DEPARTMENT OF MINES
SOUTH AUSTRALIA

GEOLOGICAL SURVEY
METALLIC RESOURCES DIVISION

SUBAQUEOUS DELTAIC SEDIMENTATION OF THE KANMANTOO GROUP, KANGAROO ISLAND

by

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CONTENTS

FIGURES

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ABSTRACT

The Kanmantoo Group sediments cropping out between West Bay and Breakneck River, Kangaroo Island, appear to have rapidly accumulated in a tectonically active deltaic complex. Lithologies and structures show ordering in two distinct types of cyclic sedimentation (Sequence 1 and 2). Cyclic sedimentation units (1-2 metres thick) are arranged in sets (0.5 to 3 km thick) of only one cycle type. Sequence 1 units, with limited sedimentary structures and massive bedding, represent deltaic bottomset sedimentation from fluidised mass flows off the delta. Sequence 2 units, containing a wide variety of syndepositional liquefaction and deformation structures, indicate oscillatory turbidity flows within migrating distributary channels on a subaqueous deltaic platform.

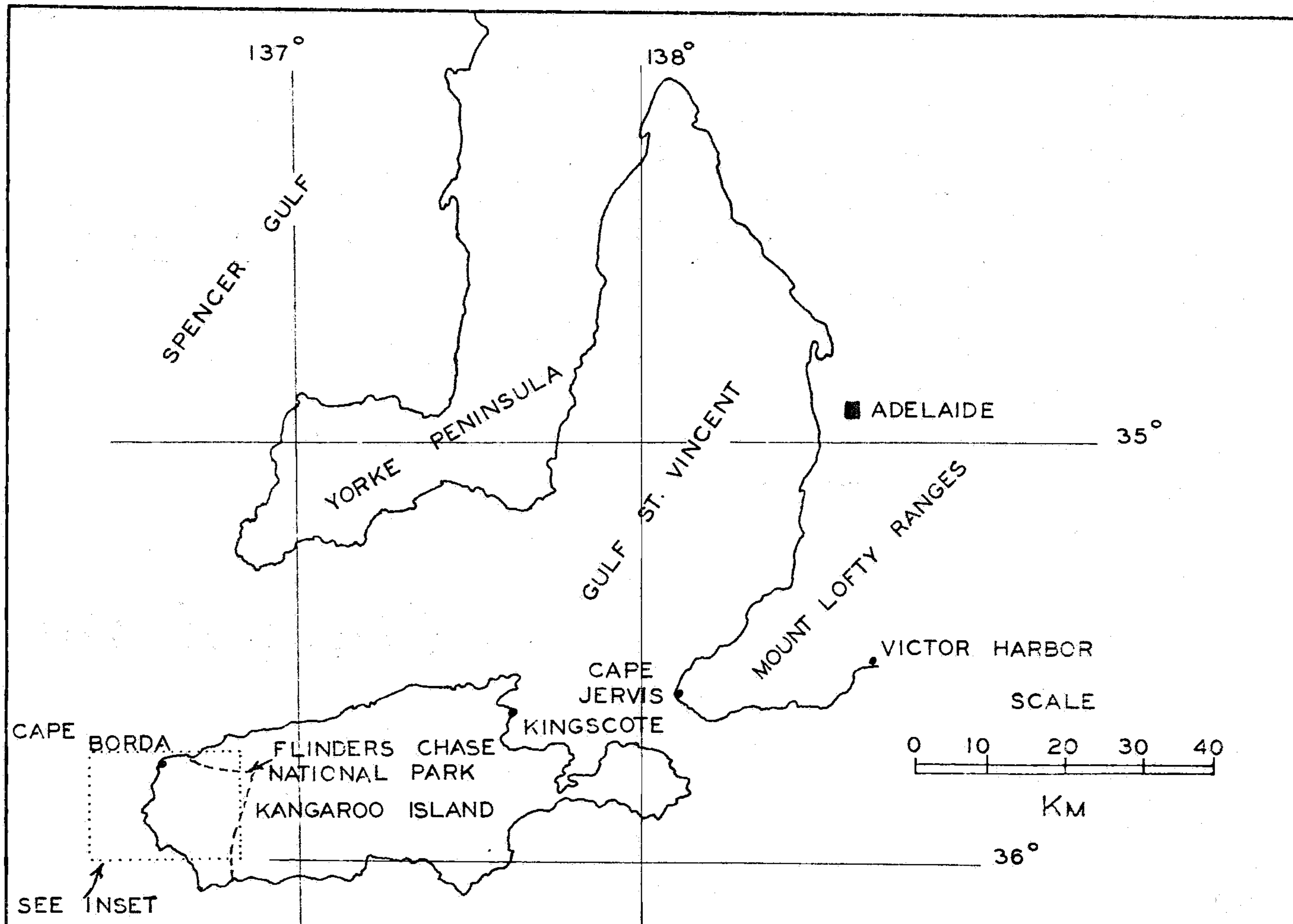
Markov analysis of deltaic units indicates cyclic sedimentation involving poorly bedded and coarse, flat bedded sandstones and laminated lutites. Foresets occur randomly within these units.

Likely source areas are the Gawler Craton extensions or the Antarctic Shield to the northwest-southwest. Palaeocurrent and palaeoslope determinations suggest distributary channel abandonment and migration on an asymmetric deltaic lobe.

INTRODUCTION

Kanmantoo Group metasediments cropping out between West Bay and Breakneck River, Flinders Chase, Kangaroo Island, South Australia (Fig. 1) were examined to determine their depositional, structural and metamorphic history. Structural and petrographic details are discussed in a companion paper (Flint, 1976b). Sedimentological aspects were investigated to determine mode and environment of deposition, transport processes, pretectonic orientation of palaeocurrent directions and palaeoslope and possible provenance.

Previous work in Flinders Chase is limited. The regional geology of Kangaroo Island was established by the Geological Survey of South Australia (Wade, 1915; Sprigg, 1954; Thomson, 1969), and for Flinders Chase by Major & Vitols (1973). It was concluded that in the Cambrian when Kanmantoo Group rocks were being deposited the sea floor in the position of Kangaroo Island area subsided (Waitpingan Subsidence) synchronously with uplift (Cassinian Uplift) of the Gawler Craton to the northwest. Grey, medium to coarse grained greywacke-arkoses with sharply truncated crossbedding to one metre high, scour channels and slump folds typify the Kanmantoo Group rocks cropping out in Flinders Chase (Major & Vitols, 1973). Slumping is towards



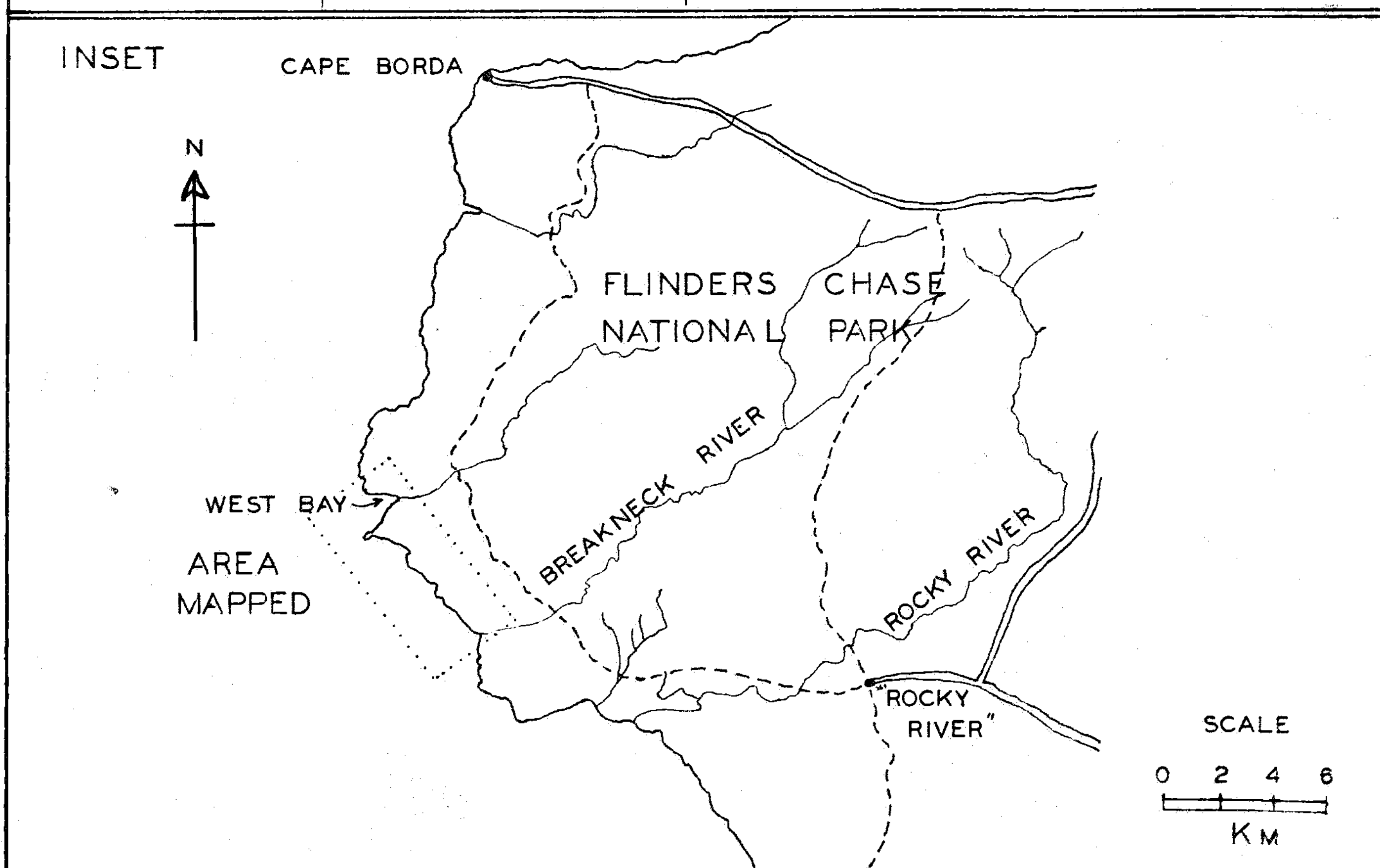


FIG 1	DEPARTMENT OF MINES–SOUTH AUSTRALIA	Scale: AS SHOWN
Compiled: D.J.F	SEDIMENTOLOGY — FLINDERS CHASE	Date: JAN 1977
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the dip direction of foresets, with a westerly source indicated. Lack of sorting, abundant submarine slump structures and sudden thickening across fault hinge zones were interpreted to indicate rapid transport and sedimentation with violent downward movements of the sea floor during sedimentation.

In Flinders Chase, Kanmantoo Group rocks are only exposed along an 8 km stretch of coastline in a strip 20 m wide from sea level to clifftop. Inland, Quaternary consolidated dunal limestone, with minor pisolitic laterite and siliceous sands, blanket the older rocks. The Kanmantoo Group comprises predominantly quartz-rich metasandstones, metalutites and quartz-mica schists, with less abundant types pelitic and biotite-rich lutites, calc-silicate boudins, and actinolitic, biotite-rich and heavy-mineral-rich sandstones. Most rocks are quartz-rich (to 30% by volume) and argillaceous (now recrystallised to biotite and muscovite). A very wide variety of traction, liquefaction, collapse and syndepositional deformation structures are developed. Lithification prior to deformation and low pressure intermediate facies metamorphism during the lower Ordovician (Dasch et al., 1971; Milnes et al., 1977), has preserved many sedimentary structures.

This report describes and interprets the sedimentary characteristics of the Kanmantoo Group, so interpretive rock names such as lutite, siltstone and sandstone are used, even though the rocks have been metamorphosed to the andalusite-staurolite zone of the amphibolite facies (Flint, 1976b).

A Markov analysis technique is used to further illustrate statistically the sedimentary cycles present. Two distinct types of cycles are developed (Sequences 1 & 2) and represent sedimentation by fluidised sediment flows and turbidity currents respectively. In the first part of this paper describing the characteristics of the cycles the non-genetic terminology of Sequence 1 & 2 units is used, but genetic terminology is used once their origin is established. The two deposit types occur in separate intervals of the succession and are not interbedded mesoscopically (Fig. 2). This type of sedimentological analysis involving Markov modelling represents the first of its kind on Kanmantoo Group sediments.

SEQUENCE 1 UNITS

Description

Deposits of sequence 1 units consist of consecutive cycles of upward fining sequences with a massive homogeneous basal sandstone and a lutite upper portion (Fig. 2, traverse A). Variation of grainsize within each unit is gradational and the basal contact with the underlying lutite (now quartz-mica schist) is sharp and planar, (Fig. 8) except where tectonically deformed. Units vary in thickness from 0.10 m to 4 m, with the average approximately 1 m. Sandstone to lutite ratio averages 1:1 and the greatest uninterrupted massive sandstone interval is 80 m. The major sedimentary structures observed within sequence 1 units are ellipsoidal intraclasts, small scale ripple cross-stratification and transposed bedding, with very rare load and flame structures, ripped-up clasts and sandstone dykes and sills. Tectonism and metamorphic differentiation has destroyed all sedimentary structures within the upper (lutite) portions of most units (Fig. 9).

Intraclasts are ellipsoidal quartz-rich sandstone bodies with axial lengths of 0.25 m and 0.15 m and oriented with the long axes parallel to bedding. Clasts occur throughout the lower half of the units. Similar clasts are described by Stauffer (1967), Fisher (1971) and Hampton (1972).

Small ripple cross-stratification and plane-parallel laminae are observed near the centre of many units. Below, sandstones are massive, while above, former lutites are extensively folded, crenulated and differentiated. Transposed bedding occurs at the same level as the ripple cross-stratification and plane parallel laminae. Flint (1976b), concluded from differential states of strain in tectonic structures that transposition of sedimentary layering was penecontemporaneous with sedimentation. Reorientation of the transposed bedding occurred during tectonic deformation.

Rarer structures in sequence 1 units are load casts with flame structures and sandstone dykes and sills. Sandstone lobes (load casts) into underlying lutite are developed where the lutite has been preserved. Load casts are either symmetrical, possibly indicating formation after deposition of the sandstone, or asymmetrical, suggesting syndepositional deformation. Injected laminated lutites between sandstone lobes resemble flame structures. Load cast height is invariably less than 0.07 m. Small sandstone dykes and sills are observed in only one locality and consist of massive coarse sandstones of similar grain size to adjacent massive sandstones. Sills (fed by the dykes) are discontinuous, while the dykes have an orientation similar to slump fold axial planes, suggesting that dyke formation is along a plane of weakness formed by down-slope penecontemporaneous creep.

Thinly laminated to massive sulphidic and actinolitic sandstones occur sporadically between sequence 1 units. They comprise less than 1% of the total thickness of all sequence 1 units.

Developed at or near the top of areas dominated by sequence 1 units are lutite intervals 10 m thick. Metamorphic staurolite is only developed in these lutite intervals, which are also host to an andalusite-bearing pegmatite. In one instance (Fig. 2), the pelitic lutite interval has gradational boundaries with underlying sequence 1 units and overlying sequence 2 units. Parallel lamination is the dominant sedimentary structure (Fig. 10) and rare structures are pseudonodules, sand ripples and thin (less than 1 cm) sand sheets (Fig. 11).

Interpretation

The sediments in sequence 1 units are interpreted to have been deposited from mass flows but not necessarily from fully turbulent flow.

Interpretation of "turbidite" sequences described here and elsewhere (Sanders, 1965; Walton, 1967; Stauffer, 1967; Carter, 1975) is controversial. Variations involve transport mechanism, mode of deposition and role of turbulent versus non-turbulent flow. The last aspect, involving pseudolaminar flow and fluidised sediment movement, has caused re-interpretation of many turbidite sequences. Inertia, debris, or mass flows with pseudolaminar movement have been postulated to explain the following features (Stauffer, 1967; Fisher, 1971; Blatt et al., 1972; Middleton & Hampton, 1973):

1. outsized clasts throughout the sequence;
2. thick, poorly graded beds, often with a massive fabric;
3. dish structures;
4. units overlying easily eroded material with little erosion;
5. lack of typical turbidite and traction structures;
6. lack of flute casts.

These features are typical of sequence 1 units. The only structure not observed is dish-shaped laminae, which is an uncommom feature of mass flows (Stauffer, 1967; Chipping, 1972; Corbett, 1972; Nagahama et al., 1975).

Transposed bedding (as described earlier) is interpreted to have formed by shearing and streaking out of original clasts and interbeds during mass flow.

Lutite sequences which are developed at the top of intervals with mass flow deposits, indicate a period of relative quiescent sedimentation. Sand ripples, thin sheets and predominantly clayey silt sedimentation, suggest deposition and reworking from slow moving, dispersed sediment currents.

SEQUENCE 2 UNITS

Description

A wide variety of sedimentary structures are observed in sequence 2 units in contrast to their absence in sequence 1 units. Structures developed are bedding (massive, plane parallel, slumped and convoluted), cusp structures, oriented clasts, climbing ripple cross-stratification, small diapir-like features and liquefaction structures. The rock types are predominantly medium to coarse grained, immature quartz-rich sandstones with concentrations of zircon (Flint, 1976a).

Observed sequences of lithologies and structures are shown in Figs. 2 and 12 and have been subjected to Markov Analysis.

At or near the base of many sequence 2 units are massive to poorly bedded, poorly sorted sandstones which have an average thickness of 1.3 m and range from 0.11 m to 4.25 m; they represent 35% of the total thickness of sequence 2 units. Clasts are occasionally developed (5 exposures) in this sandstone type and their orientation varies between parallel to eroded base, to imbricated in the direction of flow. Clasts are consistently less than 0.10 m long and predominantly of biotitic lutite. Near the base of many units are coarse, flat-bedded sandstones which form the most common lithology, both in the number of beds present and total thickness (40% of sequence 2 units). Thickness of individual flat-bedded sandstones averages 0.9 m and varies from 0.18 m to 4.60 m.

Foresets (both tabular and trough shaped) and inclined strata represent 12% of the total thickness, have an average thickness of 0.5 metres, but range from 0.03 m to 1.80 m. Many foresets are deposited in asymmetrical scours with steep upcurrent sides while the downcurrent depositional surface is nearly tangential to bedding. Intraformational recumbent folds with axial planes parallel to bedding are developed from slumping of foresets. Identical structures are recorded in Pettijohn & Potter (1964, plate 110) and may be observed elsewhere within Kanmantoo Group sediments in Flinders Chase (Major & Vitols, 1973). Selective slumping is common, with only a few in a succession of foresets being slumped. Partial slumping within individual foresets also occurs, with a marked tendency for homogenisation towards foreset tops.

The upper portion of many intervals is massive or finely laminated lutite, with alternating biotite-rich and quartz-rich layering. Lutites represent 11% of the total thickness, of sequence 2 units, have an average thickness of 0.4 m and range from 0.02 m to 1.64 m. Heavy-mineral-rich sandstones (less than 0.1% total thickness) are nearly always developed above the laminated lutite with very gradational contacts. Laterally, lutites and overlying heavy-mineral-rich lutites are particularly lenticular, and are truncated by the next sequence of structures.

Slumped and convoluted bedding is ubiquitous for all of the areas characterised by sequence 2 units. Slumping of whole sequences of structures is more common than convolution of single beds. Highly chaotic slumping with continuity of layering is typical (Fig. 13) and folds vary in style through planar-cylindrical to cust-shaped. In some instances, contorted bedding suggests collapsed megaripples. Vertical thickness of slump-folded bands ranges from a few centimetres to 6 m.

Rare diapiric structures to 0.15 m high, and liquefaction structures are observed in sandstones containing slumped bedding and cusp structures. Liquefaction features have developed from both upward and downward movement of parallel bedded sandstones. Resultant structures include disrupted domes, and sinking "tear-drop" shaped sandstones in a homogeneous matrix (Figs. 14 & 15).

Lateral variations of lithologies and structures are observed even within the narrow exposure limits. Massive, poorly bedded and flat bedded sandstones are generally laterally continuous, but foresets and laminated lutites often thin and lense out laterally. Down-current fining is noticeable in some exposures with foreset sandstones grading to climbing ripple cross-stratification or inclined laminated lutite. Small channels (less than 1 m wide and .15 m deep) are filled with massive or finely laminated lutite.

Markov Analysis

Observations suggested that sedimentation of sequence 2 units involved cycles of lithologies and structures. To test this hypothesis, statistical testing methods (Markov analysis) were used. The technique of Markov analysis in its application to illustrating sedimentation cycles is outlined in Gingerich (1969), Krumbein (1967 & 1969) and Pettijohn et al. (1972).

Tests are made to prove whether a dependence exists of one lithology or structure on the previously deposited lithology or structure. Two types of observational methods were adopted:

1. Recording lithologies and structures at a fixed interval of one metre.
2. Recording transitions at lithologic contacts and wherever sedimentary structures vary.

The greatest thickness of uninterrupted exposure was chosen and consisted of 179 m of sediment characterised by structures of sequence 2 units. Results of the analysis at a fixed interval of 1 m are tabulated (Figs. 3 & 4). Transitions are tabulated in matrix form and converted to a probability. As an example, bed type B overlies bed type A 22 times (Transition Count Matrix, Fig. 4), and hence with a probability of 0.37 (Transition Probability Matrix, Fig. 4).

SYMBOLS

A. Massive to poorly bedded coarse grained sandstone

B. Coarse flat bedded sandstone

C. Cross-bedded sandstone & inclined strata

D. Convoluted sandstones

E. Laminated, alternating biotite- & quartz-rich layered lutite

F. Heavy-mineral-rich sandstones

G. Rippled lutite

ROCK TYPE	NUMBER OF OCCURRENCES	THICKNESS (METRES)	% TOTAL THICKNESS	AV. BED THICKNESS
A	30	59	33·0	2·0
B	41	78	43·3	1·9
C	14	17	9·6	1·2
D	5	5	2·8	1·0
E	16	16	9·0	1·0
F	—	—	—	—
G	3	4	2·3	1·3
TOTALS	109	179	100 %	

OBSERVATIONS AT ONE METRE INTERVALS

FIG 3	DEPARTMENT OF MINES—SOUTH AUSTRALIA	Scale:
Compiled: D.J.F	SEDIMENTOLOGY— FLINDERS CHASE	Date: JAN 1977
Drn. / Ckd.	MARKOV ANALYSIS	Drg. No. S 12590

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TRANSITION COUNT MATRIX

	A	B	C	D	E	F	G	TOTALS
A	29	22	3	1	3	—	1	59
B	16	36	11	4	10	—	1	78
C	5	6	3	—	2	—	1	17
D	1	3	—	—	1	—	—	5
E	6	9	1	—	—	—	—	16
F	—	—	—	—	—	—	—	0
G	1	2	—	—	—	—	1	4
TOTALS	58	78	18	5	16	0	4	179

TRANSITION PROBABILITY MATRIX

	A	B	C	D	E	F	G
A	·49	·37	·05	·02	·05	—	·02
B	·21	·46	·14	·05	·13	—	·01
C	·29	·35	·18	—	·12	—	·06
D	·20	·60	—	—	·20	—	—
E	·38	·56	·06	—	—	—	—
F	—	—	—	—	—	—	—
G	·25	·50	—	—	—	—	·25

N ln P MATRIX (SEE TEXT FOR EXPLANATION)

	A	B	C	D	E	F	G
A	12·36	-3·81	-2·08	-0·41	-1·76	—	—
B	-6·74	1·60	3·70	2·04	3·68	—	-0·69
C	-0·49	-1·37	1·76	—	0·58	—	1·10
D	-0·47	0·93	—	—	0·80	—	—
E	1·03	2·17	-0·51	—	—	—	—
F	—	—	—	—	—	—	—
G	-0·25	0·26	—	—	—	—	2·53

SYMBOLS DEFINED IN FIGURE 4

OBSERVATIONS AT ONE METRE INTERVALS

FIG. 4	DEPARTMENT OF MINES—SOUTH AUSTRALIA	Scale:
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Although the units have been modelled as for a Markov process, the original sedimentation process may not be Markovian, i.e., may not have a built-in memory. Krumbein (1967) outlines statistical criteria for testing the null hypothesis, i.e., the hypothesis that successive points at regular intervals of space or time are statistically independent. A sample statistic, computed from the data, is used for the hypothesis testing (Krumbein, 1967). Sample statistic $-2 \ln\lambda = 2\sum_{ij}^{m} n_{ij} \ln (p_{ij}/p_j)$

where : $-2 \ln\lambda$ has a Chi-square distribution

m = number of states

$(m-1)^2$ = degrees of feedom

n_{ij} = transitions in i-j th cell

p_{ij} = transition probability for the same cell

p_j = sum of each column of transition counts/ total number of counts.

The portion of the sample statistic $n_{ij} \ln (p_{ij}/p_j)$ for each cell is tabulated in Fig. 4 as the N ln P Matrix. Data on Fig. 4 give $-2 \ln\lambda = 31.9$, which is less than the tabled Chi-square distribution value of 37.65 for 25 degrees of freedom at the 0.05 level of confidence. The null hypothesis of an independent-events process in sedimentation is not rejected. It is apparent that sampling at a fixed interval of 1 m, generates random sequences of lithologies and structures.

To test whether a fixed sampling interval of 1 m affects the result, the same 179 m traverse was subjected to another Markov analysis by noting transitions of lithology and structure. Results of this analysis are tabulated in (Figs. 5 & 6). The sample statistic, calculated from the

	TOTAL THICKNESS (METRES)	% TOTAL THICKNESS	NUMBER OF BEDS	AVERAGE BED THICKNESS (METRES)
A	63·2	35·3	47	1·3
B	70·9	39·6	76	0·9
C	21·1	11·8	39	0·5
D	3·9	2·2	11	0·3
E	16·7	9·3	45	0·4
F	0·1	0·1	1	0·1
G	3·1	1·7	3	1·0
TOTAL	179	100	222	

TRANSITION COUNT MATRIX

	A	B	C	D	E	F	G	TOTAL
A	0	30	7	1	4	0	0	42
B	21	0	14	4	26	0	0	65
C	7	9	0	4	11	0	2	33
D	2	5	1	0	3	0	0	11
E	13	17	9	2	0	1	1	43
F	0	0	1	0	0	0	0	1
G	0	3	0	0	0	0	0	3
TOTALS	43	64	32	11	44	1	3	198

TRANSITION PROBABILITY MATRIX

	A	B	C	D	E	F	G
A	—	0·71	0·17	0·02	0·10	—	—
B	0·32	—	0·22	0·06	0·40	—	—
C	0·21	0·27	—	0·12	0·33	—	0·07
D	0·18	0·46	0·09	—	0·27	—	—
E	0·30	0·40	0·21	0·05	—	0·02	0·02
F	—	—	1·00	—	—	—	—
G	—	1·00	—	—	—	—	—

OBSERVATIONS AT LITHOLOGIC CONTACTS

SYMBOLS DEFINED IN FIGURE 4

FIG. 5	DEPARTMENT OF MINES—SOUTH AUSTRALIA	Scale:
Compiled: D.J.F	SEDIMENTOLOGY — FLINDERS CHASE	Date: JAN 1977
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INDEPENDENT TRIALS MATRIX

	A	B	C	D	E	F	G
A	—	0·42	0·21	0·07	0·27	0·01	0·02
B	0·32	—	0·25	0·08	0·32	0·01	0·02
C	0·25	0·39	—	0·07	0·26	0·01	0·02
D	0·22	0·35	0·17	—	0·23	0·01	0·02
E	0·27	0·42	0·21	0·07	—	0·01	0·02
F	0·21	0·33	0·17	0·06	0·22	—	0·01
G	0·21	0·33	0·17	0·06	0·22	0·01	—

PROBABILITY DIFFERENCE MATRIX

(TRANSITION PROBABILITY — INDEPENDENT TRIALS PROBABILITY)

	A	B	C	D	E	F	G
A	·00	0·29	-0·04	-0·05	-0·17	-0·01	-0·02
B	·00	·00	-0·03	-0·02	0·08	-0·01	-0·02
C	-0·04	-0·12	·00	-0·05	0·07	-0·01	0·05
D	-0·04	0·11	-0·08	·00	0·04	-0·01	-0·02
E	0·03	-0·02	·00	-0·02	·00	0·01	·00
F	-0·21	-0·33	0·83	-0·06	-0·22	·00	-0·01
G	-0·21	-0·33	-0·17	-0·06	-0·22	-0·01	·00

N ln P MATRIX

(SEE TEXT FOR EXPLANATION)

	A	B	C	D	E	F	G
A	—	23·91	0·42	-0·92	-3·15	—	—
B	7·87	—	4·46	0·73	15·54	—	—
C	-0·33	-1·53	—	3·50	4·46	—	2·51
D	-0·40	1·81	-0·58	—	0·61	—	—
E	4·03	3·79	2·45	—	—	0·69	—
F	—	—	1·83	—	—	—	—
G	—	3·42	—	—	—	—	—

SYMBOLS DEFINED IN FIGURE 4

OBSERVATIONS AT ONE METRE INTERVALS

FIG. 6	DEPARTMENT OF MINES—SOUTH AUSTRALIA	Scale:
Compiled: D.J.F	SEDIMENTOLOGY — FLINDERS CHASE	Date: JAN 1977
Drn. Ckd.	MARKOV ANALYSIS	Drg. No. S 12593

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N ln P matrix, is 150.2 which is greater than the tabled value (Chi-square tables) for 36 degrees of freedom at the 0.05 level of confidence. The hypothesis of an independent trials process for sedimentation of sequence 2 units is rejected.

The sequence of structures and lithologies can be extracted from the probability difference matrix (Fig. 6). Those transitions with positive entries have a higher than random probability of occurring. The fully developed cycle is:

A →	B →	E
massive to poorly bedded sandstone	flat bedded sandstone	Laminated lutite

The cycle does not contain the foreset beds (C) as no higher than random probability exists for transition up into foreset phase; however once in the foreset phase, a high probability exists for passing up into laminated lutite (E). For the 179 m traverse, the sequence A B E is observed 11 times and the next most frequent sequence is A B C E three times.

The number of observations in this stratigraphic interval on bed types D, F and G are too restricted to allow meaningful interpretations of their relationships to other lithologies and rock types.

Examination of the observed profiles for sequence 2 units (Fig. 2) indicates that both upward fining and upward coarsening sequences exist. The range of structures is the same for both types of sequences. Observed profiles and the Markov analysis both reflect the dominance of upward fining sequences. A sequence based on average bed thickness would be 2.6 m thick. The fully developed cycle and foreset beds (A, B, C & E) total 96% of the total thickness of sequence 2 units (Fig. 5).

Where sedimentation produced inclined bedding, vertical sequences (A-B-E) are also observed laterally.

Palaeoslope and Palaeocurrents

Foresets and current scour lineations on flat bedded sandstones give a downcurrent direction concentrated in the range 015^o to 135^o (Fig. 7). Fold axes and axial planes of slump folds suggest a pretectonic palaeoslope dipping towards 115^o.

No current directions or slump folds were measured in sequence 1 units or the lutite sequences. Rare ripples and slumps are observed but are strongly tectonically deformed. All palaeocurrent and palaeoslope estimates are from sequence 2 foresets, flat bedded sandstones, laminated lutites and their slumped equivalents. Bedding normals to these lithologies are distributed about a fold axis plunging horizontally towards 079^o true north (Flint, 1976b). Single axis rotation was performed until bedding became horizontal.

Slumping is assumed to be largely down the palaeoslope so that slump folds developed have axial planes striking along the palaeoslope. Slump fold geometry strictly reflects the palaeoenergy slope; here the two slope types are assumed to be equivalent.

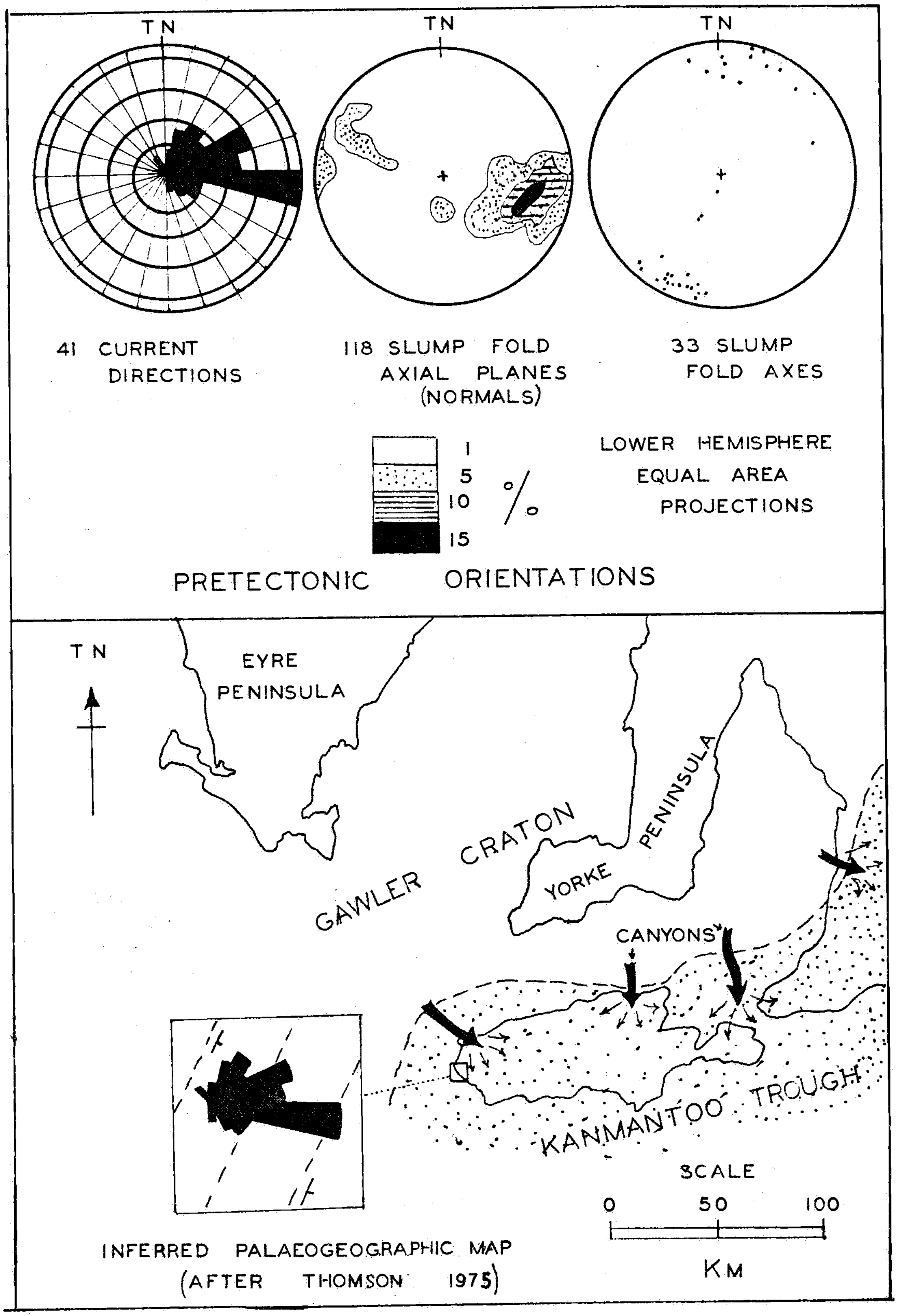

FIG. 7	DEPARTMENT OF MINES–SOUTH AUSTRALIA	Scale: AS SHOWN
Compiled: D. J. F	SEDIMENTOLOGY – FLINDERS CHASE	Date: JAN. 1977
Drn. Ckd.	PALAEOSLOPE AND PALAEOCURRENTS	Drg. No. S 12296

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The spread of current directions may be from single or multiple source flows. If a $\pm$ 15^{o} error is assumed in accuracy of palaeoslope determination, then 90% of palaeocurrents indicate flow in a 90^{o} arc between down and along the palaeoslope towards the northeast. The largest concentration of currents is at a 20^{o} angle to the assumed palaeoslope. Differences in current directions were not observed to be related to variation in lithology, structures, or their spatial relationships.

Interpretation

Sequence 2 units are interpreted to have been deposited by fast flowing, waning turbidity currents. The fully developed cycle in sequence 2 units is compared with the idealised Bouma turbidite sequence (Bouma, 1962). Divisions A, B and D of Bouma (1962) and their ordering are the same as sediments in Flinders Chase. Selley (1970) emphasises that the full idealised sequence is rarely developed and, in Flinders Chase sediments Bouma's C division of ripple coarse-lamination is almost entirely lacking. Markov analysis strongly suggests that foresets do not occupy a fixed position in sequence 2 units, but occur randomly throughout the cycle.

Upward fining and upward coarsening sequences indicate the abundance and oscillatory nature of the turbidity currents. Both Middleton & Hampton (1973) and Walker & Mutti (1973) state that the order of occurrence of Bouma's divisions is very rarely inverted, but Glaister & Hopkins (1974) interpret sequences with gradational upper and lower contacts as representing continuous deposition from pulsating turbidity currents.

Heavy mineral concentrates at the top of some sequences show that currents continued to flow after sand deposition but at a velocity sufficient only to winnow the lutite fines (Fig. 16). A variety of current types are possible for these deposits, including tidal and turbidity flow tail. Middleton & Hampton (1973) postulate a dilute entrained layer which flows after the turbidity current body and reworks upper portions of the turbidite deposit.

A channelled morphology for the depositional surface is suggested by:

1. observing the vertical sequence laterally;
2. evidence of downcurrent fining;
3. abundant foresets and inclined strata (12% of total thickness);
4. small lutite-filled channels developed at the top of some sequence 2 units.

Massive, poorly bedded and coarse, flat bedded sandstones probably represent channellised turbidity currents, with the bed load moving at upper flow regime velocities. Foresets, which are developed randomly throughout the sequences, suggest migrating point or distributary bar type of sedimentation. Layered biotite - and quartz-rich lutites indicate deposition in channels from the final waning stages of the turbidity current and as overbank deposits.

ENVIRONMENT OF DEPOSITION

Water depth during sedimentation is difficult to estimate for a succession dominated by mass flow and turbidity flow deposits. Calc-silicate mineralogy in sediments deposited between mass flow deposits, during periods of relative quiescence, suggests deposition above the calcite compensation depth. No structures are observed to indicate deposition above the storm wave base.

Sequence 2 units with foreset beds are interpreted to have been deposited in a distributary channel environment of a subaqueous deltaic platform. This conclusion is based on the combination of:

1. almost continuous, pulsating currents;
2. predominantly medium to coarse grained sandstone deposition with less than 2% inter-turbidity flow sedimentation;
3. cycles dominated by the bed-load portion of turbidity currents;
4. foreset stratification to 12% of the total thickness in sections with sequence 2 units;
5. observed and interpreted channels;
6. apparent rapid sedimentation with a high water content, as indicated by the abundance and variety of syndepositional deformation and liquefaction structures;
7. thickness of a fully developed cycle (av. 2.6 m) produced by a single waning current;
8. a regional upward thickening and overall coarsening of sequence 2 units (Figure 2).

Variability of current directions may well result from switching of distributary channels in the deltaic complex. Predominantly sand deposition, abundant and oscillatory currents and interpreted environment suggest a close proximity to the source area(s). Ancient landmasses (Gawler Craton extensions, or Antarctic Shield) to the northwest, west and southwest are indicated by the palaeoslope and palaeocurrents.

Mass flow deposits in one instance (Fig. 2), gradationally pass up to the subaqueous deltaic sediments through a pelitic lutite deposit. The interval of pelitic lutite sedimentation is interpreted to represent the down-current equivalent of the distributary channel environment and may be deltaic foresets. Mass flow deposits indicate slumps off the delta as bottomset sedimentation.

Deposition in a tectonically active environment is suggested by:

1. thickness of sequence 1 mass flow deposits, which average 1 m, but the thickest uninterrupted massive sandstone interval is 80 m;
2. thickness of sequence 2 subaqueous deltaic platform sediments, averaging 2.6 m thick for deposition from a single waning current;
3. predominance of sand sedimentation, with the sand/lutite ratio averaging 7:1 for sequence 2 and 1:1 for sequence 1 units;
4. variety and abundance of penecontemporaneous deformation and liquefaction structures;
5. the abundant slumping of individual or several sequences, while convolution of single beds is rare.

Occurrences of modern and ancient deltaic complexes with significant sand deposition and which may have many similarities to Kanmantoo Group sediments are:

1. Eocene Coaledo Formation, Oregon (Dott, 1966);
2. Carboniferous sequence of Mam Tor Series to Kinderscout Grit, Northern England (Selley, 1970);

3. Holocene fluviomarine phases of the Rhône Delta Complex (Oomkens, 1970);
4. Devonian Chemung lithofacies of the Catskill Delta Complex, New York (Friedman & Johnson, 1966);
5. Upper Ordovician Oswego Sandstone and Reedsville Shale, Central Appalachians (Horowitz, 1966);
6. Tertiary debris flow and shallow-water density flow deposits of the Mackenzie Delta, Canada (Glaister & Hopkins, 1973).

The greatest similarity in sedimentary structures and lithologies of the Kanmantoo Group is with the Eocene Coaledo Formation. Sequence 1 and 2 units also have similarities to deep-sea fans and channels (Nelson & Kulm, 1973) except for abundant foresets and well-developed flat bedded sandstones.

It is concluded that the Kanmantoo Group sediments exposed in the West Bay to Breakneck River area, Flinders Chase, represent rapid sedimentation by turbidity flows and fluidised mass flows in a tectonically active subaqueous deltaic complex. Turbidity flows occurred in a channelled deltaic platform environment, with a down-current variation to lutite deposits as deltaic foresets. Mass flows occurred off the delta as bottomset sedimentation. The combination of deltaic environment and predominantly sand deposition strongly suggests shallow-water sedimentation.

STRATIGRAPHIC CORRELATION

Recognition of some Kanmantoo Group sediments in Flinders Chase as likely subaqueous deltaic deposits necessitates reassessment of regional correlations and depositional environments of Kanmantoo Group sediments in other areas. A knowledge of the probable sedimentary environments and possible regional marker horizons are necessary before regional correlations are undertaken. Comparison of formations on particular structures or gross lithologies are not particularly meaningful.

Sedimentary environments represented by Kanmantoo Group sedimentation have not previously been evaluated fully. Sprigg & Campana (1953) compare sedimentation with "the Alpine Flysch", but Daily & Milnes (1973) emphasise the possibility of shallow-water sedimentation. A deep-water origin is presumed by Skinner (1958) for the Nairne Pyrite Formation.

On available information (Daily & Milnes, 1971, 1973) the most likely correlative of West Bay to Breakneck River sediments is the Tapanappa Formation, which is equivalent to the Inman Hill Formation of Thomson (1969). Other possible equivalents are the Backstairs Passage and Balquhidder Formations. However, this involves correlations over 100 km with little intervening control, and with deposition in a tectonically active environment producing numerous local and regional variations. Nevertheless, the similarity of Flinders Chase sediments to these other formations, suggest a wider occurrence of probable shallow-water Kanmantoo Group sediments.

SUMMARY

A very wide variety of syndepositional deformation and liquefaction structures are developed within the observed Kanmantoo Group sediments. Two distinct sequences of structures and lithologies are recognised, which occur in adjacent areas but are not intermixed. Sequence 1 units are always upward fining and have characteristics of fluidised mass flow deposits. Sequence 2 units, with both upward and downward fining, represent oscillatory turbidity flows, and have a superimposed foreset phase. Markov analyses establish the ordering in sequence 2 units and the random occurrence of foresets within the cycle.

It is concluded that the sediments were rapidly deposited, probably in shallow water, within a tectonic subaqueous deltaic complex. Sequence 2 units indicate a distributary channel environment of a subaqueous deltaic platform, while sequence 1 mass flows form from slumping off the delta as bottomset sedimentation. Thin finer-grained pelitic lutite deposits may represent deltaic foreset sedimentation. Many similarities exist between Kanmantoo Group sediment and some modern and ancient tectonic deltaic complexes.

Penecontemporaneous slump folds suggest a pretectonic palaeoslope dipping towards 115^{o}. Palaeocurrents are concentrated in the range 015^{o} to 135^{o} but with the greatest concentration oblique to the palaeoslope. Migrating distributary channels on an asymmetric deltaic lobe is likely. Proximal landmasses are likely to be Gawler Craton extensions or Antarctic Shield.

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FIGURE CAPTIONS

8. Little deformed sequence 1, mass flow units; massive sandstone base and lutite top.

9. Strongly deformed mass flow deposits; most common type of outcrop.

10. Lutite sequence; finely laminated with ripples.

11. Lutite sequence; ripple and laminated with a disrupted thin sand sheet.

12. Sequence 2 deltaic units with abundant foresets, in places extensively slumped.

13. Chaotic, hydroplastic slumping in layered fine grained sandstone, sequence 2 units.

14. Liquefaction structure with minor 'tear-drop' forms, sequence 2 units.

15. Liquefaction structure with domed, disrupted layering, sequence 2 units.

16. Poorly bedded sandstone, overlying heavy-mineral-rich sandstone overlying laminated lutite, overlying convoluted fine grained sandstone; sequence 2 units.

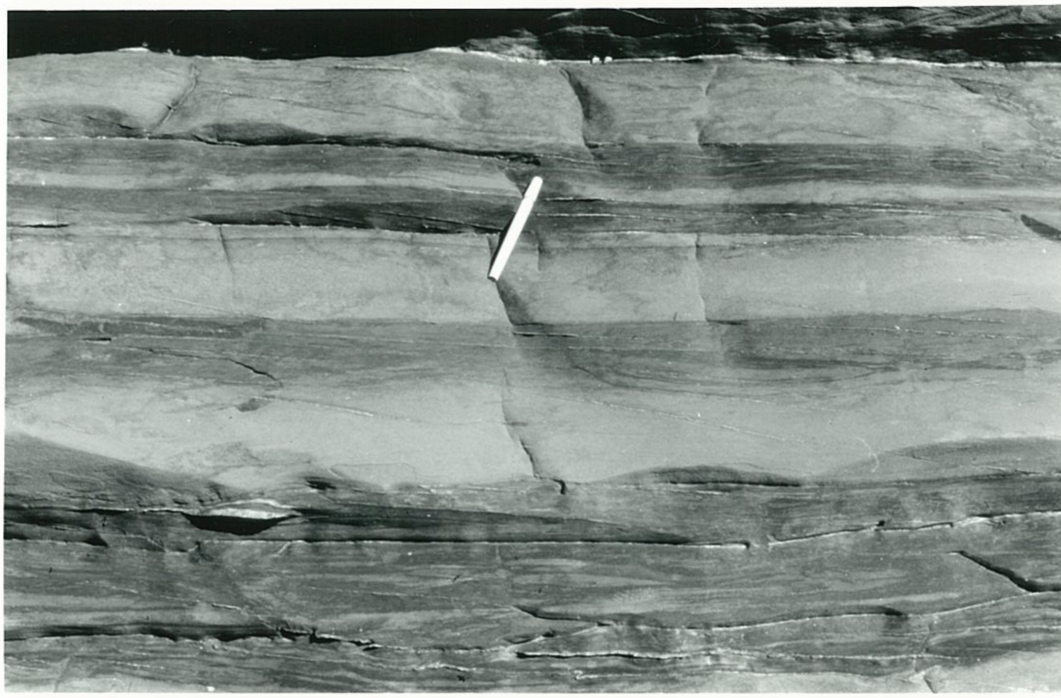

FIG. 8

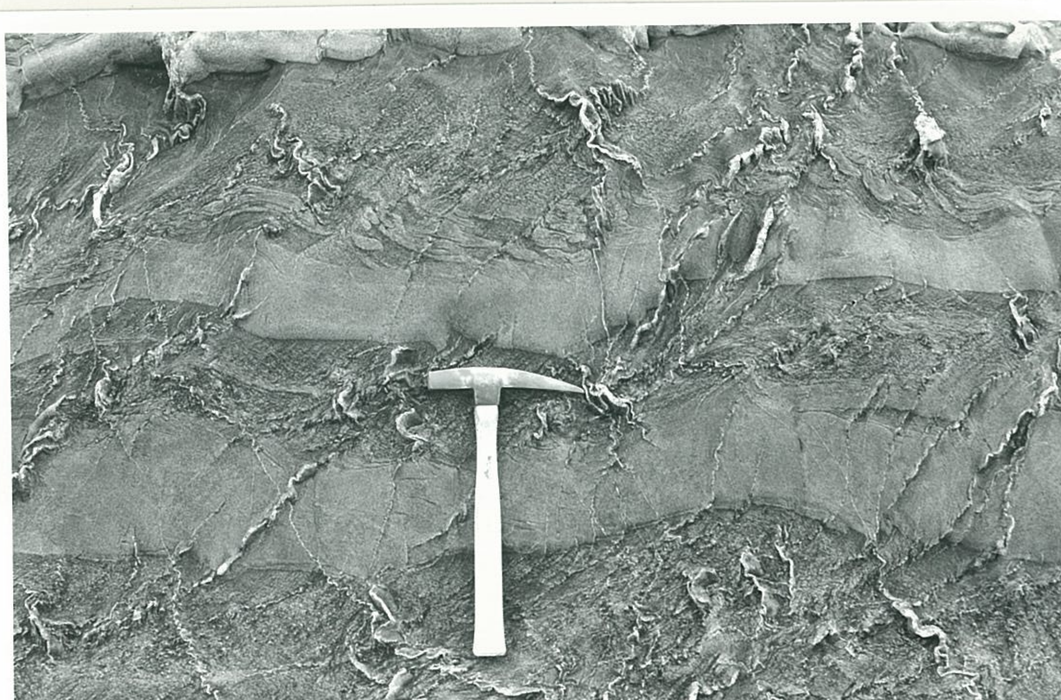

FIG. 9

FIG. 10

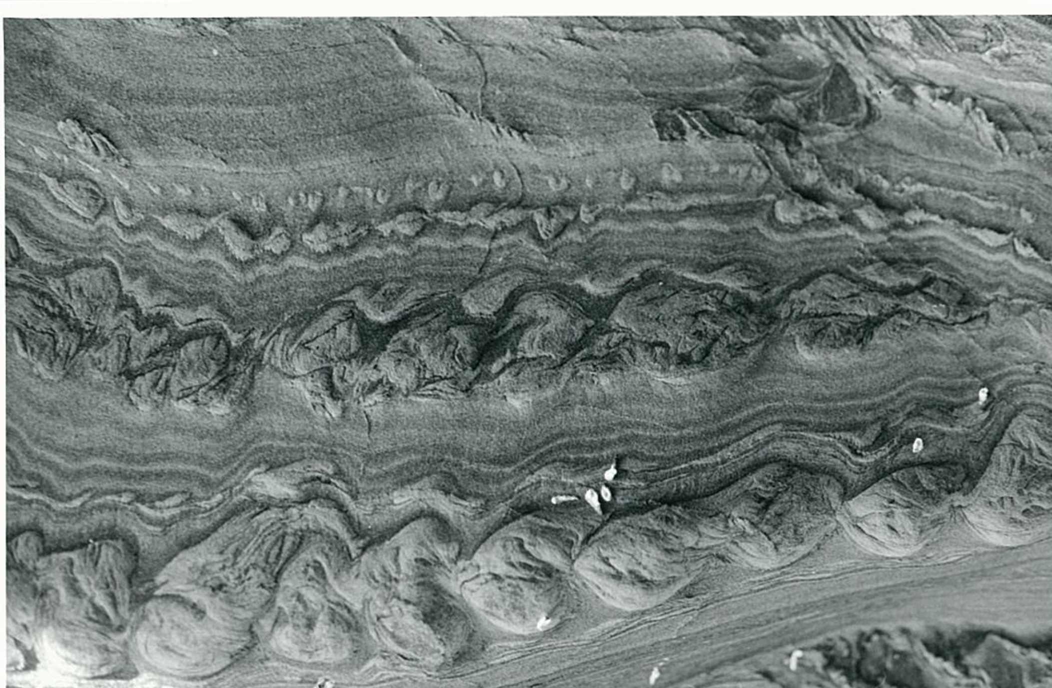

FIG. 11

10 cms.

FIG. 12

FIG. 13

10cms.

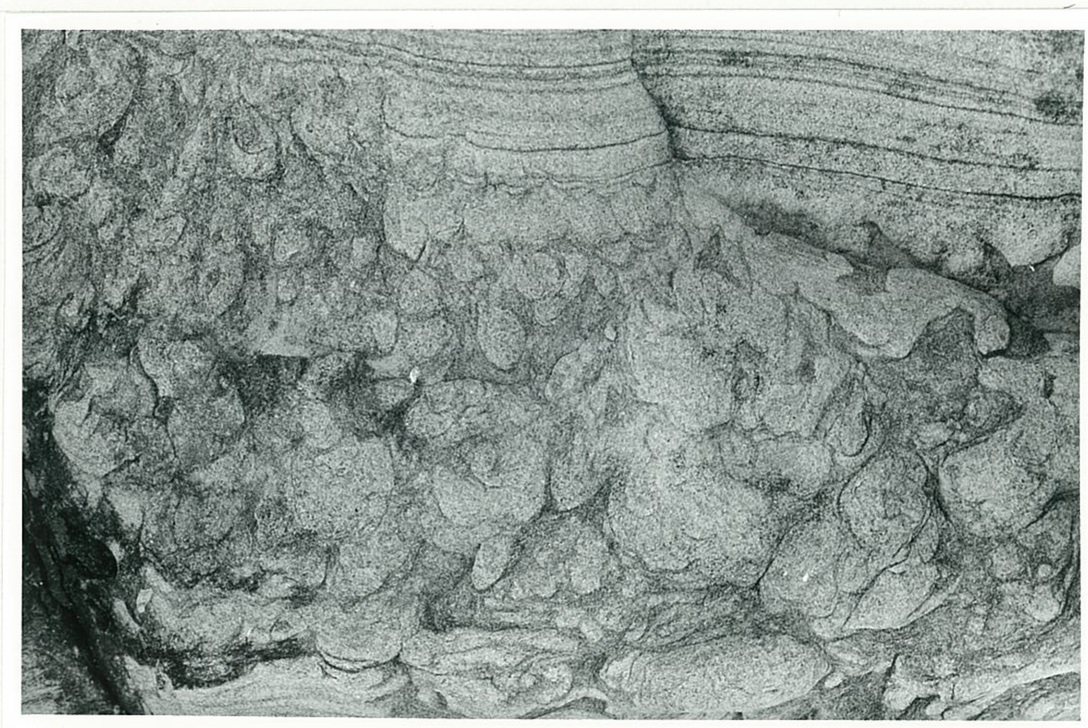

FIG. 14

10cms

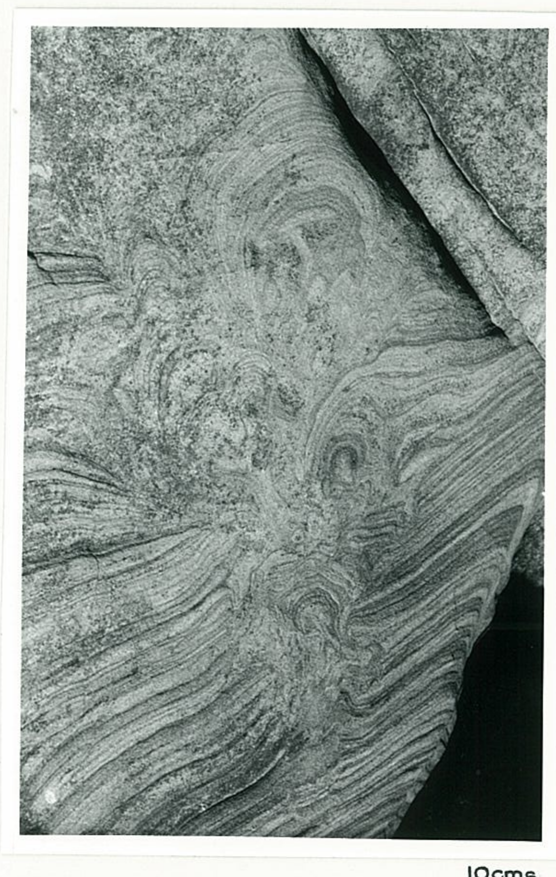

FIG. 15

10cms

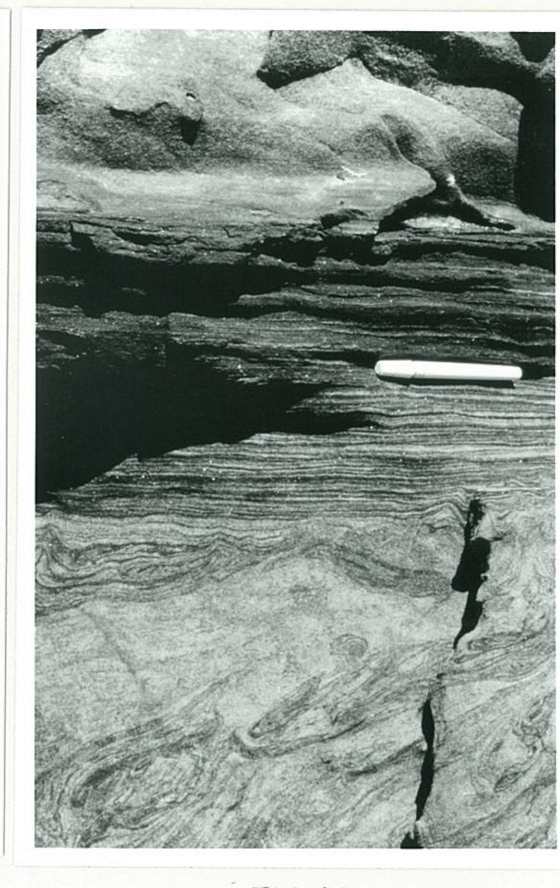

FIG. 16

OBSERVED LITHOLOGICAL LOGS. FIG. 2

77-74