CHAPTER 7

THE PROCESSES AND ENVIRONMENTS OF SEDIMENTATION OF THE KEEPIT CONGLOMERATE

A. INTRODUCTION:

The only previous sedimentological work of any detail upon the Keepit Conglomerate fell within the framework of a regional stratigraphic and sedimentological study by White (1964c,1966). He considered the Keepit Conglomerate to be the product of turbidity currents, subaqueous slides and subaqueous mudflows, with deposition occurring upon relatively steep slopes at bathyal depths (White, 1964c,p.213; 1966, p.246-248).

An understanding of the sedimentological processes and environments of deposition of the Keepit Conglomerate involves an understanding of the processes and environments of sedimentation of conglomerates. Walker (1975b) lists the present day environments in which conglomerate is forming, and has a chance of preservation, as alluvial fans, braided rivers, shorelines, deep sea submarine fans, and marine or nonmarine glacially influenced environments. A glacial origin for the Keepit Conglomerate may be excluded on the basis of the absence of features typical of glacial sedimentation (e.g., Harland *et al.*, 1966). An absence of characteristically disc shaped beach gravel clasts (Dobkins and Folk, 1970; Chapter 5, this thesis) and typical beach gravel textures (Bluck, 1967) in association with the thickness of the Keepit Conglomerate, shoreline conglomerates typically being relatively thin (e.g., Turner and Walker, 1973, p.838), and the turbidite characteristics of the associated sandstones would argue against a shoreline origin for the Keepit Conglomerate.

Within the Keepit Conglomerate, both a terrestial and a marine domain of sedimentation have been recognised. Walker discusses the differentiation of thick sequences of clast supported conglomerates, on the basis of fabric, stratification and grading, from deep water and fluvial environments. He concludes "The distinction of the two environments on these physical criteria may in places be subtle and can only be based upon association and relative abundance of features. The stratigraphic setting of the conglomerate can be more informative"

(Walker, 1975b,p.157). The presence of marine fossil fragments, the association with marine mudstones and turbidite sandstones, and the occurrence of large intrabasinal mudstone blocks is considered significant in the identification and interpretation of the conglomerates of the marine domain, while the association of all features exhibited by the facies A conglomerates, the facies B sandstones and the facies C mudstones, together with the lack of marine fossils, turbidite sandstones and large intrabasinal mudstone blocks, is considered significant in the identification and interpretation of the conglomerates of the terrestial domain.

In the absence of features typical of shoreline or glacial marine sedimentation, the conglomerates of the marine domain are interpreted in the light of present knowledge of submarine fan environments. The conglomerates of the terrestial domain may have been deposited within either an alluvial fan or braided stream environment. These two environments often occur in close association, alluvial fans passing downslope to braided stream environments, and the depositional processes operative in the two accordingly overlap to some degree. Alluvial fans are characterised by the deposits of debris flows, sheetwash and braided streams (Blatt *et al.*, 1972, p.197), while braided streams are characterised by bed load sediment transport through a system of braiding channels and bars. The conglomerates of the terrestial domain are interpreted with respect to these processes.

B. THE INTERPRETATION OF THE FACIES OF THE TERRESTIAL DOMAIN

1. Introduction

The facies A conglomerates closely resemble the coarse gravel facies deposited by recent braiding streams. Such include facies G and F of Williams and Rust (1969), facies B of McDonald and Banerjee (1971), upper fan and upper midfan facies of Boothroyd (1972) and Boothroyd and Ashley (1975), facies 6 of Rust (1972a), facies I of Gustavson (1974), facies D of Smith (1974), and coarse fluvial gravels described by Fahnestock (1963,p.A22), van de Kamp (1973) and Gupta

(1975). The presence of imbricate clasts, interbedded, often parallel laminated, sandstone horizons and the absence of cross stratification within the facies A conglomerates is also characteristic of these recent deposits. The rapid and pronounced lateral and vertical textural and lithological changes exhibited by the terrestial facies of the Keepit Conglomerate is in character with the common and abrupt lateral and vertical grain size variation (Williams and Rust, 1969), and the rapidity of change of braid bars and channels (Ore, 1964; Smith, 1974) of braiding stream.

The facies A conglomerates and facies B sandstones are also closely comparable to many ancient deposits variously interpreted as the products of fluvial processes or debris floods in both alluvial fan and braiding stream environments (e.g., Nilsen, 1969; Miall, 1970a,b; Wilson, 1970; McGowen and Groat, 1971; Ryder and Scholten, 1973; Turner and Walker, 1973).

Deposits resembling mudflows (Bull, 1964,1972; Hooke, 1967; Ryder, 1971) are absent. Sieve deposits (Hooke, 1967), characteristic of some recent alluvial fans, are also absent. The terrestial facies are thus considered to be the products of fluvial sedimentation processes. They are interpreted as having been deposited within braiding stream environments, and are discussed with respect to features of such environments.

2. The Interpretation of the Facies A Conglomerates and Facies B Sandstones

a. *Introduction:*

The various recent fluvial gravel facies recognised in numerous studies have been attributed to formation as sheet (Boothroyd, 1972) or longitudinal bars (McDonald and Banerjee, 1971; Rust, 1972a; Gustavson, 1974), or to bar (longitudinal and diagonal) and channel deposits (Williams and Rust, 1969; Smith, 1974). Bars and channels are morphological features of braiding streams and rarely observed as such in ancient sediments. Their recognition in ancient conglomerates depends upon internal features. In general, distinction between the deposits of bars and adjacent channels is not easily made (Smith, 1974, p.216; Gupta, 1975, p.836), especially when the sediments are of similar grade and contacts are gradational (Rust, 1972a,p.234). Occasionally, morphological features of bars may be preserved and exposed within ancient braided stream deposits (e.g., Banks, 1973; Asquith and Cramer, 1974).

b. *Bar and Channel Deposits within the Conglomerate and Sandstone Facies:*

Bar and channel deposits within the facies A conglomerates and facies B sandstones are not readily discernible. A number of features, however, do exist which enables recognition of the presence of bar and channel environments and deposits.

Rapid alternation of facies A conglomerates and facies B sandstones frequently occurs. In such instances the conglomerates range from medium beds to layers only one clast thick. Laterally they may become thicker and coarser. The conglomerates are interpreted in part as the thinning margins of bar deposits, perhaps analagous to the downstream fining noted in such deposits. The sandstones would thus represent channel fill deposits. Rapid alternation of the two would suggest aggradation by migrating thin gravel sheets or bars and adjacent shallow channels. More isolated one clast thick layers could represent lag gravels in sandy channels, mobile at higher flow velocities and stationary at lower velocities. Such layers are often discontinuous. Fahnestock and Haushild (1962) showed consistent downstream movement of pebbles and small cobbles on a sandy bed during upper flow regime. It is interesting to speculate as to whether these layers are comparable to the transverse ribs (McDonald and Banerjee, 1971; Boothroyd, 1972; Gustavson, 1974; Boothroyd and Ashley, 1975), interpreted as upper flow regime features of riffle zones within channels. Such have been observed as bedforms by the above authors but not recorded in vertical sections of recent deposits.

Bar deposits: Within the Keepit Conglomerate steep erosional contacts (Fig. 6.1) resemble the low erosional banks cut into braid bars by the adjacent channels (Rust, 1972a). Fig. 6.1a illustrates a cross stratified coarse sandstone adjacent to a pebble conglomerate body. Such probably represents a lateral sand wedge developed adjacent to a longitudinal bar (cf, Rust, 1972a; Smith, 1974; Boothroyd and Ashley,

1975) or a sandy slipface developed in finer sediment at the downstream extremity of a gravelly longitudinal bar (cf, Ore, 1964; Smith, 1970; Boothroyd, 1972; Gustavson, 1974).

Channel deposits: Several features may be used to identify channel deposits. Erosional surfaces, often gently curved, are present, though more obvious in the finer conglomerate and sandstones. Such include scour and fill structures and steep erosional contacts shown in Fig. 6.1 and 6.2. Erosional contacts are also seen between the coarser conglomerates (Plate 6.3). Larger clasts, concentrated within or lining the bottom of scours cannot always be attributed to a lag resulting from reworking of the underlying deposit, especially where sandstone or a finer grade conglomerate channel substrate lacks clasts of the appropriate size. They more likely represent coarse detritus transported within the channel and deposited as a lag during waning or lower flow conditions.

Lensoidal sandstones are interpreted as the fill of shallow channels. Shallow wide channels are common associated with sheet, longitudinal and diagonal bars(Ore, 1964; Williams and Rust, 1969; Boothroyd, 1972) often dissecting the tops of such bars. These channels frequently lack flow during low water stages. Similar channel deposits have been described by Eynon and Walker (1974). Cross stratification is uncommon, when present often occurring as a low angle cross lamination. Such resembles the oblique lamination in channel fill sands described by Doeglas (1962) and resulting from lateral filling of the channel.

Fining up Sequences: Fining up sequences occur associated with the massive and stratified facies A conglomerates. They are interpreted as channel fill deposits, similar to those described by Williams and Rust (1969) and Eynon and Walker (1974). Such sequences represent a reduction in the competence of the flow through a channel, as a result of sedimentation or aggradation within that channel. Those fining up sequences composed entirely of conglomerate may represent the deposits of unit bars (Smith, 1974) which exhibit vertical and downstream fining (Smith, 1974; Hein, 1974)*, or channel fill deposits in which the

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* Hein (1974), cited within this thesis, is an unpublished M.Sc. thesis from McMaster University, Canada. I have not seen this thesis, all points referred to Hein deriving from Walker (1975b).

sandstone has been subsequently eroded or was never deposited. This serves to illustrate the difficulty of identifying the deposits of the morphologically different but frequently lithologically similar bars and channels (cf. Smith, 1974, p.216).

Coarsening Up Sequences: One explanation for the coarsening up, or inverse graded sequences in the Keepit Conglomerate relates to bar deposits instead of channel fill deposits, in contrast to Costello and Walker (1972)*. With bar deposits known to often fine downstream, (Doeglas, 1962; Ore, 1964; Williams and Rust, 1969; Smith, 1970, 1974; Boothroyd, 1972; Gustavson, 1974; Hein, 1974; Boothroyd and Ashley, 1975), progradation or downstream migration of a bar coupled with vertical accretion would result in a finer grade basal interval coarsening up, instead of fining up as in a unit bar (Hein, 1974; Smith, 1974).

Alternatively, the coarsening up intervals may represent deposition under flood conditions. Smaller grade detritus, e.g., pebbles, would be deposited under rising flood conditions and the overlying coarser conglomerate deposited during peak flood conditions (McGowan and Groat, 1971).

Many thick conglomerate beds lack, within the confines of the outcrop, features which would unequivocally indicate their being either bar or channel deposits. The massive, often polymodal nature of many of these beds, the inverse grading in some, and the occasional steeply oriented large clasts suggest a possible origin as flood deposits. Such were probably deposited within channels, but may have also resulted from the movement of sheet or longitudinal bars during flood stages.

c. *The Boulder Bearing Conglomerates:*

Rounded medium to large boulders are common within the conglomerates (Plate 6.1), in most instances representing the coarsest of a range in clast size. In some instances, however, the large boulders are out of character in that they occur within much finer grade conglomerate.

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* The coarsening up sequences within the terrestial facies of the Keepit Conglomerate differ to those described by Costello and Walker (1972), in which a basal interval of clay coarsening up to silt is considered an integral part, and interpreted as the infilling of deserted channels by deposition from current flow of increasing velocity. Rust (1975) offered as an alternative explanation for the coarsening up sequences of Costello and Walker the deltaic style infilling of depressions formed as a result of melting iceblocks.

Boulder transport is readily achieved during high velocity flow conditions (floods) (Scott and Gravlee, 1963; Bull, 1964; Malde, 1968), especially if slopes are steep. Boulders may also move downstream in an erratic manner, by scour of lee side support resulting in usually short distance forward motion (e.g., Gupta, 1975, p.842). Where boulders occur in banks, undermining of the bank might result in their being released into the current flow (Gage, 1953; Fahnestock, 1963). Once moving the boulder might travel some distance before coming to a halt, especially if the current flow is strong and/or slopes steep. By these methods of lee side scour or bank undermining, boulder movement is initiated at velocities lower than those required to initiate conventional rolling, and motion may be maintained by these velocities combined with the forward momentum of the boulder to enable short distance transportation by rolling. Such boulders may thus end up enclosed by finer grade conglomerate as an "erratic", i.e., not deposited by the same mechanism as the enclosing sediment.

Boulders may occasionally occur as one clast thick layers of often short lateral extent. They are considered to be lag deposits, possibly resulting from the reworking of poorly sorted flood deposits. The large boulders would be easily transported during flood conditions (Krumbein, 1940,1942; Scott and Gravlee, 1963; Malde, 1968).

d. *The Pebbly Sandstones:*

The isolated clasts within sandstone beds possess features which suggest sedimentation about them in some instances has been episodic, i.e., the clasts were buried by the accumulation of several distinct layers of sand and/or mud. Laminae and thin beds of mudstone and sandstone may be seen to abut against the clasts, and in one case an isolated boulder is covered by the cross stratification of an advancing bedform, probably a dune. Such isolated clasts may well originate from the collapse of a steep erosional gravel bank, the fall providing them with enough momentum to roll into the central portions of a sandy floored channel. They would presumably undergo movement during upper flow regime conditions, or may become buried as a result of upstream scour during lower flow regime conditions (Fahnestock and Haushild, 1962). Scattered clasts within massive sandstones possibly result from transportation of both clasts and sand during high flow conditions and rapid deposition with waning flow. Similar isolated clasts within sandstone beds have been interpreted as the deposits of sheetflood by Turner and Walker (1973). Sheetflood deposits have been likened to the deposits of braided streams by Bull (1972, p.66).

3. The Interpretation of the Facies C Mudstones

The infrequency and manner of occurrence of facies C mudstones is typical of braiding stream conditions. Solitary mudstone laminae occur draping surface features, e.g., a gravel bed (cf. Doeglas, 1962, p.178) and asymmetrical ripples (cf. Doeglas, 1962; Williams and Rust, 1969; McDonald and Banerjee, 1971; Boothroyd, 1972; Rust, 1972a; Gustavson, 1974; Boothroyd and Ashley, 1975), or as irregular laminae within sandstone beds and apparently deposited upon irregular sandy surfaces. Thin sequences of laminated medium sandstone and mustone also occur within the facies B sandstones. These mudstones within the sandstone beds indicate the latter to be the product of more than one depositional episode.

The occurrence of fine sediment within braiding streams, discussed in some detail by Doeglas (1962), requires sedimentation from suspension in quiet portions of the river tract, usually cut off channels. Mud settling out from suspension in ponded waters would tend to drape surface features, such as a gravel bed, ripples or an irregular sand bed. Alternation of thin sand and mud beds or laminae would reflect periodic small scale introduction of sand by slight overflow into the disused channel, or possibly even blown into the dry channel. This interpretation for the mudstone facies is consistent with the above interpretation of the facies B sandstones as representing channel deposits, many probably occurring in bar top situations which with falling water level would become cut off and the site of mud sedimentation from ponded waters (cf. Williams and Rust, 1969, p.650).

Intraformational mudstone fragments may occur within the sandstones, and, less commonly, within the conglomerates. This indicates an environment in which current conditions fluctuate from those under which mud can be deposited to those under which such will be eroded. Mud clasts may be derived by erosion of a pre-existing mud layer or by reworking of fragments from dessication cracked layers. Smith (1972), considers on the basis of flume studies, dessication cracking unlikely to provide a source of durable mud fragments, and the presence of mud fragments to indicate minimal transport. In some instances, mudstone clasts occur in well defined one clast thick layers within sandstone beds; considering the probable deposition site of the original mudstone layers, such may represent in-place burial of a dessication cracked bed (cf. Williams, 1966).

4. The Interpretation of the Facies D Interbedded Mudstone-Sandstone

The interbedded mudstone-sandstone facies D represents sedimentation in an environment which was sheltered from the major part of the braided stream region. Such could be an abandoned channel. However, the persistence of such a channel in order to accumulate the numerous beds of mudstone and sandstone present in this facies is unlikely in an environment characterised by high velocity flow conditions and frequent scour and fill.

An alternative considered more reasonable is that these sediments are quiet water shallow marine deposits interfingering with the coarse fluvial conglomerates. Sedimentation occurred in a low energy nearshore marine environment characterised by mud accumulation and intermittent traction current activity. The abundant *Leptophloem australe*, "which appears to have inhabited the strandline area" (Gould, 1975, p.455) is in character with nearshore sedimentation of this facies. The low energy nature of the environment is supported by the apparent absence of beach and/or bar sandstones, and the conclusions drawn from the shape study, namely rapid progradation of fluvial deposits into a low energy coastal environment. The interfingering of fluvial and marine deposits is discussed in more detail for MS25 (p.193).

5. Some Consideration on the Conditions of Sedimentation of the Facies A Conglomerates

a. *Introduction:*

The conglomerate facies are characterised by their coarse nature and the high degree of clast roundness. Such implies transportation under vigorous flow conditions. The high degree of competence these flows were capable of attaining is indicated by the frequent occurrence of rounded large boulders up to 198 cm maximum diameter. Certain conclusions may be made upon the nature of the flow conditions from various features of these conglomerates.

b. *The Implications of the Stratification:*

The stratification within thick facies A conglomerate sequences was initially either horizontal or of low angle inclination. Horizontal stratification within conglomerates has been interpreted by Gwinn (1964) as indicating upper flow regime conditions. Walker (1975b, p.137), however, makes the cautionary comment "No comparable experimental work has been attempted for conglomerates, and the stratification types recognised in conglomerate (horizontal and oblique) cannot now be related to flow conditions or a sequence of flow strength."

Within the deposits of present day braiding streams, however, coarse gravels are observed to be massive or horizontally bedded. Gravel movement is uncommon under low flow conditions, occurring predominantly during high flow conditions or under high velocities with associated upper flow regime surface waveforms (Fahnestock, 1963; Boothroyd, 1972; Rust, 1972a; Gustavson, 1974). In the steeper regions of many braiding streams upper flow regime conditions are common even under lower discharge conditions (e.g., Boothroyd, 1972). Rust (1975) considers that under high flow conditions (floods) with all bed material in motion, gravel bars will be stable bedforms which will migrate and/or accrete.

Gravel is considered whilst in transport to move as sheets, thus producing a horizontal stratification (Rust, 1972a,1975; Eynon and Walker, 1974; Hein, 1974). We may conclude that the massive and horizontal stratified gravel deposits of braid bars are the product of sediment transported during upper flow regime conditions; the bedforms and their internal structures are unlikely to be modified by lower flow regime conditions with waning flow due to the coarseness of the sediment. Fahnestock and Haushild (1962) showed that no downstream movement of pebbles and cobbles on a sandy bed occurred during lower flow regime conditions. This is in contrast to sand which may be moved under both upper and lower flow regime conditions. With waning flow bedforms change from those typical of upper to those typical of lower flow regime (Harms and Fahnestock, 1965).

The terrestial conglomerate facies of the Keepit Conglomerate are thus considered to have undergone transportation under upper flow regime conditions. Gravel probably moved as sheets and with fluctuating flow conditions and vertical accretion, horizontal stratification would result. Alternating layers of conglomerate and sandstone need only reflect slight fluctuation in current velocity; bedload rolling of pebbles and cobbles would cease and with a further slight velocity drop sand would be deposited, such no longer capable of being carried in suspension (Walker, 1975b).

c. *The Absence of Cross Stratification in the Coarse Conglomerates:*

The absence of cross stratification within the facies A coarse conglomerates is significant with respect to flow conditions. Cross stratification in coarse conglomeratic braid bar deposits is considered to reflect flows of high velocity and discharge in channels of reasonable depth (Rust, 1975; Appendix 3), with greater discharge and depth associated with larger scale cross sets. Hein (1974) considers the rates of water and sediment discharge to control the type of stratification developed within bars. If both are high downstream migration exceeds vertical accretion, but if both are low vertical accretion is greater and cross stratification related to the development of a downstream slip face results.

The absence of cross stratification within the facies A conglomerates can thus be taken to imply high fluid and sediment discharge but under shallow flow conditions. This is consistent with the movement of gravel as sheets under upper flow regime conditions.

d. *The Implications of the Conglomerate Textures:*

Eynon and Walker (1974) and Walker (1975b) considered that the flow conditions necessary to move gravel as bedload would result in sand being transported in suspension. Bimodal size distributions resulted from infiltration of the sand into the interstices once the gravel had ceased movement and sand deposition was occurring. Similar conditions probably operated for those facies A conglomerates of the Keepit Conglomerate which possess a relatively well sorted sandy matrix and a continuous framework.

Polymodal facies A conglomerates are considered to result from deposition of a concentrated poorly sorted bed load being transported under high velocity flow conditions, i.e., under flood conditions. Failure of the current to carry all sand in suspension, despite its predicted ability to do so, would result from the high sediment concentration and high velocity flow conditions. Under these conditions the graph of Walker relating the size of clasts transported by rolling to the size of sand suspended by the same flow may not be valid (Walker, 1975b, p.139). Such conditions inferred for these polymodal clast supported facies A conglomerates resemble those for texturally similar flood deposits described by Krumbein (1942).

e. *The Implications of the Conglomerate Fabrics:*

A axes oriented transverse to flow direction reflect rolling of the clasts, about the A axis, along the bed surface (Johansson, 1963). A axes oriented parallel to flow direction may be a result of any of the following:

1. *Slope:* Steeper slopes produce $A//a$ orientations (Ruchin, 1958, in Reineck and Singh, 1973, p.126; Sengupta, 1966, p.364). Sengupta considered this to be a result of the higher velocity of flows on steeper slopes. The slope effect was also noted by Johansson (1963) in laboratory studies of clasts deposited in deltaic situations. In this instance the gravitational effect upon clasts moving down the foreset beds result in an $A//a$ orientation.

2. *Velocity:* Under higher velocity conditions the A axis lies parallel to the flow direction. This has been observed, e.g., from flood deposits by Krumbein (1940,1942). Gwinn (1964) notes clast A axes to be oriented parallel to channel directions in conglomerates inferred to have been deposited under upper flow regime conditions. Richter (1936) and Johansson (1965) note that under higher velocity conditions smaller clasts tend to move in a skipping like fashion, falling to the bed with an $A//a$ orientation. Unrug (1957) reports large cobbles in fluvial deposits to have their A axes oriented parallel to flow direction. He considers this to reflect the position of minimum resistence under high velocity flow conditions. Rusnak (1957), studying sand grain orientation, also considers $A//a$ the most stable orientation, but only when the roughness elements of the bed are of the same order of magnitude of size as the depositing particles. If the

former is finer, an A orientation transverse to flow direction will result. In contrast, Kelling and Williams (1967) report on the basis of flume studies A becoming oriented transverse to flow with increasing velocity. However, the clasts lay upon a sand bed (note comment of Rusnak above) and reorientation was an in-place effect with no significant downstream transportation involved.

3. Concentration of Clasts and Frequency of Collision

When the grain concentration on the bed is higher, smaller clasts are reoriented to an A//*a* position by collision with immobile larger clasts (Johansson, 1963,1965). A//*a* orientations attributed to grain collisions have also been described from clast supported resedimented conglomerates by Davies and Walker (1974). The mechanism by which this occurs is discussed by Rees (1968).

In summary, A axes oriented parallel to flow direction can reflect either, or any combination of, steep slopes, high flow velocities and high clast concentrations with frequent grain collisions. Various other factors, such as grain size, shape and density, will undoubtedly be of influence. A certain degree of interdependence, e.g., steep slopes and high velocity flow, is to be expected. Walker (1975b, p.137) states, regarding A//*a* orientations, "it may prove to be a fairly reliable indicator of transport processes that maintain cobbles and boulders in suspension above the bed", i.e., as a concentrated dispersion (Middleton and Hampton, 1973).

Fabric study localities F10-28, F11-29 and F13-31 possess A axes oriented essentially parallel to flow direction, while that for F12-29 is nearer a transverse orientation. All are clast supported conglomerates, thus a high clast concentration and frequent collisions could be expected during sedimentation. The occurrence of both parallel and transverse A axis orientations would thus suggest steep slopes and/or high velocities to have been significant conditions under which sediment transport occurred.