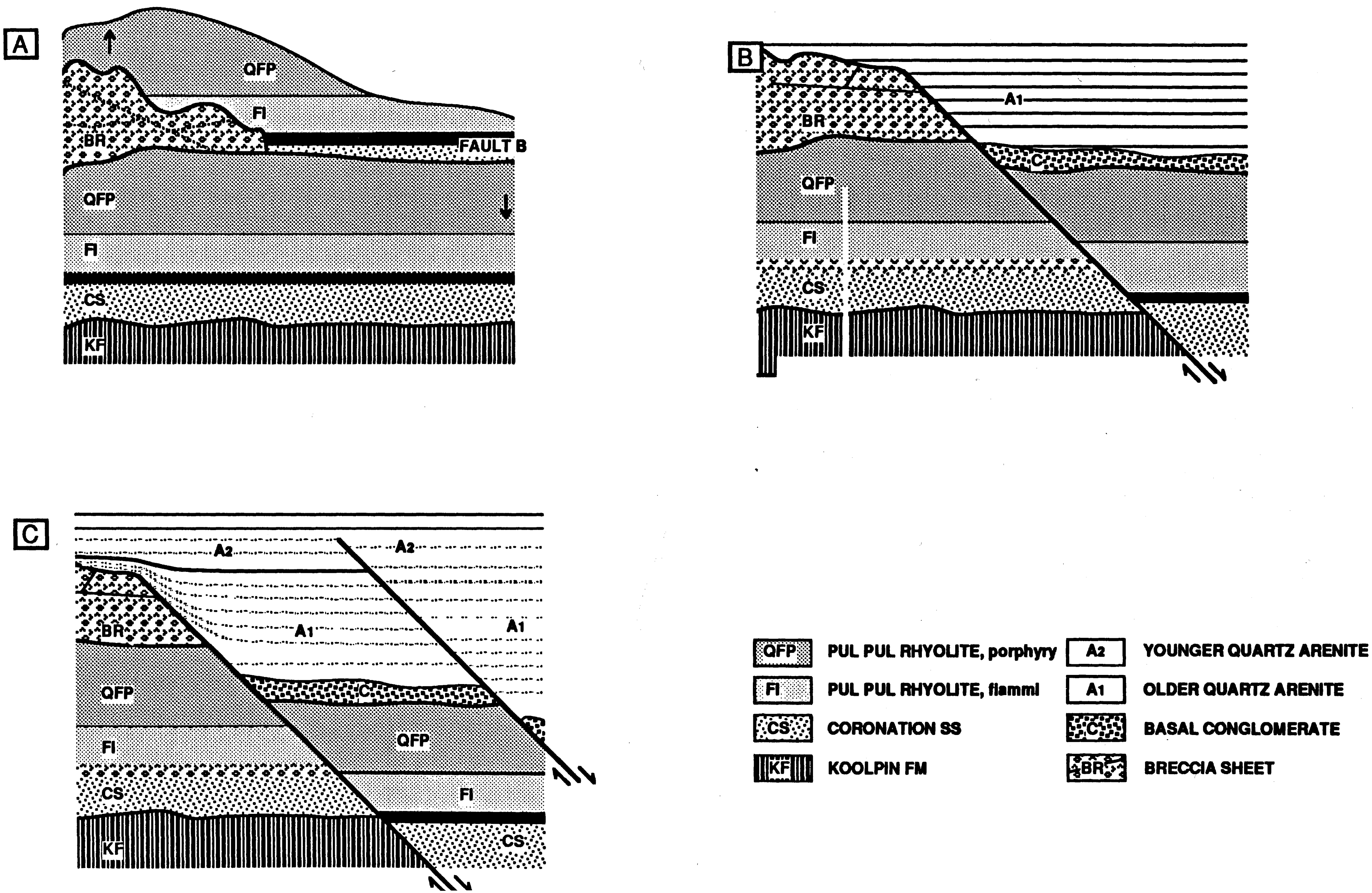
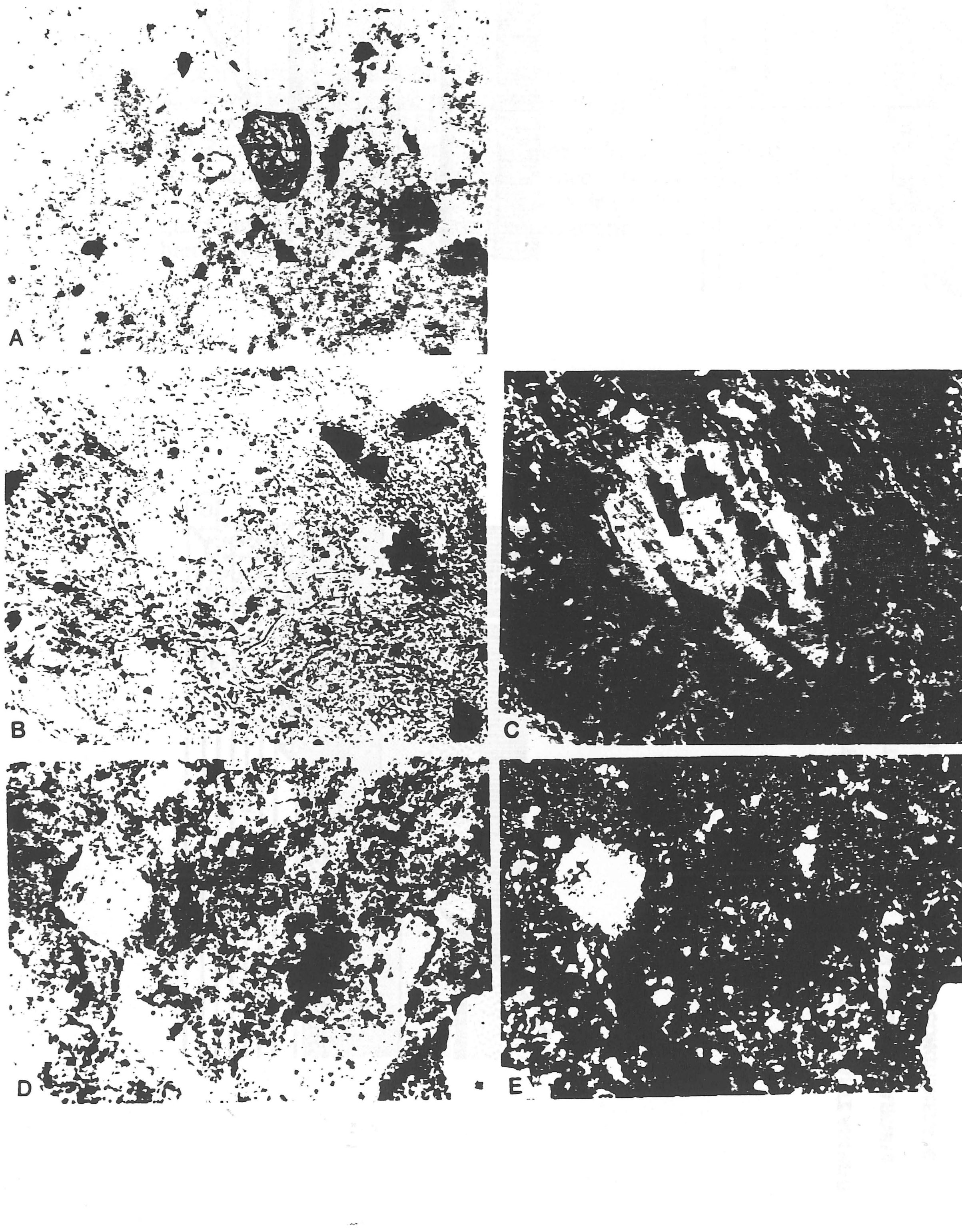

A
B
C
D

Fig 14. A schematic representation of Palette faulting and sedimentation; cross sections as viewed to the northeast perpendicular to fig 11. (A) Faulting parallel to the plane of the page lifts El Sherana Group material to the northeast, shedding Pul Pul Ryolite in breccia sheets towards the field of view; (B) down-to-the-southeast normal faulting cuts breccia sheets, with scarp related sedimentation to the southeast; (C) fault surfaces reactivate and both fold and fault overlying quartz arenites; late stage quartz arenites overlap deformed quartz arenites and breccia sheets unconformably.


A
QFP
FI
BR
FAULT B
QFP
FI
CS
KF
B
A1
BR
C
QFP
FI
CS
KF
C
A2
A2
BR
A1
A1
C
QFP
QFP
FI
FI
CS
KF
CS
QFP PUL PUL RHYOLITE, porphyry
FI PUL PUL RHYOLITE, flamml
CS CORONATION SS
KF KOOLPIN FM
A2 YOUNGER QUARTZ ARENITE
A1 OLDER QUARTZ ARENITE
C BASAL CONGLOMERATE
BR BRECCIA SHEET


A
B
C
D
E

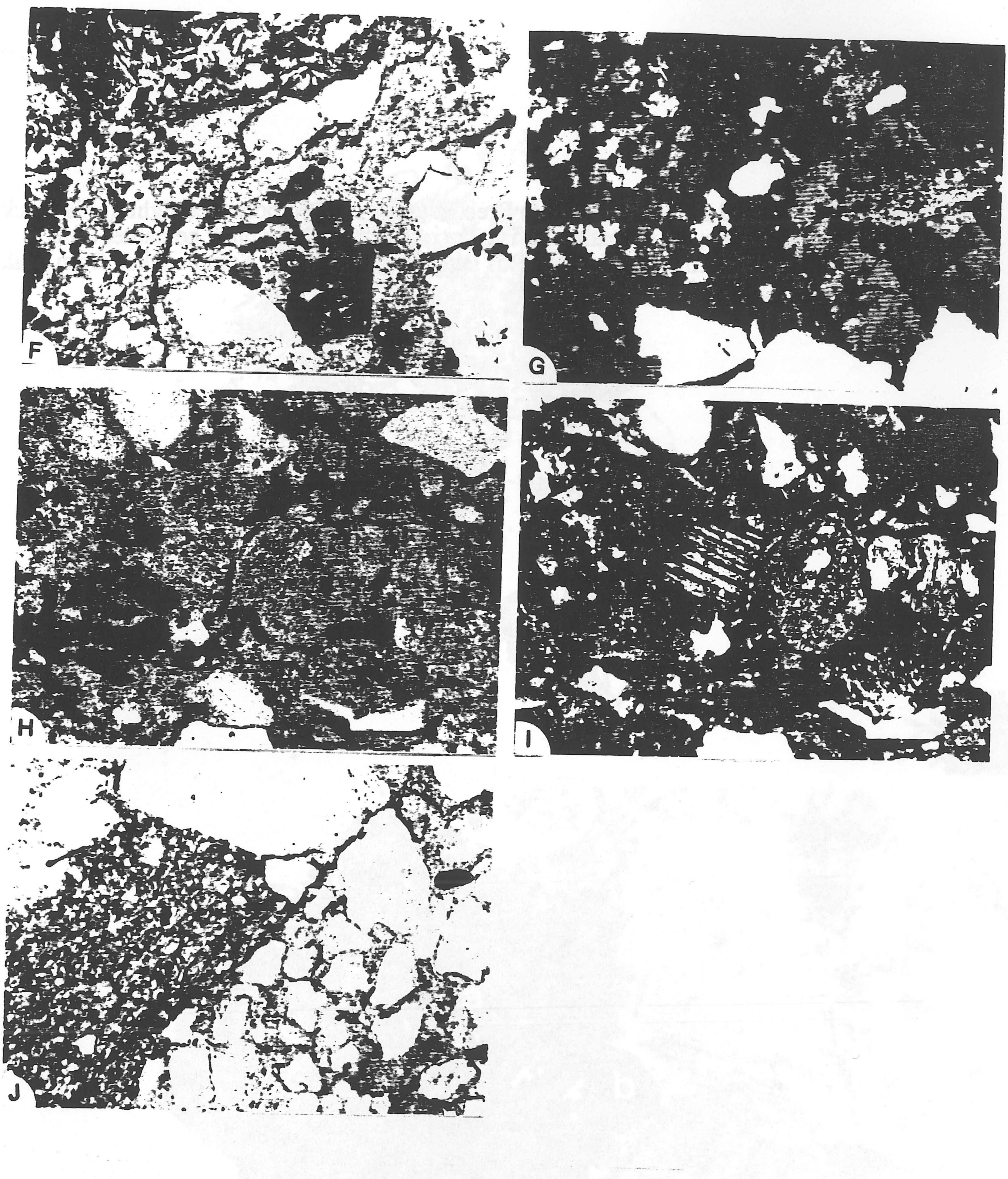


Fig 15. Photomicrographs of El Sherana/Edith River lithologies. (a) fresh detrital epidote from Coronation Sandstone, plane-polarized light; (b,c) phosphate cements from Coronation Sandstone; plane-polarized light and cross-polarized light. Note multi-colliform laminated fabric; (d,e) Alteration fabrics in Pul Pul Rhyolite, plane-polarized light and cross-polarized light; (f,g) clasts from conglomerate in Big Sunday Unconformity valley fill facies. Includes detrital epidote bundle (f), chloritized dolerite (f), carbonate-replaced volcanic (g), and phyllite clast (g); plane polarized light and cross-polarized light; (h,i) feldspatholithic greywacke from Big Sunday Formation. Note fresh feldspars versus altered Pul Pul Rhyolite sample in (e), plane polarized light and cross-polarized light; (j) Kurrundie Sandstone with felsic rhyolite fragment and detrital epidote, plane-polarized light.

Fig 16. Void fill sequence in Scinto Breccia under crossed polarized light. (a) is blocky phosphate; (b) is apatite; (c) is quartz; (d) is needle or platy hematite; (e) is unknown fibrous mineral, (f) is latest stage wavelite. Sample taken from peak of Coronation Hill (fig. 1).

Fig. 15

Fig 17. Isopach maps for El Sherana and Edith River units, with reference map. a) Coronation Sandstone; note the coalescing isopachs at the syncline, and that a zero isopach lies northeast of the reference map; b) Pul Pul Rhyolite; c) Big Sunday Formation; note the placement of the zero isopach; d) Kurrundie Sandstone. Numbered spots are reference measured sections; only sections with stratigraphic caps are included. Arrows represent dominant paleocurrent azimuth during deposition of that unit; note reversal between units. Shaded areas are older units exposed and eroded during deposition of a unit.

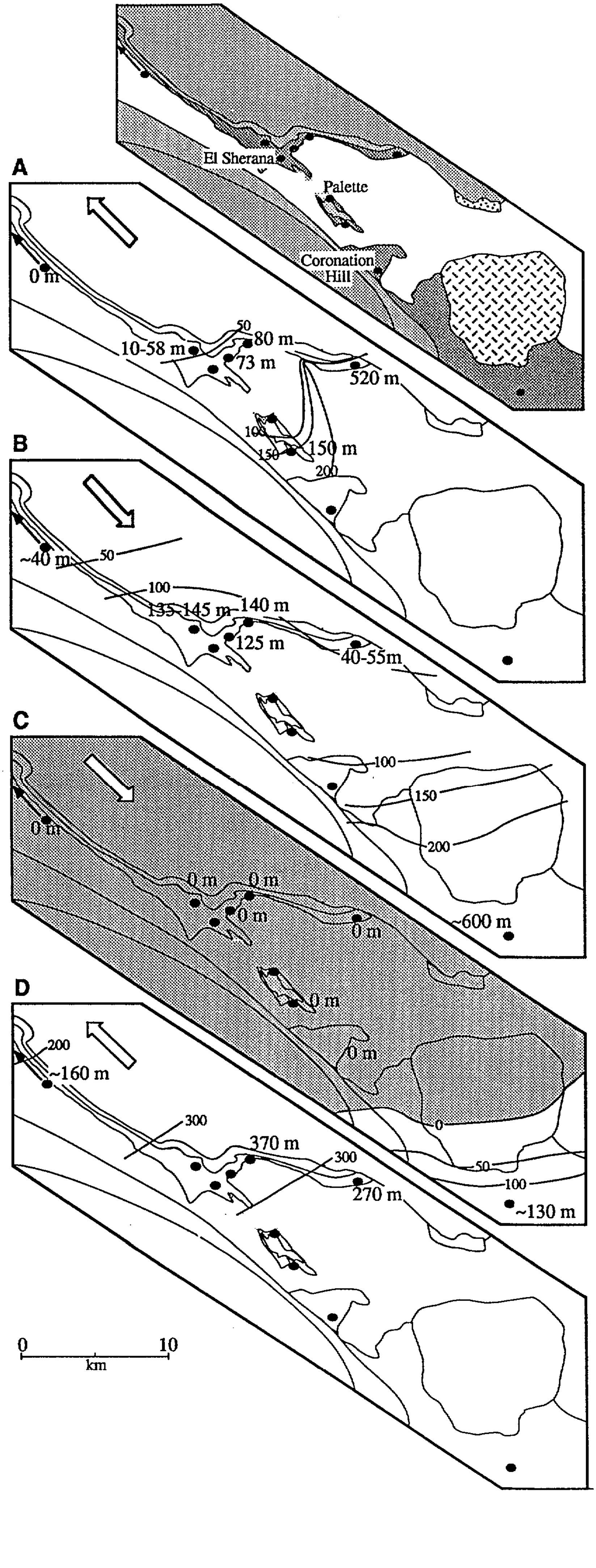
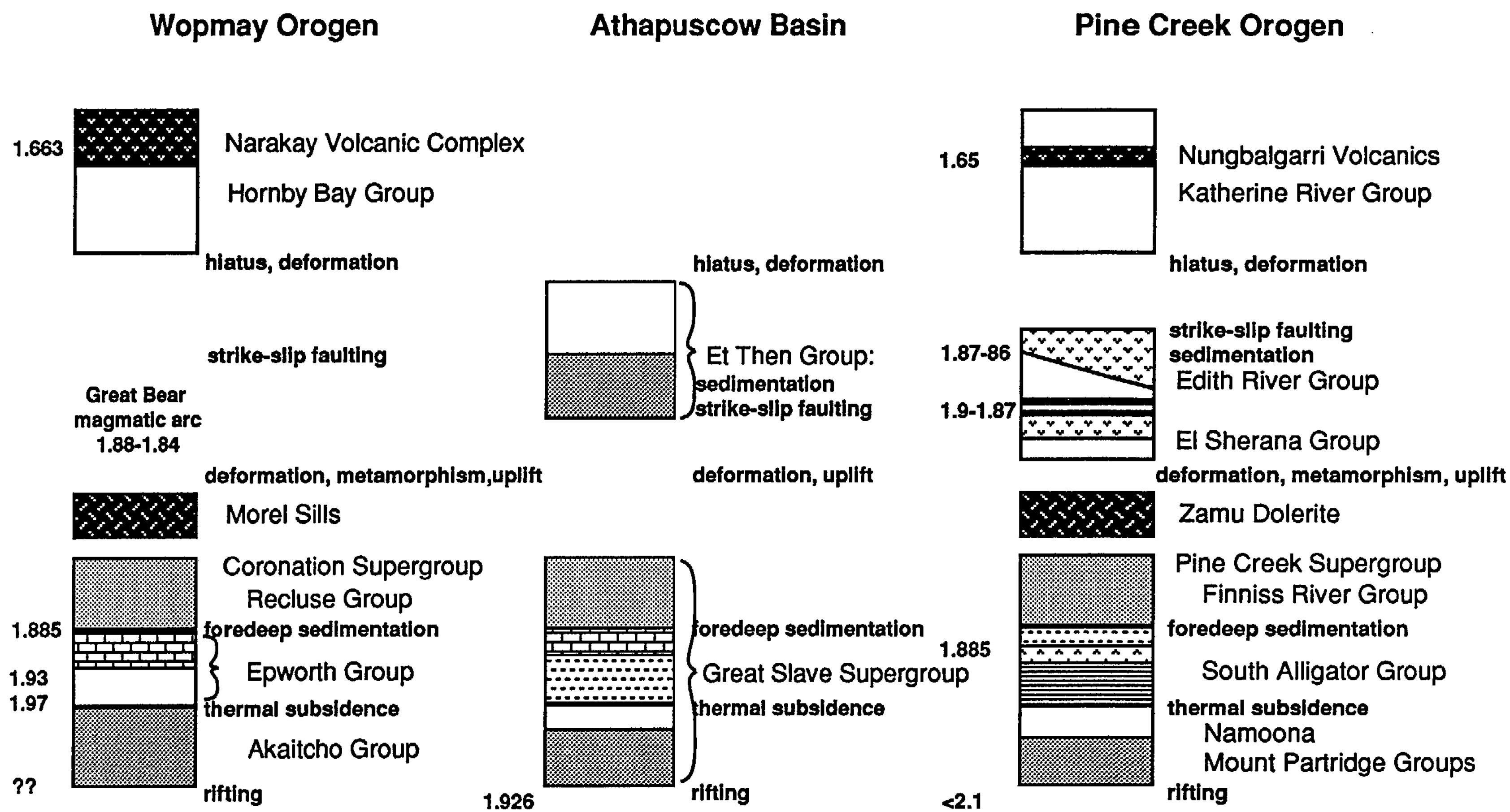
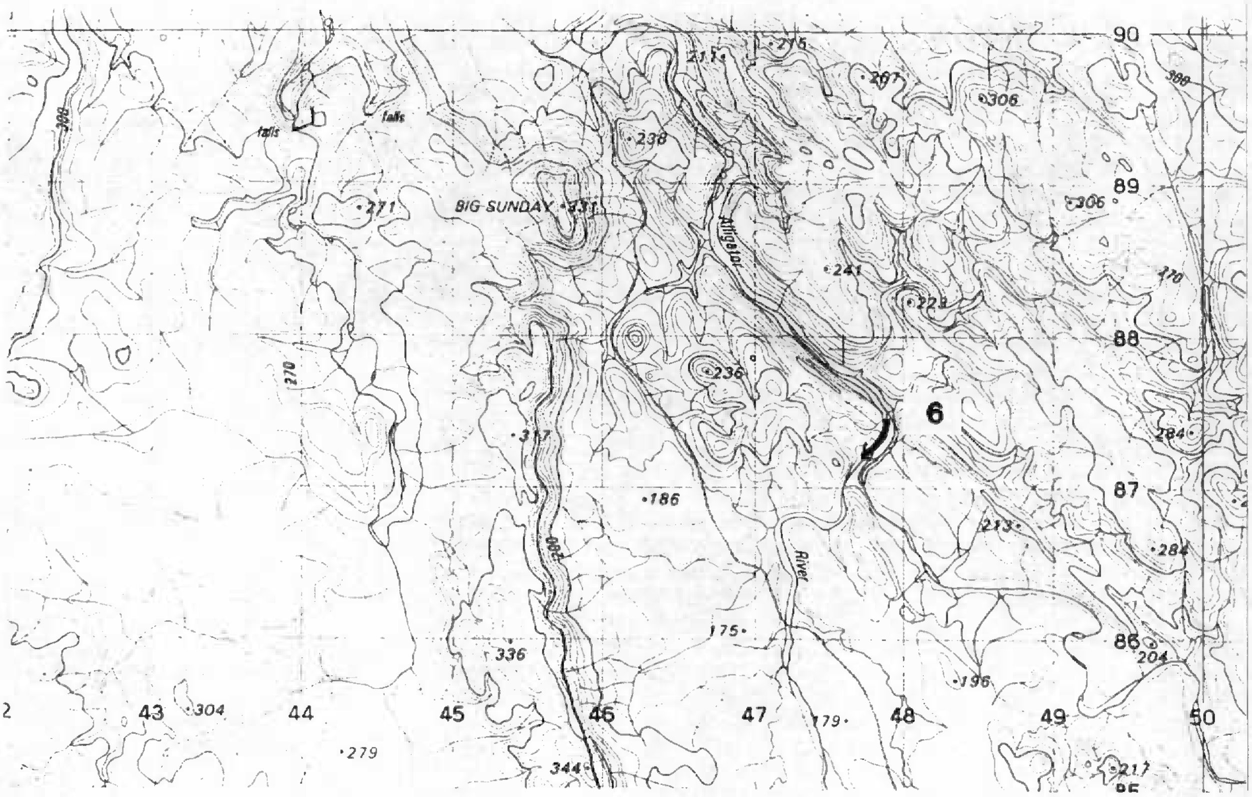

El Sherana
Palette
Coronation Hill
A
0 m
50
10-58 m
80 m
73 m
520 m
100
150
150 m
200
B
~40 m
50
100
135-145 m
140 m
125 m
40-55m
100
150
200
C
0 m
0 m
0 m
0 m
0 m
0 m
0 m
~600 m
D
200
~160 m
300
370 m
300
270 m
0
50
100
~130 m
0
10
km

Fig 18. Schematic comparison between Wopmay Orogen, Athapuscow Basin, and Pine Creek Orogen from 2.0-1.6 Ga. Key similarities include basal Wilson cycles with foreland basin sedimentation beginning at 1.885 Ga, post-orogenic deformation and/or sedimentation, and 1.65 Ga platform cover.

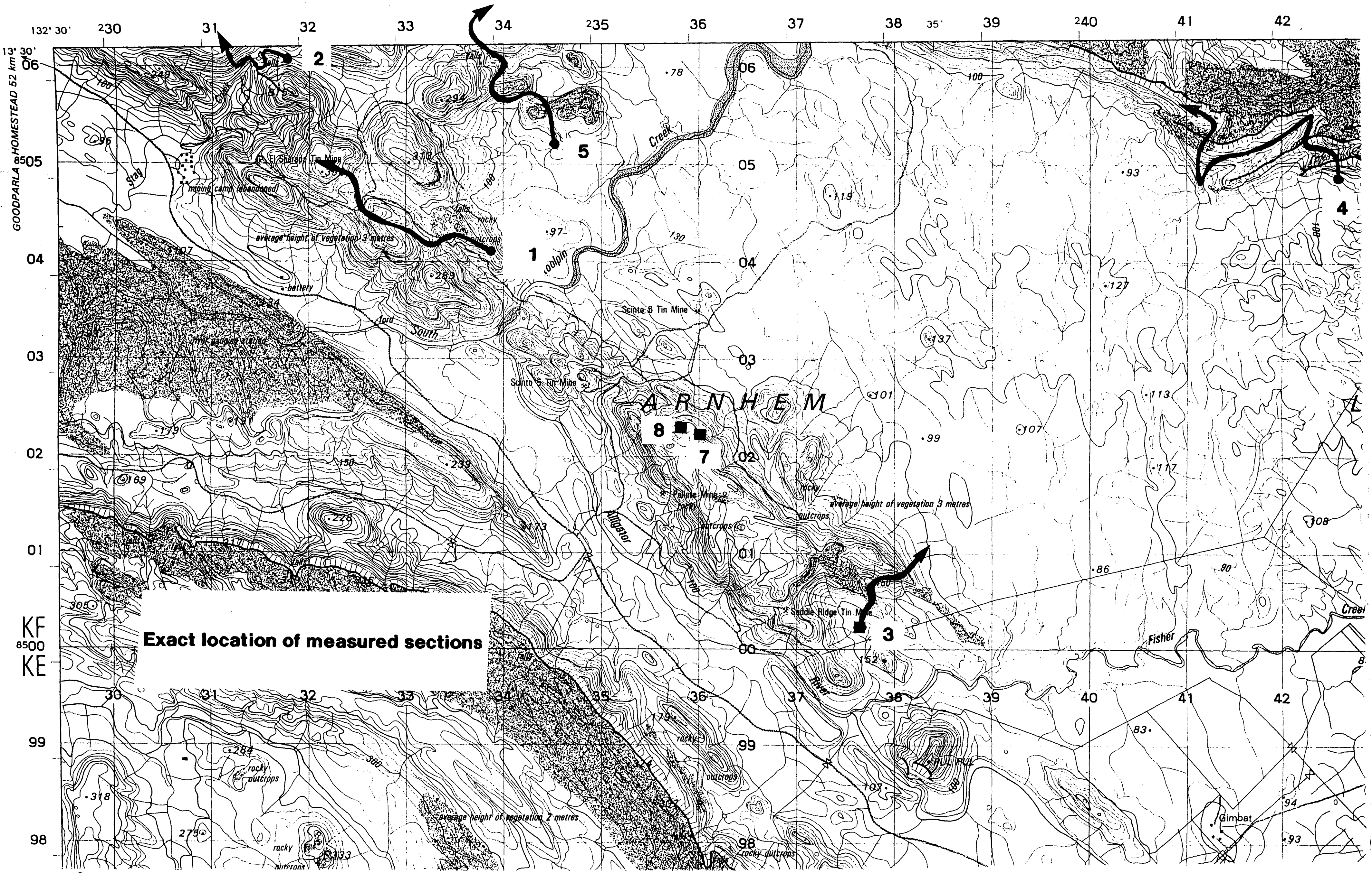

Wopmay Orogen
Athapuscow Basin
Pine Creek Orogen
1.663
Narakay Volcanic Complex
Hornby Bay Group
hiatus, deformation
strike-slip faulting
Great Bear magmatic arc 1.88-1.84
deformation, metamorphism,uplift
Morel Sills
Coronation Supergroup
Recluse Group
1.885
foredeep sedimentation
1.93
Epworth Group
1.97
thermal subsidence
Akaitcho Group
??
rifting
hiatus, deformation
Et Then Group:
sedimentation
strike-slip faulting
deformation, uplift
foredeep sedimentation
Great Slave Supergroup
thermal subsidence
1.926
rifting
1.65
Nungbalgarri Volcanics
Katherine River Group
hiatus, deformation
strike-slip faulting
sedimentation
1.87-86
Edith River Group
1.9-1.87
El Sherana Group
deformation, metamorphism, uplift
Zamu Dolerite
Pine Creek Supergroup
Finniss River Group
foredeep sedimentation
1.885
South Alligator Group
thermal subsidence
Namoona
Mount Partridge Groups
<2.1
rifting

Appendix A

Stratigraphic columns at various locations within and near the study area, (see fig.1) (1) Monolith; (2) Stag Creek; (3) Saddle Ridge, (4) the "syncline"; (5) the "Hogbacks", Fisher Creek area. Section (6) is from a waterfall along the South Allligator River. Section (7) and (8) are sections through the Palette Sub-basin on Scinto Plateau.



falls
falls
BIG SUNDAY
Alligator
River
6
·271
·238
·241
·236
·186
·175
·336
·304
·279
·344
·213
·284
·196
·204
·217
·306
·306
43
44
45
46
47
48
49
50
90
89
88
87
86

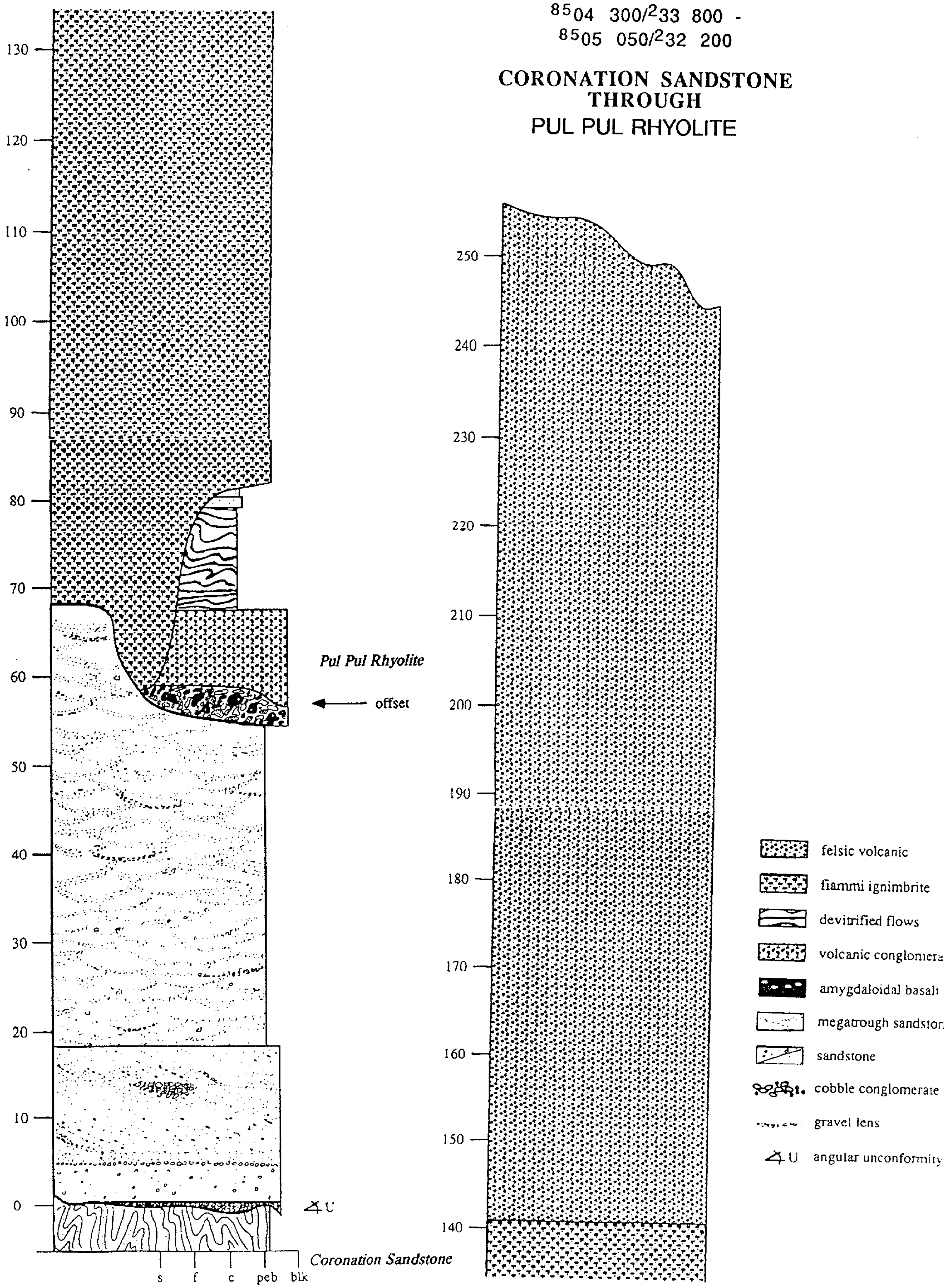


Exact location of measured sections
1
2
3
4
5
7
8
A R N H E M
El Sharana Tin Mine
mining camp (abandoned)
Sciato 6 Tin Mine
Sciato 5 Tin Mine
Palette Mine
Saddle Ridge Tin Mine
Koolpin Creek
Alligator River
Fisher Creek
Gimbat
GOODPARLA HOMESTEAD 52 km
average height of vegetation 3 metres
average height of vegetation 2 metres
rocky outcrops
KF
KE

SECTION 1

MONOLITH
85 04 300/2 33 800 -
85 05 050/2 32 200

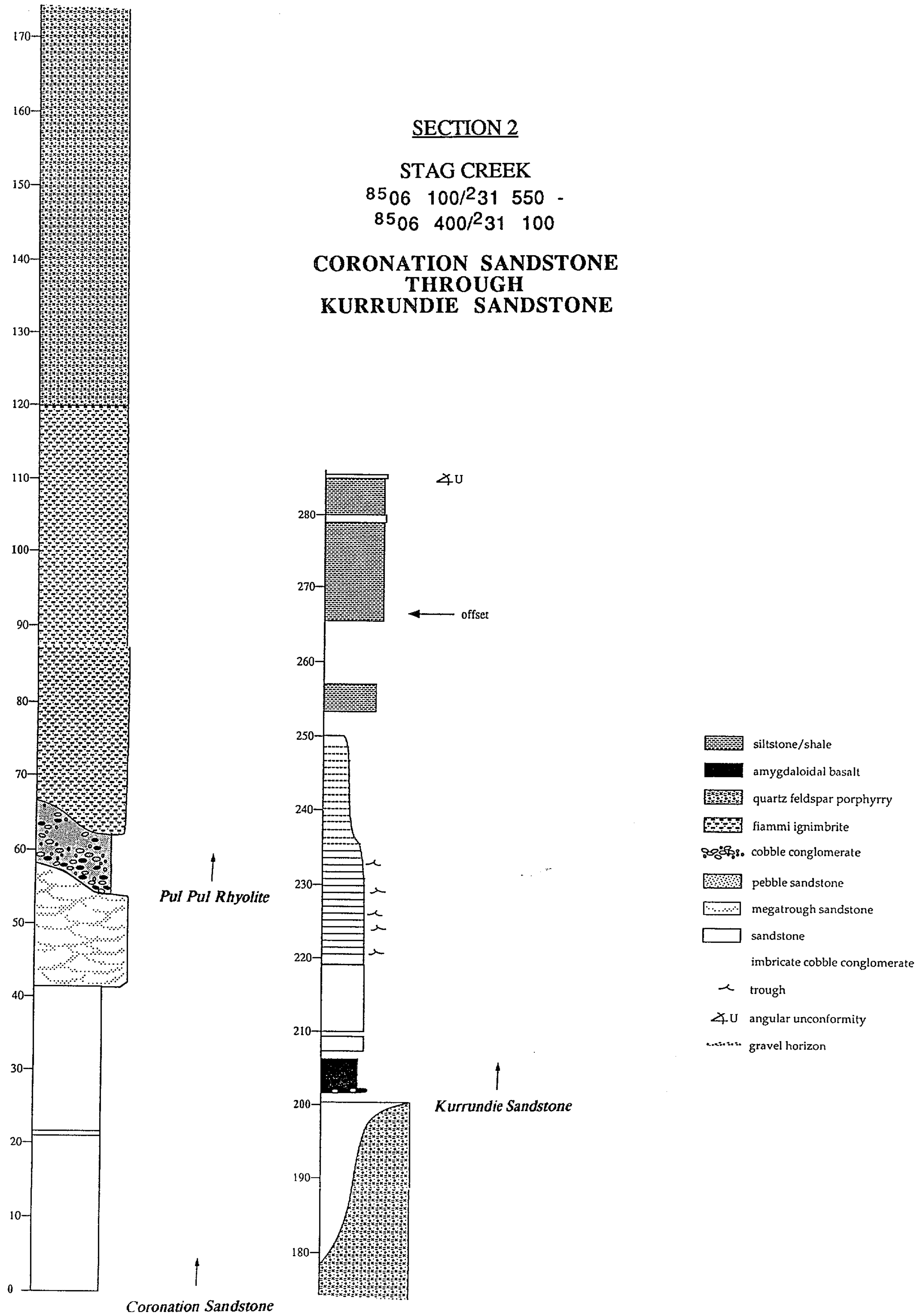
CORONATION SANDSTONE THROUGH PUL PUL RHYOLITE

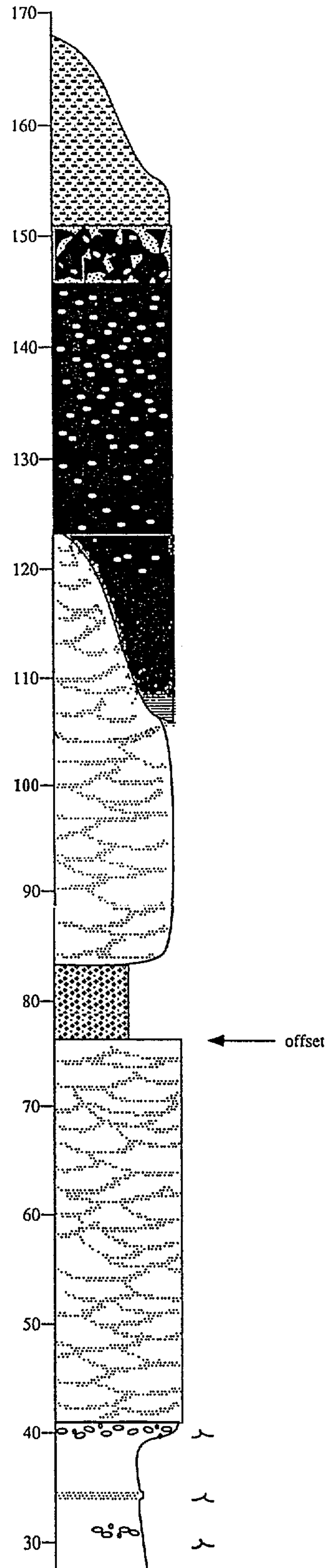


<u>SECTION 2</u>

STAG CREEK
$^{85}06\ 100/^{2}31\ 550$ -
$^{85}06\ 400/^{2}31\ 100$

CORONATION SANDSTONE
THROUGH
KURRUNDIE SANDSTONE



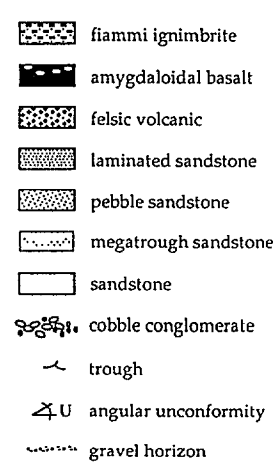


SECTION 3

SADDLE RIDGE

^{85}00 300/^{2}37 500 -
^{85}06 400/^{2}31 100

CORONATION SANDSTONE

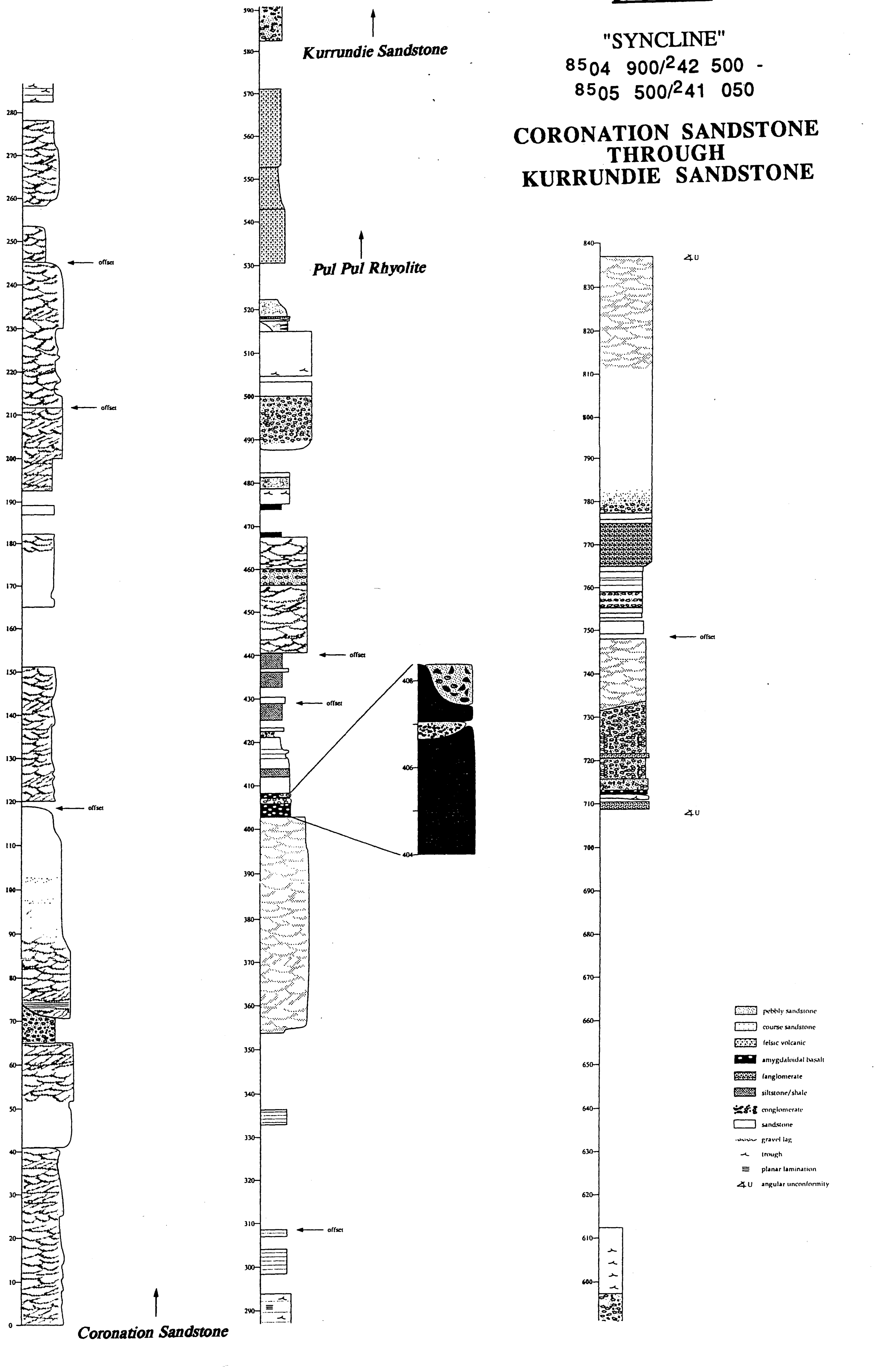


SECTION4

"SYNCLINE"

85$_{04}$ 900/^{2}42 500 - 85$_{05}$ 500/^{2}41 050

CORONATION SANDSTONE THROUGH KURRUNDIE SANDSTONE

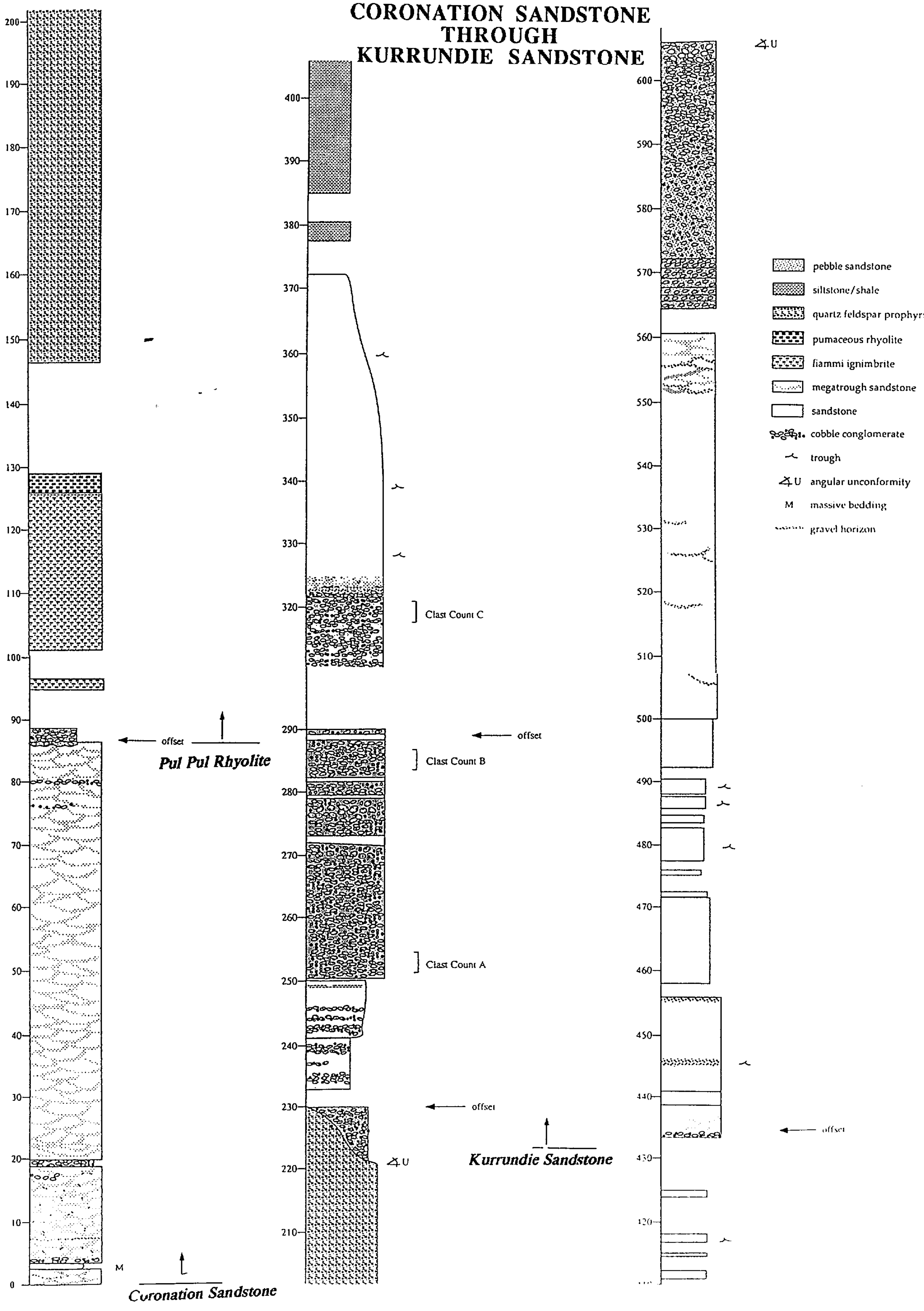


SECTION 5

"HOGBACKS"

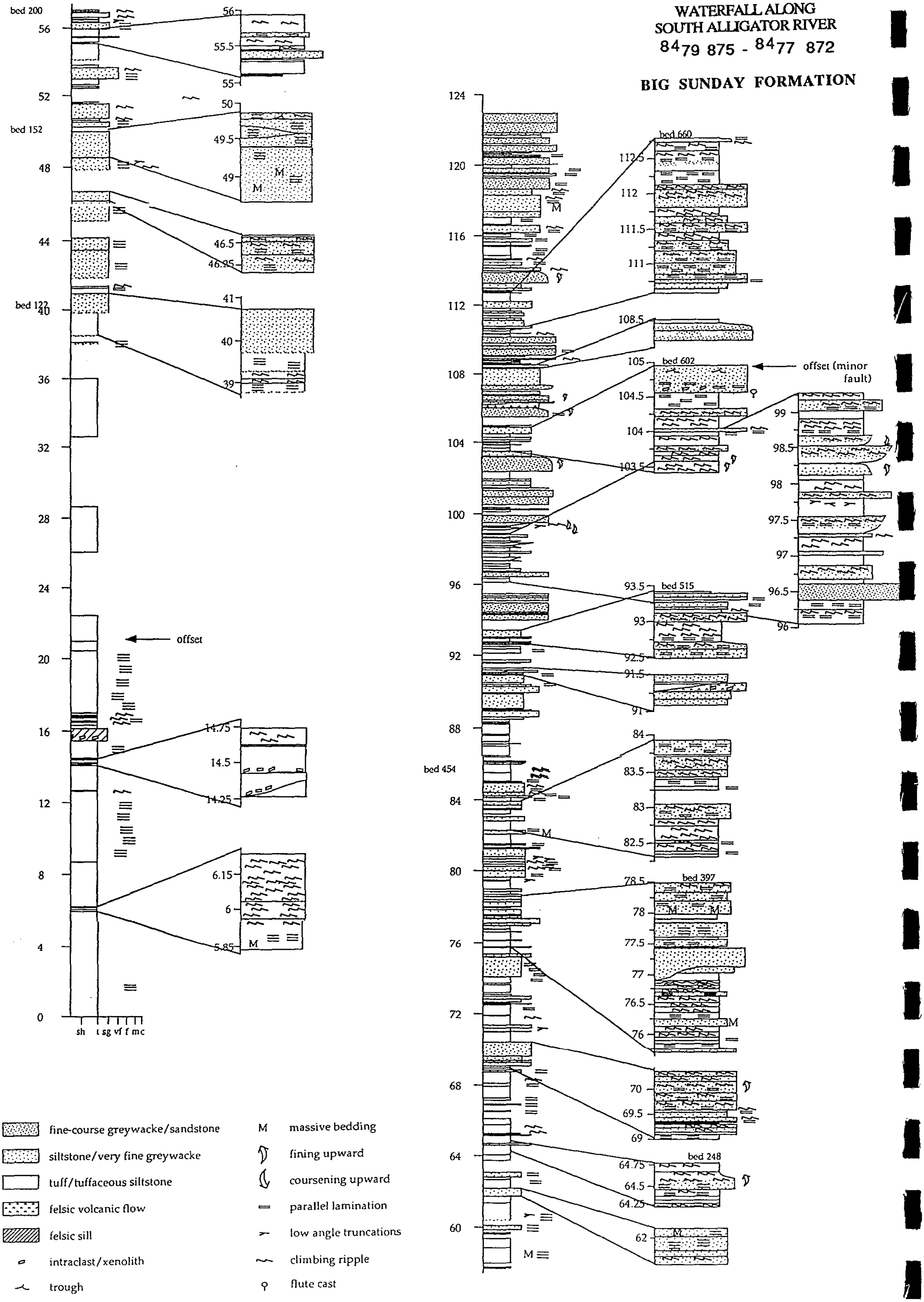
8505 200/234 500 -
8506 700/233 900

CORONATION SANDSTONE THROUGH KURRUNDIE SANDSTONE



WATERFALL ALONG
SOUTH ALLIGATOR RIVER
8479 875 - 8477 872

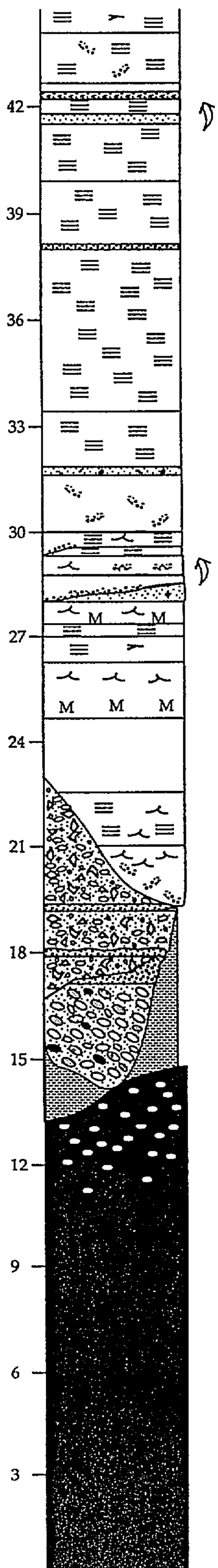
BIG SUNDAY FORMATION

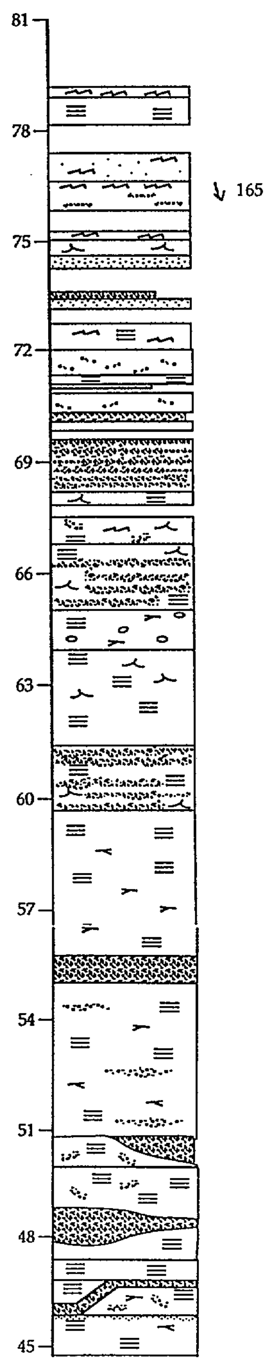


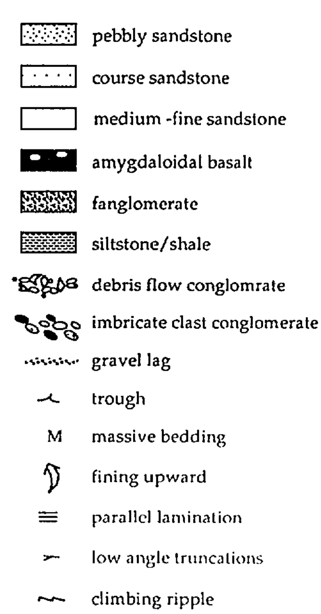
SECTION 7

SCINTO PLATEAU
8502 400/236 000

PALETTE SUB-BASIN 1





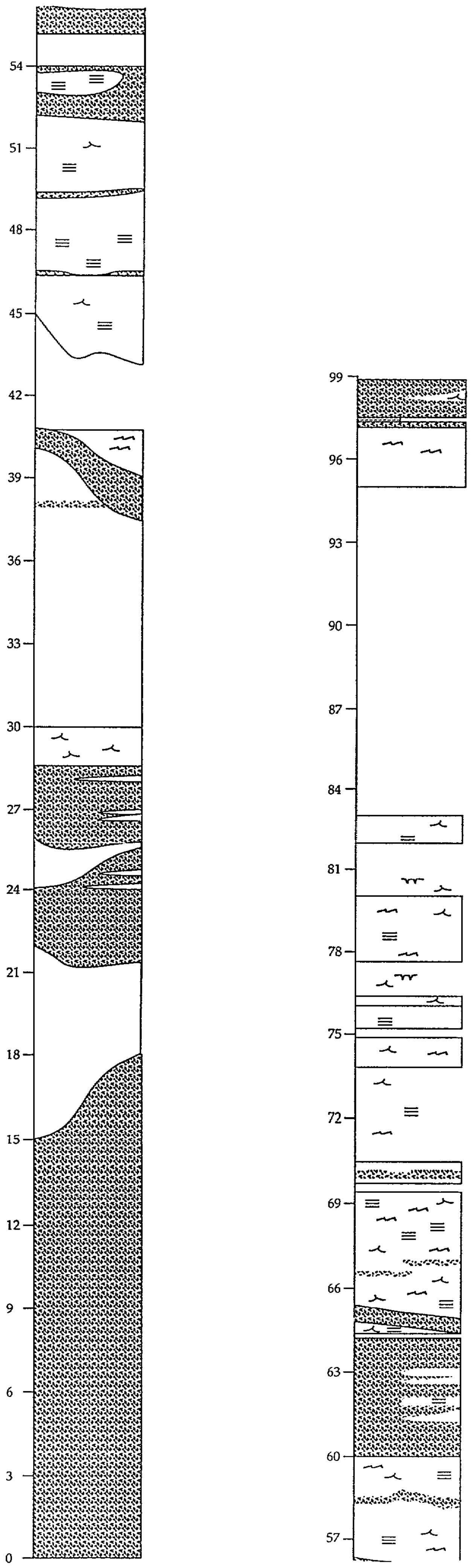


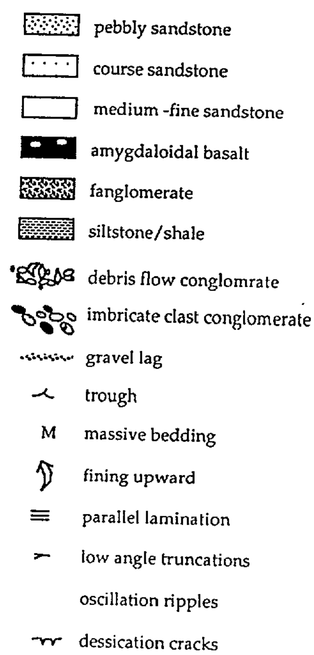
SECTION 8

SCINTO PLATEAU

$^{85}02$ 490/$^{2}35$ 800

PALETTE SUB-BASIN 2





Appendix B

Point Counts

Appendix B

Point Counts

sample	location	Q	F	L	Qm	Qp	Lv	Ls	Lt	Fp	Fk	Fund	D. mica	Matrix	Chl	Hem	HiClay	LoClay
11	p	299	3	3	295	4	2	1	7	1	1	1	0	20	0	0	14	2
62	k	196	1	58	177	19	47	11	77	0	0	1	0	63	0	1	9	51
13a	c	237	0	4	208	29	4	0	33	0	0	0	0	0	0	0	21	0
35a	c	265	0	4	210	55	0	4	59	0	0	0	0	46	0	0	45	0
79	b	113	37	7	104	9	5	2	16	12	17	8	13	99	4	1	3	19
40b	c	265	3	6	208	57	3	3	63	3	0	0	0	41	0	1	40	0
100	r	116	11	45	82	34	33	12	79	0	4	7	0	28	2	0	31	10
65	k	240	10	2	227	13	1	1	15	0	0	10	15	78	3	74	20	18
58	c	157	20	16	131	26	9	7	42	0	18	2	0	104	103	1	14	4
5	p	264	2	1	262	2	1	0	3	0	2	0	0	1	32	1	2	1
4a	p	315	2	9	305	10	9	0	19	0	2	0	0	7	0	7	4	3
31b	p	287	1	7	267	20	6	1	27	0	0	1	0	55	0	7	20	13
92	b	121	53	8	103	8	7	1	16	10	22	21	10	147	37	15	12	11
115	k	261	5	4	210	51	4	0	55	0	0	5	0	35	0	7	6	20
63	k	277	3	16	241	36	14	2	52	0	2	1	0	68	5	6	20	32

p Coronation Sandstone
r Pul Pul Rhyolite
b Big Sunday Formation
k Kurrundie Sandstone

Lt=Qp+Lv+Ls
Fund=feldspar undifferentiated
D. mica=demonstrably detrital mica
Matrix=not detrital grain or syntaxial overgrowth
HiClay= High birefrinent clay minerals
LoClay= Low birefringent clay minerals
Chl, Hem, HiClay,. LoClay: only replacement or authigenic minerals

Lithotype (by percent)

Formation	Location strat. and geogr.	coarse ss	fine ss	maf vlc	fel vlc	chert	vein quartz	shale	Fe-stone	scinto br.	gwke	qtze	alt/repl	tuff	largest	max. mean clast size
Cor. ss	section 1, base	5.5	22.8		24.8	11	29.3	5.5			0.9				55/12 *	49/10 **
	section 1, top	1	14		7	6	65	3			2				30	19
	section 3, base	10	41		15	3	4	10	21		2			2	55	38.5
	section 4	10*	16		4	22	10	12	1		1	8	14		38	32
Cor. Unc.	section 1	5.3	7.1	34.5	26.5	20.3	1.8	4.4							66	46
	section 3	8	8	13	29	18	4	5		5					60	49
Kurr.	section 5A	1	4		94***	1									42	35
	section 5B		1		87	1	1			1			8		45	36.3
	section 5C	2	7		27	6	3		2		2		51		67	43.5
Palette	Basal Cong. 1	24	10	3	17	13	3	8		22					50	42
	Basal Cong. 2	10	6		3	15	1	20	14	31					42	31
	d.f. cong., basal	41.3	2.2		4.3	10.8	2.2	19.5	4.3	2.2			14.3		48	43.3
	d.f. cong., middle	23	7	17(?)	2	16	2	7		12			6		<>	<>
	d.f. cong., upper	15	7		7	20	10	4		20			17		29	18.6

* largest and m.m.c. listed as such: indisputable Koolpin Formation/other lithotypes.

** this also includes the only clasts of quartz-pebble conglomerates

*** sections 5A and 5B are almost entirely composed of Pul Pul Rhyolite, mostly the quartz feldspar porphyry member.

TABLE 1

Appendix C

1:10,000 scale geologic map of the South Alligator Valley from El Sherana to Saddle Ridge. Map commentary, stratigraphy and key included.

El Sherana and Edith River Groups

1-10,000 scale

South Alligator Valley, Pine Creek Orogen

Northern Territory, Australia

The South Alligator River carves a valley several 10's of km wide for several hundred kilometers northward to the Van Dieman Gulf. Near its headwaters, the critical relationships between three intervals of sedimentation are moderately well exposed in the steep cliffs cut by the path of the river and its tributaries. This map focuses on these relationships in the area running roughly from the El Sherana mining camp to the northwest and Pul Pul Hill, an aboriginal monument, to the southeast.

The three groups represent at least three distinct tectonic environments. The basal units were deposited during rifting and establishment of an Early Proterozoic margin as well as the subsequent Top End Orogeny (Needham et al, 1988). The Pine Creek Supergroup is a new name to include all of these units, including the Namoona Group, the Mount Partridge Group, the South Alligator Group, and the Finniss River Group (Stuart-Smith et al., 1980, 1988). The stratigraphy and correlative tectonic environments can be determined crudely from gross changes in lithology, textural and compositional. In this way, the Namoona and Mount Partridge Groups can relate to rifting of a continental margin, the South Alligator Group could represent passive margin sedimentation, and the Finniss River Group may correspond to flysch sedimentation in a foreland basin.

The predominant unit of the Pine Creek Supergroup in the map area is the Koolpin Formation. The Koolpin Formation, lower unit of the South Alligator Group, consists of finely interbedded hematitic siltstone and chert or jasper. Its stratigraphy can be sub-divided into several units; a basal sequence chert and iron siltstone, followed by an interval of interbedded fine sandstones and siltstones, capped by a felsic volcanic, then completed with another cherty ironstone. There are additional minor intervals of interbedded cherty ironstone, and it seems likely that future work can further differentiate between all of these chert and hematitic siltstone units based on the small scale bedding habit of the chert (R. Valenta, pers. comm. 1989). It is capped by the Gerowie Tuff, a felsic crystal tuff which is a regional marker horizon. This stratigraphy has made possible the mapping of large scale structural elements in the metasedimentary units.

Metamorphism and deformation of the Early Proterozoic sediments occurred at ~1.870 Ga (Needham et. al., 1988) during the Nimbuwah event. This corresponds to intrusion of syn-orogenic batholiths, the Nimbuwah Complex, approximately 200 km to the North-northeast of the study area, from 1.87 to 1.80 Ga. A series of deformational events affected these sedimentary rocks (Johnston, 1984; Valenta, 1989). In the map area, recumbent, isoclinal, subvertical, northwest-trending folds penetratively deformed the South Alligator and Finniss River Groups reflected here on a kilometer scale by the geometry of the Koolpin Formation volcanics. The Mundogie Sandstone, although also steeply dipping, does not reflect this folding, suggesting that a regional décollement occurs at the base of the Koolpin Formation. A similar conclusion was made by Johnson, 1984. Needham et.al. (1988) disagree and consider the Koolpin/Mundogie contact an angular unconformity. All sediments of the Pine Creek Supergroup underwent lower greenschist grade metamorphism or higher (Stuart-Smith et. al, 1980). Lastly, major thrust faults with significant stratigraphic and lateral displacement are not present on this map, yet their likely presence and importance to future work can not be over emphasized.

The sedimentary package immediately overlying the Pine Creek Supergroup is comprised of the El Sherana and Edith River Groups. They are separated by an unconformable surface known as the Kurrundie Unconformity, and disconformably lap onto the basement along the Coronation Unconformity at the base of the El Sherana Group. Sedimentation and paleoflow along the Coronation Unconformity is governed by the antecedent topography formed by northwest trending folds in the Pine Creek Supergroup. The lower three members of the El Sherana group include the following: braided stream lithic sandstones, conglomerates, and interbedded volcanics of the Coronation Sandstone; conglomerates, ignimbrites, and felsic porphyries of the Pul Pul Rhyolite; and turbiditic tuffs, tuffaceous siltstones, and feldspatholithic greywackes of the Big Sunday Formation. Each unit is bound by an unconformity. The Big Sunday Formation lies to the south of this map, as do mafic volcanics and intrusives associated with the Pul Pul Rhyolite (Jagodzinski, pers. comm.). The next package is the Edith River Group, which consists of conglomerates and course to fine siliciclastics of the Kurrundie Sandstone followed by felsic porphyries of the Plum Tree Volcanics. The Plum Tree Volcanics also do not appear on this map.

The unconformities bounding each of the lithologic packages described above formed in response to base level changes induced by tectonism. This is based on episodes of growth faulting which resulted in local sedimentary stacks directly below the next unit. The first of these packages can be found along the ridge directly above the El Sherana mining camp cut by Stag Creek. Sedimentation is defined by relationships along to the Pul Pul Unconformity and the Big Sunday Unconformity as well given the instantaneous extrusion of the Pul Pul Rhyolite. Development of the Big Sunday unconformity was accompanied by a reversal of paleocurrent directions between the Coronation Sandstone (northwest dominated) and the Big Sunday Formation (southeast dominated). Another syntectonic package is recorded by growth faulting found on the Scinto Plateau near the Palette mine, which resulted in the development of a tectonically distinct sub-basin. Facies of this sub-basin, the Palette Formation, are likely correlatives of the Kurrundie Sandstone, yet may belong to other units instead. This was also accompanied by a reversal of paleocurrents between the Big Sunday Formation (southeast dominated) and the Kurrundie Sandstone (northwest dominated). Despite paleocurrent changes, sedimentation remained strongly governed by northwest trending basement structures.

Deposition of the El Sherana and Edith River Groups follow closely on the heels of orogeny, as determined by U-Pb zircon dates in igneous rocks. The Gerowie Tuff dates at 1.885 Ga ± 2 Ma (Needham et.al., 1988), before onset of flyschoid sedimentation in the Finniss River Group. The El Sherana Group, which disconformably overlies these units, is dated between 1.90 and 1.87 Ga (Page and Williams, 1988) leaving at most 15 Ma for flysch sedimentation in the Finniss River Group, burial, deformation, metamorphism, uplift, erosion, and terrestrial sedimentation of the El Sherana Group. Dates from the Plum Tree Volcanics lie between 1.87 and 1.86 Ga, leaving at most 10 Ma for development of the Kurrundie Unconformity and the deposition of the Edith River Group. Orogenic granitoids of the Nimbuwah complex are dated from 1.87 to 1.80 Ga, from the onset of El Sherana sedimentation through to the end of Edith River sedimentation. A later series of intrusions ranging from 1.848 to 1.80 form the Cullen batholith near Pine Creek, approximately 100 km from the map area.

A deformation event of undetermined age involved the El Sherana/Edith River sequence before the next phase of sedimentation. After a hiatus of approximately 200 Ma, the El Sherana and Edith River Groups are unconformably overlain by the Katherine River Group. The Kombolgie Sandstone, the youngest unit in the study area, dominates the Katherine River Group. It is a thick, siliciclastic, fluvial package, mostly trough-cross bedded, medium- to fine-grained sandstone, with a basal conglomerate which compositionally reflects the immediately underlying facies.

The Scinto Breccia is a highly siliceous, hematitic, often phosphatic breccia in which the host lithology is indeterminable due to the extremity of replacement. Previous examination concluded that this lithology represented a deep weathering horizon which formed above carbonates in the orogenic metasedimentary package Walpole, 1968, Stuart-Smith et al., 1988). There is, however, considerable evidence that there are several lithologies formed from different geologic processes in different environments which fit this description. The previous type section is a sub-vertical ridge at the Cliff Face mine. However, these and other locations, such as near the Palette mine suggest a tectonic/hydrothermal origin. We recommend Cliff Face and the peak of Coronation Hill as type locations of this sort of Scinto Breccia, and a thin pavement below and southeast of the Saddle Ridge mine as the type location for an unconformity breccia above carbonate.

Faults with several recurring geometries cut rocks of the El Sherana and Edith River Groups. East-West trending, moderately-dipping reverse faults, with small (less than 100 m) stratigraphic displacements both to the north and south, have the best constrained geometries. A series of north-northeast trending, up-to-the-south reverse faults cut the El Sherana Group but have not been found to cut the Edith River Group. Moderately-dipping, northeast trending, down-to-the-southeast normal faults are common only along the Scinto Plateau, and are related to opening of the Palette sub-basin. Steeply-dipping, northwest trending faults of variable stratigraphic displacement cut all units in the area. Needham et. al. (1988) calls these transfer faults, and Valenta (1989) finds foliations and fault lineations indicating dextral motion; stratigraphic arguments indicate that they may be strike slip faults, with less than one kilometer lateral displacement and less than 150 meters stratigraphic throw across their length. These faults cut the Edith River Group, and may cut the Kombolgie Formation.

While the other faults in area, particularly the E-W reverse and SW-NE normal faults, may be kinematically linked to these longer faults as antithetic and secondary synthetic shears respectively (Christie-Blick and Biddle, 1985), evidence for major deformation and syntectonic sedimentation typical of transform zones and major strike-slip faults is absent. The only evidence of post-El-Sherana syntectonic sedimentation is preserved in the Palette sub-basin. Consequently, any through-going strike-slp faults in the South Alligator Valley are not likely to be significant in length or displacement, and probably total to less than 5 km total displacement (Valenta, 1989).

Most of the conclusions of this map are documented and discussed in Friedmann and Grotzinger (1990).

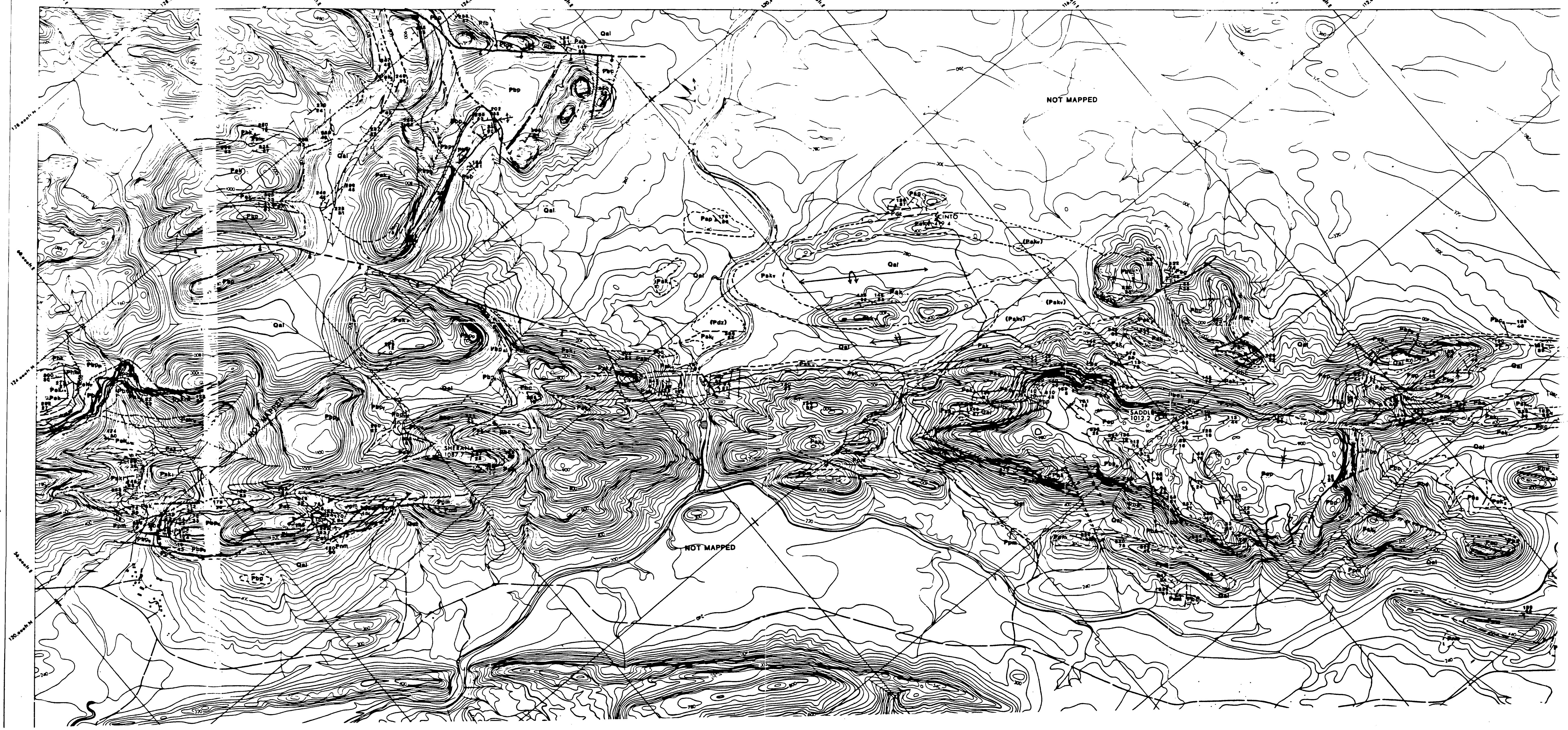
El Sherana Group	Pul Pul Rhyolite	Pbpp	*Quartz-feldspar porhpyr, often containing lithic fragments.*
	Pul Pul Rhyolite	Pbpf	*Fiammi-rich ignimbrite, with abundant quartz phenocrysts and frequent feldspars.*
	Pul Pul Rhyolite	Pbpa	*Autobrecciated, lithic ignimbrite. Lithic fragments are sandstone and greywacke. Abundant unoriented fiammi.*
	Pul Pul Rhyolite	Pbpc	*Cobble conglomerate, bimodal, with abundant mafic volcanic clasts.*
	Coronation Sandstone	Pbcv	*Rhyolite flow, qtz and feldspar phenocrysts.*
	Coronation Sandstone	Pbcb	*Basalt; locally amydaloidal, locally hematitic.*
	Coronation Sandstone	Pbc	*Pebbly, very course to course, planar cross-bedded, trough cross-bedded sandstone.*
	Coronation Sandstone	Pbcc	*Boulder to pebble, imbricated, planar cross-bedded or massive interbedded conglomerates and verycourse to fine sandstone.*
	Coronation Sandstone	Pbs	*Several unrelated units (see explainations), all siliceous and hematitic. Possible unconformity related, phosphatic breccia; tectonic gouge; hydrothermal breccia*
Zamu Dolerite		Pdz	*Course dolerite with plagioclase phenocrysts, typically expressed as surface cobbles.*
Finniss River Group		Pfb	*Greywackes, siltstones, and shales; well develped cleavage, occasional chevron folds.*
		Psh	*Altered mafic volcanic or hypabyssal intrussive*
		Psp	*Medium-very fine sandstones, greywackes, and shales; well developed cleavage.*
		Psg	*Devitrified felsic tuff, occasional quartz phenocrysys*
		Pskv	*Altered felsic volcanic, not a tuff. Possible mafic volcanics as well.*
South Alligator Group	Koolpin Formation	Psk8	*Dololutite and silicified grey to blue dolomite, often with microdigitate stromatolites.*
	Koolpin Formation	Psk=∴	*Interbedded fine-veryfine grained sandstones, siltstones, and shales.*
	Koolpin Formation	Pski	*Laminated hematitic siltstone and chert, occasionally jasper. Chert laminae may be centimeter or millimeter scale as well as nodular.*
	Koolpin Formation	Psk∴	*Medium-very fine sandstone, often penetratively fractured.*
Mount Partridge Group		Ppm	*Course, trough crossbedded sandstone and quartz pebble conglomerate, decimeter scale bedding*

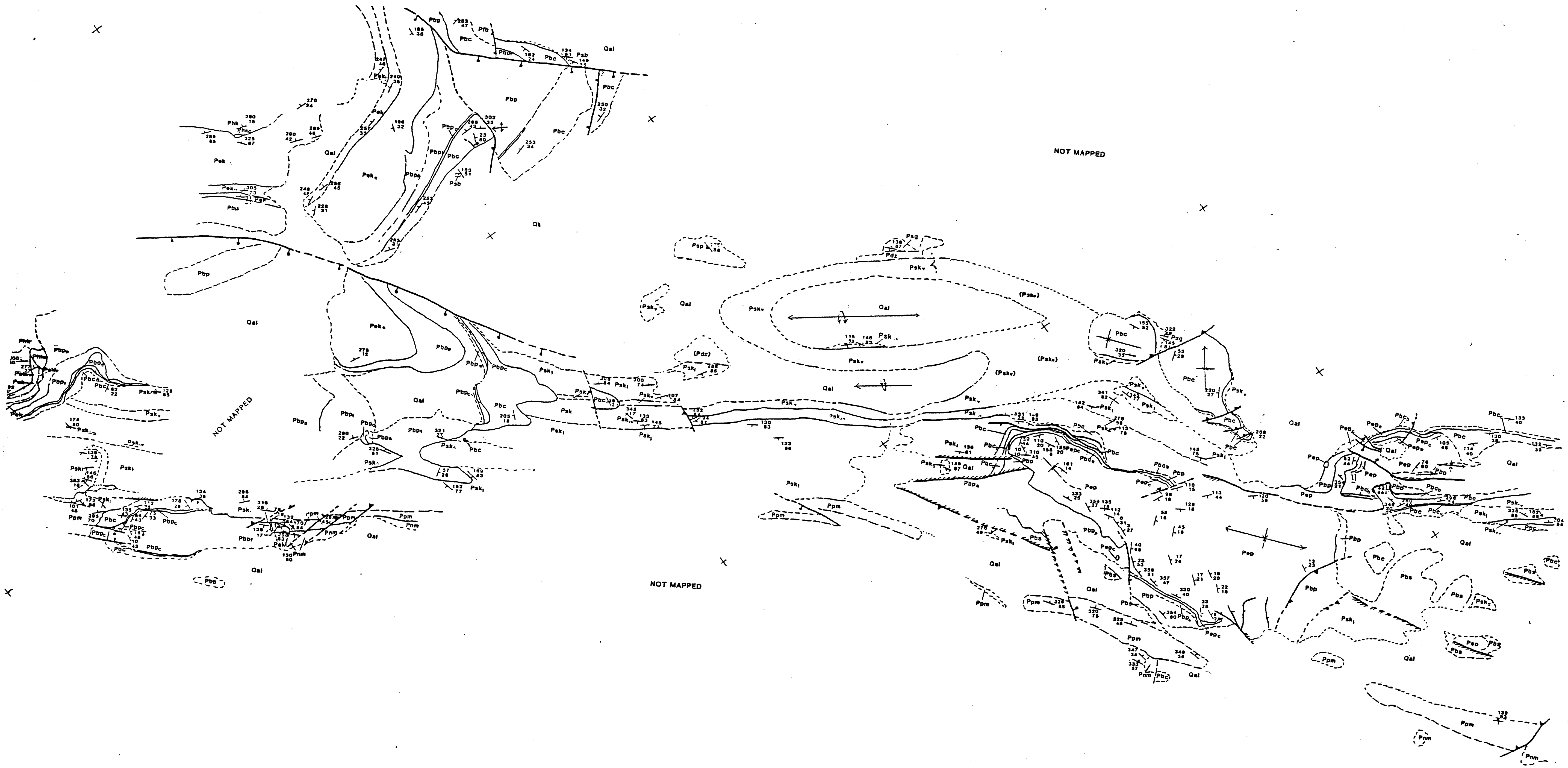
Key

- Stratigraphic contact
- Stratigraphic contact (approximate location)
- Scinto Breccia (tectonic breccia)
- Reverse Fault
- Normal Fault
- Fault, with ball on downside
- Syncline
- Anticline
- Overturned syncline
- Overturned anticline
- Double-plunging syncline

Katherine River Group		Phk	*Trough and planar crossbedded course - fine quatz sandstone.*
		Phkc	*Boulder conglomerate, rounded to angular clasts of nearest underlying lithology*
Edith River Group	Palette Sub-Group	Pepv	*Basalt.*
	Palette Sub-Group	Pep	*Dominantly trough cross-bedded, planar-bedded, current-rippled medium-fine sandstone and interbedded matrix supported angular conglomerate lenses.*
	Palette Sub-Group	Pepc	*Cobble conglomerate, dominantly clast supported. Chief clast composition is Pul Pul Rhyolite.*
	Palette Sub-Group	PepΔ	*Sedimentary breccia of Pul Pul Rhyolite clasts interbedded with medium-fine quartz arenite, often hematite cemented.*
	Kurrundie Sandstone	Pek∴c	*Interbedded course pebbly trough sandstone and quartz pebble conglomerate.*
	Kurrundie Sandstone	Pek=∴	*Interbedded vey fine to medium quartz sandstone and shale.*
	Kurrundie Sandstone	Pek	*Pebble-medium trough cross bedded sandstone. Bedding typically 10-40 cm. thick Pervasive liesegang banding common*
	Kurrundie Sandstone	Pekv	*Felsic and mafic exrtusives, typically altered to silica and hematite.*
	Kurrundie Sandstone	Pekc	*Bimodal, boulder-cobble conglomerate, often imbricate, and interbedded course - fine sandstone. Clasts are chiefly rhyolite. Pervasive liesegang banding common.*

R.F. 1:10,000 | SOUTH ALLIGATOR RIVER | SHEET NO. 2

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