# PROTEROZOIC MASS-TRANSPORTED BRECCIAS NEERENO HILL, WESTERN AUSTRALIA

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ABSTRACT

Coarse mass-transported breccias which locally form part of the middle Proterozoic Neereno Sandstone near Neereno Hill are interpreted as the products of rock avalanches and associated debris flows. These fast-moving rock flows, descended from hearby hilly terrain, spread across an alluviated piedmont zone, and entered a quiet-water basin. Their catastrophic impact on the alluvial and basinal sediments generated conglomeratic mud flows and turbidites.

## INTRODUCTION

This paper describes an occurrence of Proterozoic breccias and associated mudflows and turbidites discovered near Neereno Hill (lat. 29°25′S, long. 115°58′E) during geological mapping of the Perenjori 1:250 000 Sheet (Baxter and Lipple, 1979).

This occurrence appears to be the first of its type to be documented from the Western Australian Precambrian. It has some importance in that it indicates for this region, the eastern limit of Proterozoic sedimentation on the western Yilgarn Block, and that these deposits must have only travelled a short distance from comparatively hilly terrain.

## REGIONAL SETTING

Proterozoic sedimentary rocks occur both in the Irwin Sub-basin of the Perth Basin and eastwards on the adjacent Yilgarn Block (Fig. 1A). A basin sequence, about 2-3 km thick, composed mostly of lithic siltstone and wacke (Yandanooka Group) occupies the Irwin Sub-Basin and overlies the Mullingarra Inlier. Immediately east of the Irwin Sub-basin, a thin platform sequence (Moora Group), divisible into a lower coarse clastic section (Neereno Sandstone of the Billeranga Subgroup) and an upper, clastic-dolomite-chert section (Coomberdale Subgroup), overlies Archaean rocks of the Yilgarn Block with an irregular nonconformity. A stratigraphic scheme, originally proposed by Arriens and Lalor (1959), was published by Low (1975), but following regional mapping and comparison of type sections, a revised stratigraphy was proposed by Baxter and Lipple (1979). The correlation between this and the previous stratigraphic scheme by Low (1975) is summarized in Figures 1A and 2A. The basin sequence is correlated with the lower (Billeranga Subgroup) platform sequence, and the latter is conformably to disconformably overlain by Coomberdale Subgroup, which forms the upper sequence. Although the precise age of these rocks is uncertain, Compston and Arriens (1968) obtained a whole-rock Rb-Sr age of 1400 m.y. from basalt flows (Morawa Lavas) in the lower platform sequence. Several generations of mafic dykes intrude platform sequence rocks.

The basin sequence adjoining the lower platform sequence, consists of laminated, graded lithic siltstone, wackes and minor turbiditic wacke, in which scouring, slump folding and disruption, flame and sedimentary dyke structures are well developed.

The lower platform sequence (Fig. 1A, B) is best exposed at the west of Neereno Hill, where it has been studied in detail. Between the Bateman and Hebiton farms, a section comprising megabreccia, conglomeratic mudstone, shales and wacke attains a thickness of about 200 m (Fig. 2B), but thins rapidly eastwards. Nearby, laterally equivalent fluviatile arkose and breccia (Neereno Sandstone of Low,

Figure 1. Regional setting, rock distribution and location index. ▶

A. Regional setting of the Proterozoic sedimentary rocks in the Northern Perth Basin. Numerals I—III refer to locations of stratigraphic columns in Figure 2A.

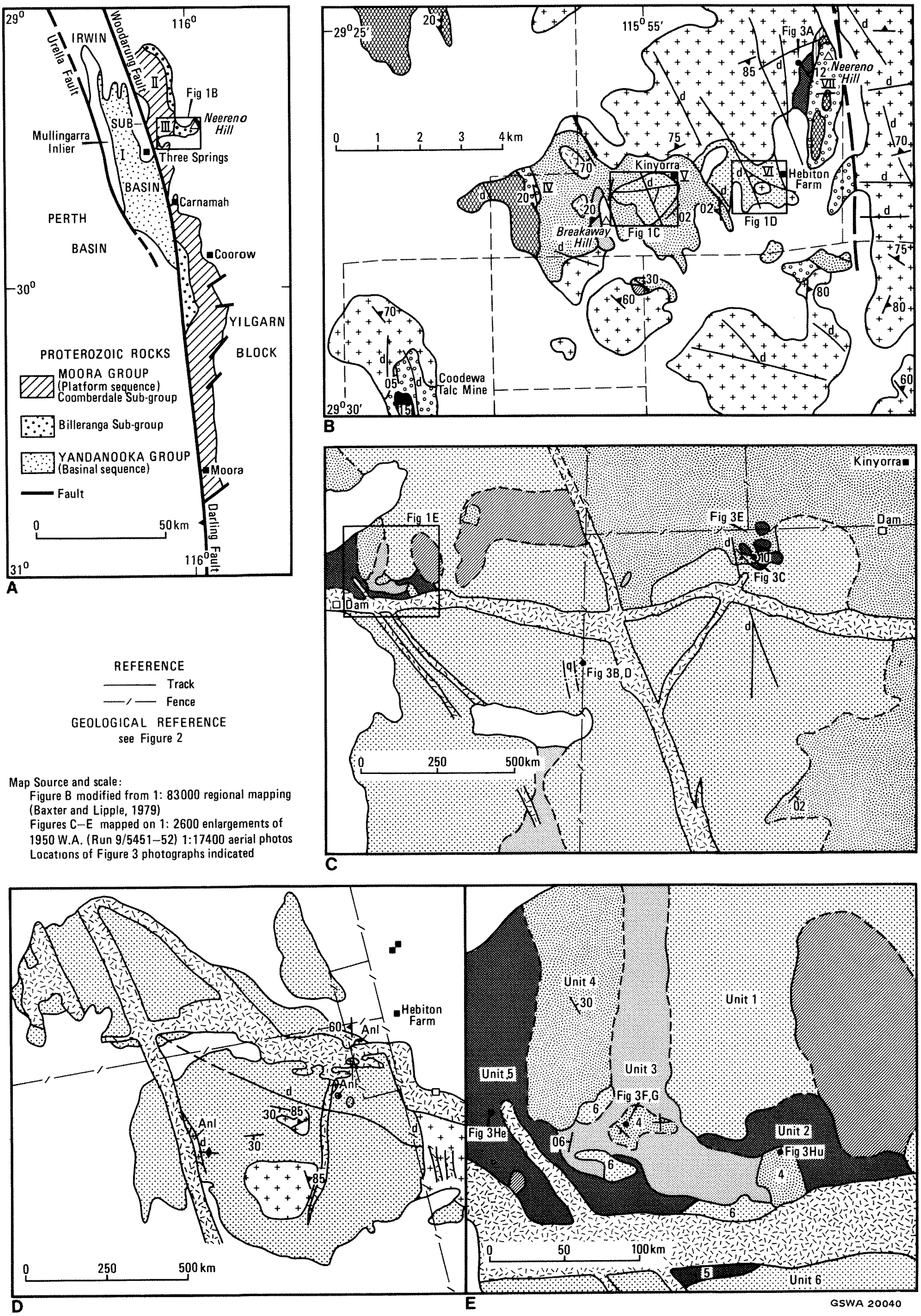
B. Regional geology of the Neereno Hill area. Numerals IV—VII refer to locations in Figure 2b.

C. Rock distribution, Kinyorra; showing locations of Figure 1E and 3B-E.

D. Megabreccia on basement gneiss: Hebiton Farm.

E. Interfingering facies relationships, West of Kinyorra; units are numbered oldest (1) to youngest (6). Locations 3F-H refer to Figure 3.

Lithological reference for Figures 1B-E shown in Figure 2.


A
29°
116°
IRWIN
Urella Fault
Woodarung Fault
SUB
BASIN
Mullingarra Inlier
Fig 1B
Neereno Hill
Three Springs
Carnamah
PERTH
BASIN
Coorow
30°
YILGARN
BLOCK
PROTEROZOIC ROCKS
MOORA GROUP (Platform sequence) Coomberdale Sub-group
Billeranga Sub-group
YANDANOOKA GROUP (Basinal sequence)
Fault
Moora
0 50km
Darling Fault
31°
116°
B
29°25′
115°55′
0 1 2 3 4km
Fig 3A
Neereno Hill
Kinyorra
Hebiton Farm
Fig 1D
Fig 1C
Breakaway Hill
Coodewa Talc Mine
29°30′
C
Kinyorra
Fig 1E
Fig 3E
Dam
Fig 3C
Fig 3B, D
0 250 500km
D
Hebiton Farm
Anl
0 250 500km
E
Unit 4
Unit 1
Unit 3
Unit 5
Fig 3F,G
Fig 3He
Unit 2
Fig 3Hu
0 50 100km
Unit 6
GSWA 20040
REFERENCE
Track
Fence
GEOLOGICAL REFERENCE
see Figure 2
Map Source and scale:
Figure B modified from 1: 83000 regional mapping (Baxter and Lipple, 1979)
Figures C–E mapped on 1: 2600 enlargements of 1950 W.A. (Run 9/5451–52) 1:17400 aerial photos
Locations of Figure 3 photographs indicated

1975) are interlayered with purple amygdaloidal basalt flows (Morawa Lavas) capped by lithic siltstone and red chert (Oxley Chert Member) (Fig. 2B). The whole section has a total thickness of about 50 m but includes units which are partly repeated and offset by minor strike and oblique faults.

Equivalence of the lower platform sequence with the basin sequence is indicated by common rock types and comparable environments. A complex alluvial/talus-fan environment merging laterally westwards into a quiet basin intermittently disturbed by slumping and turbidity currents, is envisaged.

A more widespread, upper platform sequence (Mokadine and Campbell Sandstones, Noondine Chert and Jingemia Dolomite) attains a maximum thickness of 250 to 400 m. It consists of cyclically repeated, upward-fining, sequences of conglomeratic sandstone, sandstone, siltstone, chert and dolomite. Stromatolites are common in cherts and dolomites. The upper sequence is much more siliceous than the lower sequence. Feldspathic sandstones are restricted to near the base in contrast to the consistently feldspathic composition of sandstone and wacke in the lower sequence.

The Proterozoic rocks are little deformed, and regional metamorphism is of very low grade. Very open, concentric folding is present northwest of the study area, and some shales contain a weak to moderately spaced cleavage. Dips are generally low ( < 10°), although some moderate (30°) to high (70°) dips were recorded immediately adjacent to faults. Some dolerite dykes occupy north-northwest or east-trending faults. The distribution of the units across the mildly undulating topography also indicates a gently dipping sequence. Local syn-sedimentary slump folding next to breccia units is open concentric style (20-30° dips) to isoclinal style (70-90°) and is best seen between Kinyorra and Breakaway Hill.

For the purpose of this paper, two areas of good exposure were studied in detail (Figs 1C and 1D), and further observations were made on related rocks at Neereno Hill itself (Fig. 1B).

## GEOLOGY OF BRECCIAS AND ASSOCIATED ROCKS

### *GENERAL*

The spatial distribution of the breccias and associated rocks is shown in Figure 1B. The various rock types exhibit abrupt lateral and vertical facies changes (Figures 1C, D, E, and 2B). It is difficult to unravel the nature of these changes in detail because they represent end members of the range of facies present. There is a change southwestwards from sandy, framework breccia and sandstone (best developed at Neereno Hill), through megabreccia (dominant at Hebiton-Kinyorra farm), and conglomeratic mudstone (Kinyorra), to graded, interbedded breccia, sandstone, wacke and shale (Kinyorra-Breakaway Hill). The variation in rock types and thickening of the sequence southwestwards is schematically illustrated in Figure 2B.

### *HEBITON-KINYORRA FARM ROCKS*

The megabreccias and breccias are unsorted, thick-bedded to massive rocks. Angular clasts of feldspathic gneiss are irregularly distributed and form a very close-packed, anisotropic framework. The sparse matrix consists of lithic sand and/or green to black mudstone. Although individual beds have sharp basal contacts and consist of only one breccia type, a continuous range of breccia types is defined by variation in clast size and matrix-to-clast proportions. For mapping purposes, three types were distinguished: (i) matrix-poor (about 2%) megabreccia with clasts predominantly greater than 5 cm (commonly 50-200 cm) maximum dimension; (ii) matrix-poor (about 2%) breccia; with clasts mostly 2-10 cm maximum dimension and (iii) framework breccia (about 20% sandy matrix) (Figs. 1C-E, 3A, B, D). Megabreccia is the dominant type, and types (ii) and (iii) occur mostly in the area 500-2 000 m west southwest of Kinyorra homestead. Type (iii) breccia is best developed at Neereno Hill.

The three breccia types interfinger with shale, sandstone, and conglomeratic mudstone (Fig. 2B). Northeast of Breakaway Hill (Fig. 1E), megabreccia (here > 1 m thick) is overlain by flat-lying breccia (0.5-1 m); feldspathic pebbly wacke (0.5 m) and lithic siltstone-shale; conglomeratic sandstone and siltstone (0.5-1 m, Fig. 3F, G, H), breccia and megabreccia ( > 2 m). About 500 m further west, megabreccia (0.8 m) is bounded by breccia ( > 0.5 m) with irregular contacts. West-southwest from Kinyorra, small breccia lenses form a channel in (Figure 1C) slump folded and chaotically mixed conglomeratic mudstone (Fig. 3E). A thin, bedded sandstone is draped over the irregular breccia surface (Fig. 3E). An extensive megabreccia sheet about 20 m thick, abuts the more thinly bedded units at these localities. In detail the margin is sharp and irregular, and appears to partly correspond with the original lateral contact with stratigraphically equivalent conglomeratic sandstone.

In instances where breccia overlies mudstone or siltstone, there there are flame structures along the base, and slump folding in bedded siltstone (Fig. 3E) appears to be most intense adjacent to breccia margins. Megabreccia also directly overlies basement rocks (Fig. 1D) with an irregular nonconformity which has a general dip southwards at up to 3 degrees. Neptunian dykes of breccia fill crevices in the basement. A characteristic red or purple

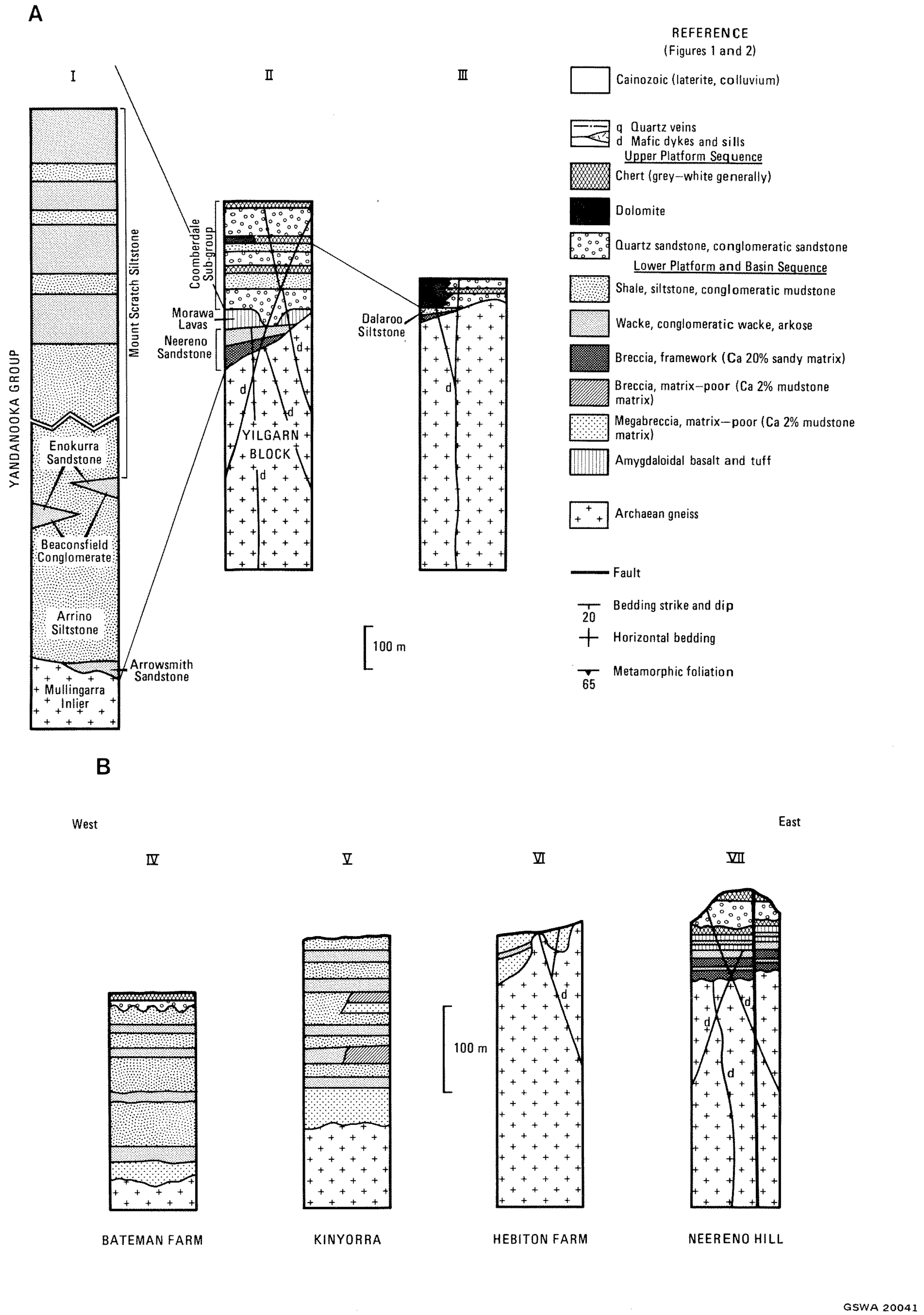



Figure 2. Stratigraphic relationships (Locations of columns shown in Figure 1)
A. Regional stratigraphy.
B. Schematic stratigraphic relationships, Neereno Hill area.

oxidation colour is present in most of the breccia and megabreccia and in basement rock adjacent to joints. Elsewhere, basement rocks are unaffected by this oxidation and thus it can be distinguished from Cainozoic weathering.

Clasts are very angular, with elongate to equant shapes and numerous planar faces derived from joints and foliation in the source rock. Clast types can be directly traced to the adjoining basement. Feldspathic orthogneiss is dominant. A few amphibolite, dolerite, semipelitic paragneiss, ultramafic schist and metaperidotite fragments were noted. Clasts of vein quartz are rare, estimated at one representative locality to be less than 0.01% of the rock volume. Size distribution of clasts appears to be polymodal and skewed towards the coarse end of the range (Fig. 3B). Clasts range from less than 1 mm up to 8 x 3 m and 5 x 7 m dimension in pavement outcrops. In the megabreccia, blocks exceeding 1 x 1 m in size are common. Most clasts have face, rather than point or edge contacts (Figs 3B, D). (Planar to indented contacts (concavo-convex to weakly sutured, Pettijohn, 1975, p. 75) up to 2 m long with little or no intervening groundmass are common).

Some clasts are partially crushed to a mosaic of subgrains in a braided fracture pattern. Mudstone matrix has been introduced along these fractures (Fig. 3D). The very close packing has resulted in a much lower matrix content than is normal for framework deposits (Pettijohn, 1975, p.73). Very rare voids are present, either with quartz rims coarsening inwards to chlorite centres, or with complex quartz-chlorite zoning.

Two types of matrix are recognized. The common matrix in framework breccia is purple, angular, unsorted sand, composed of lithic grains, quartz, feldspar and iron oxides (Fig. 3F). Green to black mudstone including angular mineral and lithic grains forms the second matrix type common in megabreccia and matrix-poor breccia (Figure 3B, D). A squeezed appearance is caused by irregular, sharp, re-entrant contacts between clasts and sandy matrix (Figure 3B, D), and contortion of indistinct bedding. In megabreccia, thin dykes (up to 1 m long and 3 cm wide) of mudstone between clasts, along pre-depositional joints of clasts (Figure 3B, D) also indicate hydroplastic flow. Although the fabric of the megabreccia and breccia is typically massive and disorganized, imbricate fabrics, grading and/or inverse grading are present locally, such as 500 m west-southwest of Kinyorra. These features may be accompanied by an increase in sandstone and/or mudstone matrix. In a few places (e.g. Hebiton Farm, Figure 1D) distinct beds of megabreccia and breccia up to 10 m thick are separated by less than 20 cm of lithic siltstone or immature, weakly bedded, graded sandstone.

*Conglomeratic and laminated mudstone and siltstone*

These rocks are widely distributed (Fig. 1B) and best developed on Kinyorra Farm (Fig. 1C). Typical

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Figure 3. Typical illustrations of facies types. ▶

A. Framework (sandy matrix) breccia containing angular, poorly sorted gneiss clasts (gn) and rare quartz pebbles (q). An imbricate fabric is present. Bedded pebbly sandstone lens (BS) shows indentation of clasts into the top margin. Disoriented, contorted sandstone slab (DS) is included in breccia bed. Hammer head is 18 cm across. Beds dip 12°NE, strike 150°.

B. Coarse blocky breccia with sparse massive pelitic mudstone matrix (S) between angular clasts of gneiss, rare pegmatite (P) and dolerite (V). Clasts have face contacts, are indented (I) and pressure marked (PM). Oxidation has especially affected feldspar (ox fd). Siltstone has been forced along clast joints (SJ).

C. Conglomeratic mudstone has matrix-supported angular gneiss (gn) and minor granitoid (gr) clasts in massive and indistinctly bedded pelitic mudstone.

D. Coarse blocky breccia (polished slabs from 3B), shows indented (I) face contacts. There is selective mosaic (M) crushing (cf. right-hand centre clast). Mudstone matrix has been forced along compaction fractures (SJ). Recent fractures (F) cross rock indiscriminantly.

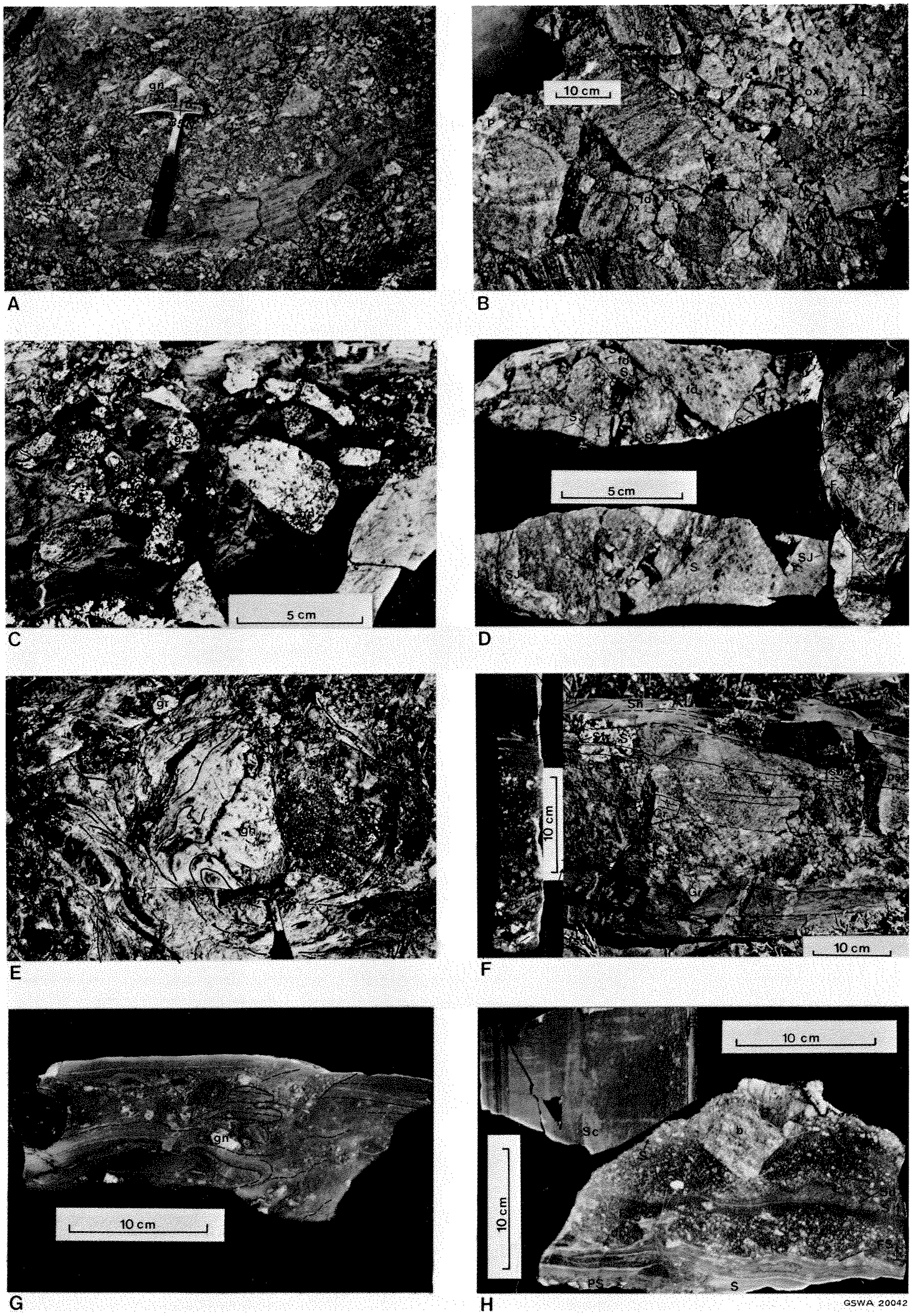
E. Slump-folded, disrupted conglomeratic mudstone contains rafts of conglomeratic mudstone (CM), pebbly sandstone (PS) and gneiss (gn), granitoid (gr) clasts. Hammer head is 18 cm across.

F. Interbedded graded rudites and shales (Left side). Polished slab showing Bouma sequences A-E (Pettijohn, 1975) Graded, imbricate pebbly matrix-rich (sand, mudstone) framework breccia (A) with siltstone clasts (Sc) occurs in 3 cycles. Disrupted laminated siltstone (Ds) is a ?B interval, scoured by overlying (A) interval of pebbly sandstone and showing load features.

Sandstone grades up to laminated, graded siltstone and shale. (Right side) Poorly sorted, laminated siltstone (S), fine sandstone (fsd) exhibit load and flame structures (FS) with matrix-rich framework breccia. Note irregular and tabular, bedded striated (Str) siltstone clasts (Sc). Uppermost shale is cleaved (Cl).

G. Slump-folded chaotic pebbly siltstone, has subrounded red granite (gr), angular gneiss (gn) and disoriented siltstone clasts (sc). Scours and depressed bedding (left side) are featured.

H. (Lower right) Interbedded graded rudites and laminated siltstone. Three cycles of well-laminated, graded, disrupted purple sandstone and grey-green siltstone (S) exhibit flame (FS), attenuation, scour and load structures with overlying graded pebbly sandstone or breccia (b). Density-current-suspended pebbles (dp) were dropped onto siltstone, depressing and truncating laminae, and overlapped by succeeding laminae. (Upper left) Interbedded graded pebbly sandstone, siltstone and shale is interpreted as Bouma sequences A, C-E (Pettijohn, 1975) and features a siltstone clast (SC) and dropped density current-suspended pebble (Dp.)


A
B
10 cm
C
5 cm
D
5 cm
E
F
10 cm
10 cm
G
10 cm
H
10 cm
10 cm
GSWA 20042

rocks are shown in Figures 3C, E. Subordinate laminated siltstones and mudstones are interbedded with conglomeratic varieties (Fig. 3F, H). The conglomeratic deposits are matrix to framework supported, with various types of clast compositions. Internal stratification is apparently absent or indistinct but some thin to medium bedding is present. Disrupted bedding, slump folding and chaotic mixing are common features (Fig. 3E).

Clasts range from sand to boulder size and comprise red to purple gneiss, equigranular and porphyritic pink granitoid, and lesser amounts of vein quartz, amphibolite, biotite-chlorite schist and numerous kinds of sedimentary rocks. Most clasts are angular, but granitoid types are also subrounded. Sedimentary clasts are less clearly differentiated from the matrix but are typically well rounded and irregularly shaped. These sedimentary clasts can be matched with rock types in the surrounding sediments from which they were probably derived.

*Interbedded pebble breccia, sandstone and shale.*

This group of rocks is important in the western part of the sequence (Fig. 1C, E), where it interfingers with all the previously described rocks, and becomes finer grained westwards towards the basin centre. Interbedded, sharp-based breccia, laminated sandstone and shale (Fig. 3F, G, H) show features such as inverse or normal grading, parallel laminations, imbricate fabrics, sole marks, scours, slump folding, disruption and disorientation of bedding which are typical of turbidite deposits. Truncation and disturbance of shale bedding by gneiss or granitoid clasts is a feature of these rocks (Fig. 3F, G, H). Several large elongate pebbles which disrupt siltstone lamination are oriented with their long axis perpendicular to bedding. These occur both as isolated clasts and in thin (1-2 cm) pebbly layers within siltstone, and the long axis of the pebble is up to twice the bed thickness. The sandstone is a poorly sorted, purple or green arkosic wacke, with angular quartz, plagioclase, microcline and iron oxide grains and abundant fine fragments of gneiss and shale. Some units contain patches (1-2 cm diameter) of carbonate, epidote and sericite, possibly of diagenetic origin. Detrital and secondary magnetite are abundant in these rocks, but pyrite occurs only very rarely in lithic siltstone.

NEERENO HILL ROCKS

These rocks consist of interlayered sandy framework breccia, purple feldspathic sandstone, thin amygdaloidal basalt, red chert and lithic siltstone (Fig. 2B). The best exposures are southwest of Neereno Hill and form the type section of the Neereno Sandstone (Low, 1975). Total thickness is about 50 m and the rocks dip at an average of about 10° east.

The feldspathic sandstone forms poorly bedded units about 3 m thick, with low-angle, planar cross-bedding, rare undulating bedding, sole marks and festoons, and minor grading. The sole marks are interpreted (R. Hocking pers. comm.) to represent turbulent-flow ripple marking. Sand grains are moderately to well sorted and moderately rounded; the main components are unstrained quartz, plagioclase, microcline, chert, quartzo-feldspathic (?granitoid) rock and minor altered dolerite or mafic volcanic rock.

Purple breccia crops out as small rock humps, in units about 10 m thick. The breccia (Fig. 3A) is framework supported, and contains angular, pebble- to cobble-sized clasts of gneiss and minor vein quartz which define an imbricate fabric. The sandy matrix (about 20%) is similar to the interbedded sandstone beds. The breccia contains thin (2-20 cm), moderately sorted and bedded sandstone lenses, which separate layers of breccia 0.5-1 m thick. The sandstone lenses exhibit grading, low-angle cross-bedding and scours. Some lenses show disruption features (Fig. 3A), including disorientation and contortion of sandstone masses, because of incorporation into breccia, and compaction of breccia clasts into underlying sandstone layers.

A distinct imbricate fabric is shown by elongate clasts sub-parallel to bedding, but with no single prevailing vector in the bedding plane; although in one exposure, clasts have longest axes prevalently oriented in the downcurrent (eastward) direction, and inverse grading in the bed. Here a large boulder of gneiss in the breccia is disrupted by thin (1-2 cm) dykes of pebbly coarse sandstone continuous with the groundmass. The disaggregated components of the gneiss clast show no rotation of the foliation.

The rocks are preserved in the terminal part of a palaeovalley extending at least 30 km north-northwest from Neereno Hill. The palaeovalley has an average southward gradient of 0.4° and is defined by the contours of the unconformity, the restriction of the sedimentary rocks and basalt to the valley and the progressive onlap of younger units onto the basement forming the valley walls.

## SEDIMENTARY ENVIRONMENT

Interpretation of Proterozoic climatic, weathering and depositional conditions by direct comparison with modern analogues is prone to be speculative, but many of the features described are consistent with a uniformitarian interpretation. Rare dropstones in laminated siltstone in the basin sequence of the adjoining Irwin Sub-basin (Baxter and Lipple, 1979) because of their Middle Proterozoic age are probably ice-rafted debris rather than plant-rafted. This suggests a cool temperature climate with at least some local ice-formation.

*BRECCIAS*

Applying a uniformitarian interpretation advocated by Allen (1965) and Dal Cin (1968) (reporting principally on Quaternary deposits) would suggest that the compositional immaturity of the breccias as shown by predominance of feldspathic and mafic clastic material and virtual lack of vein quartz, implies limited transport, rapid deposition and preservation in a cool or cold, possibly semi-arid climate though with episodes of heavy rain which mobilized the considerable quantities of detritus which accumulated during drier periods. However, the important role in weathering since Silurian times of humic acids derived from land plants probably precludes strict application of Cainozoic paleoclimatic data to climatic interpretation of the Neereno Hill deposits. Using modern analogues (Caine and Jennings, 1968, p.100; Dawson, 1977; Ollier, 1975, p.11, 112-113, 188), the coarser, angular unsorted material with abundant planar faces and little matrix in the breccia is consistent with an origin by frost wedging. This talus was weathered *in situ* because breccia clasts show widespread oxidation in contrast with the dark unoxidized siltstone matrix.

The predominance of locally derived angular clasts, and the fabric of the breccias indicate rapid near-source deposition in a high-relief setting, probably by mass transport of talus-slope material. Although a steep initial gradient for the nearby source area is required to generate the kinetic energy necessary for the lateral transport of the boulders, some with calculated masses up to 300 t only a gentle south-sloping relief is indicated by the nonconformity. Krieger (1977) described megabreccias formed by catastrophic landslides and avalances initiated by rockfalls or slides on elevated steep source areas, which travelled at high speeds (100-350 km/h) across gentle piedmont (1-2°) slopes before coming to an abrupt stop. If the megabreccias near Neereno Hill are correctly interpreted as having a similar origin, and applying Kreiger's (1977, Table 1) average coefficient of friction (total vertical fall to horizontal travel) of 0.2, then because the minimum travel distance of the megabreccias is 2 km, a total vertical fall exceeding 400 m is implied.

The absence of clasts of banded iron-formation, which is in fact exposed in nearby basement to the west, south and southeast (Baxter and Lipple, 1979), indicates a northern source. Distinctive Archaean volcanic rocks and banded iron-formation within a large belt exposed 35 km east are not represented as clasts in the breccia.

Sandstone at Neereno Hill, although feldspathic, is moderately rounded and sorted, and is probably derived from more distant granitoid rocks to the north. Pink granitoid cobbles and pebbles occur in equivalent sandstone about 12 km northwest near Oxley Hill. Porphyritic red granitoid cobbles and boulders in sedimentary rocks west and southwest of Kinyorra are probably derived from the same source.

The breccia at Neereno Hill was probably generated by both fluviatile and debris-flow transport. Sandstones interbedded with the breccia are fluviatile as seen from their shape and internal texture, and the presence of cross-beds and festoons. Breccias disrupt and contort thin sandy lenses, contain pebbly sandstone clasts, and have inverse-graded, imbricate fabric, all of which indicate debris-flow transport (Walker, 1975). The sandy lenses represent minor end-stage fluviatile deposition on top of successive debris flows. Disruption was caused by slight remobilization of the unconsolidated flows either by subsequent debris or lava flows. Direction of flow was off the slopes of the palaeovalley and southward along the valley floor. The more rounded sand grains in the matrix contrast with the angular clasts, and were incorporated by reworking the sandstone. The presence of a disintegrated boulder in one layer is interpreted as disaggregation by matrix injection during mass transport.

The megabreccia and breccia at Hebiton-Kinyorra farm have possible origins by several transport mechanisms, including debris flow (Allen, 1965; Bull, 1972; Stephenson, 1972; and Walker, 1975), landslide (Burchfiel, 1966; Kreiger, 1977) or catastropic avalanche (Crandell and Fahnestock, 1965; Shreve, 1966, 1968a, b; Kent, 1966; Plakfer 1977; and Kreiger, 1977). Transport of the breccias by catastropic avalanching is the mechanism consistent with their very coarse, angular, disorganized fabric and other features.

The breccias, which have a sheet-like shape, are uniformly thin but areally extensive (2.5 $km^2$ on Hebiton farm, and 1.4 $km^2$ at Kinyorra-Breakaway Hill). There is no lateral sorting within the two main sheets and only little vertical sorting. Fragments lack rounding but may be shattered or pressed together with irregular planar contacts. Clast indentation and mosaic-braided fracture patterns in individual clasts (Fig. 3B, D) indicate failure under impact or compaction rather than selective tectonic deformation. These features were probably produced either during initial collapse of the source material in a rockfall, collision during transport or impact upon the abrupt deposition characteristic of avalanches (Kent, 1966; Kreiger, 1977). Entrapped, compressed air was the probable supporting medium during lateral transport (Kreiger, 1977). Planar clast contacts may have resulted from the collapse of the air support when the avalanche came to rest. Lubrication along the base probably took place by means of a thin mudstone layer which was partially incorporated into the breccias. Compaction, dehydration and hydroplastic squeezing of mudstone between clasts and into fractures occurred during post-depositional consolidation. This probably accounts for the low porosity of the breccias, which is otherwise problematic, although Kreiger (1977) cites examples of avalanche breccias with both high and low porosities.

The low proportion of sandy matrix poses problems in understanding the origin of the breccias. Talus-slope material characteristically has a low sand content. Derivation by avalanching from talus-slope material or rockfall material, with creation of mostly coarse fragments appears the best explanation.

An alternative origin by other forms of debris flow of the type common in an alluvial fan environment is consistent with some of the features present. However, the sheet-like shape of the breccias, the low proportion of sand and mud matrix, and the large number of planar clasts, all pose problems in accepting such an origin.

Other possible mechanisms for the origin of the breccias include formation by sheet ice, a rock glacier, landsliding or as *in situ* talus-slope deposits. These mechanisms are rejected as discussed below. Tillite formed by sheet ice would be expected to contain a uniform distribution of particle sizes with much more fine material (Pettijohn, 1975, p.172) than is seen. A rock glacier, as described by Caine and Jennings, (1968) or Dawson, (1977), could account for many of the features present; however, the resulting breccia would typically lack stratification and graded fabrics, have high porosity, and lack the mudstone matrix. Traces of distorted bedding in the mudstone matrix are more consistent with incorporation of underlying material and hydroplastic squeezing under pressure, rather than later introduction of matrix by fine-sediment infiltration.

Landslides (Kreiger, 1977) are characterized by a widespread crackle brecciation (a feature absent from these breccias), thicken downslope, and are generally nonturbulent with relict preservation of lithological variation in source rocks. Although the basement gneisses show some lithological variation, the breccias have a chaotic mixture of rock types. Talus-slope deposits are typically cone-shaped, of limited areal extent with steep initial dip, exhibit gravity sorting with coarsest material at the lower distal end, and show a marked thickening downslope (Kent, 1966).

*CONGLOMERATIC MUDSTONE AND INTERBEDDED RUDITES, SANDSTONE AND SHALE*

The impact of advancing megabreccia and breccia avalanche flows probably caused slump folding and disruption of mudstones (Kreiger, 1977) and triggered mudflows (Crandell and Fahnestock, 1965) and turbidity currents in the Neereno Hill area. Debris (mud)-flow transport (Dott, 1963; Fisher and Mattinson, 1968; Fisher, 1971) is indicated by the disruption, slump folding, and chaotic incorporation of multiple-reworked sedimentary clasts in conglomeratic mudstone. Bedding disruption of well-laminated, graded wacke and shales resulted from dropping of pebbles and cobbles transported in high-density currents. Some of these graded sequences (Fig. 3F) are interpreted in terms of the Bouma sequence in turbidites (Pettijohn, 1975, p.561). Shale clasts in breccia occur near bed tops, above denser basement clasts, and are strongly aligned parallel to bedding (Fig. 3F, G, H). These features, together with scouring, inverse grading, and imbricate fabrics (Fig. 3F, G, H) indicate near-source turbidite deposition (Fisher and Mattinson, 1968; Fisher, 1971; Pettijohn, 1975, p. 561-562; Walker, 1977).

## SUMMARY

The general sedimentary environment of the breccias, as indicated by the debris mudflows and proximal facies turbidites, seems to have been within the westward transition from an alluvial fan to a quiet-water basin. The range of sedimentary facies over a short stratigraphic interval indicates that the surrounding land had a high topographic relief. Rock avalanches, possibly triggered by nearby volcanic activity, or movement on the Darling Fault plunged into this environment depositing coarse debris on the alluviated piedmont slopes. The foot of the debris mass entered the quiet-water basin causing the normal sequence of muddy sediments to be interrupted by debris flows and which induced slumping and turbidity currents.

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