Sediment Transport and the Genesis Flood — Case Studies including the Hawkesbury Sandstone, Sydney

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ABSTRACT

The rates at which parts of the geological record have formed can be roughly determined using physical sedimentology independently from other dating methods if current understanding of the processes involved in sedimentology are accurate. Bedform and particle size observations are used here, along with sediment transport equations, to determine rates of transport and deposition in various geological sections. Calculations based on properties of some very extensive rock units suggest that those units have been deposited at rates faster than any observed today and orders of magnitude faster than suggested by radioisotopic dating. Settling velocity equations wrongly suggest that rapid fine particle deposition is impossible, since many experiments and observations (for example, Mt St Helens, mud-flows) demonstrate that the conditions which cause faster rates of deposition than those calculated here are not fully understood. For coarser particles the only parameters that, when varied through reasonable ranges, very significantly affect transport rates are flow velocity and grain diameter.

Popular geological models that attempt to harmonize the Genesis Flood with stratigraphy require that, during the Flood, most deposition believed to have occurred during the Palaeozoic and Mesozoic eras would have actually been the result of about one year of geological activity. Flow regimes required for the Flood to have deposited various geological cross-sections have been proposed, but the most reliable estimate of water velocity required by the Flood was attained for a section through the Tasman Fold Belt of Eastern Australia and equalled very approximately 30 ms^{-1} (100 km h^{-1}).

Case studies were made of the Hawkesbury Sandstone in the Sydney Basin (Australia) and the Coconino Sandstone which is exposed in the Grand Canyon (USA). Both of these sandstones cover thousands of square kilometres. About half of the 250 m thick Hawkesbury Sandstone could have been deposited in about two days according to calculations based on bed forms, with the water flowing over the whole Hawkesbury Sandstone continuously at the calculated velocity of 15 ms^{-1}. The calculated duration of deposition for the remainder of the sandstone, which includes a minor mudstone lithosome, greatly exceeds the duration of the Genesis Flood, and therefore in context must be grossly in error. Thus known sediment transport equations do not seem to be fully applicable to deposition of all of the Hawkesbury Sandstone if it was deposited during the Genesis Flood. The deposition of the sandstone was, however, much more catastrophic

than any deposition observed in the world today if these calculations are accurate. The same conclusion can be reached for other basins, as the bed forms and grain sizes of many of their sandstones are similar to those found in the Hawkesbury Sandstone.

INTRODUCTION

Over the years, the geological time-scale has been presented as being longer and longer, and evidence suggesting that it should be shorter has often lacked publicity. One such body of evidence is encompassed in physical sedimentology.

Humphreys[1] calculated, using a global collection of present day sediment transport rate measurements, that if sediment transport were to continue at the current global rate, then in 15 million years all land would have been eroded to sea level. Most of this land is supposed to have been periodically above sea level for hundreds of millions of years according to the currently popular geological time-scale. The current rate of mountain uplift would cause a negligible amount of land to rise over such a period when compared with this rate of erosion. The author has checked Humphreys' calculations using data from Weaver[2] and confirmed that they are reasonable. Using similar reasoning, all rock known to have sedimentary origins would be deposited in 250 million years. One must conclude that either sedimentation is now occurring unusually fast, or that catastrophic uplift and thus erosion has occurred in the past, and that the currently popular geological time-scale is orders of magnitude too long.

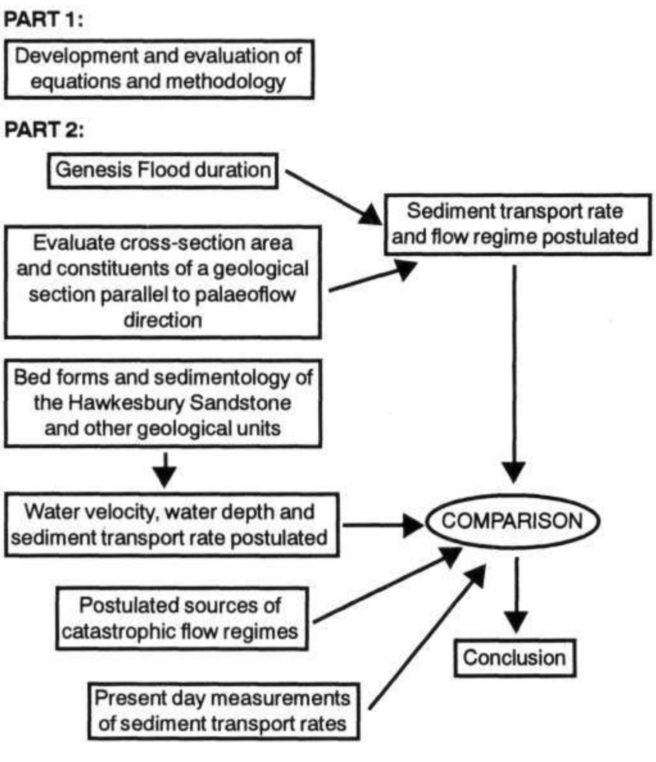

Figure 1. *A flow diagram explaining the procedures used in this paper for testing various theories on the rate at which the geological column has been deposited.*

Models for the Genesis Flood suggest that much uplift occurred during the Flood, and that much of the geological column was deposited during that catastrophic event. If these models are correct, then the geological time-scale should actually be very short. In this study, physical sedimentology was used to test different ideas on the geological time-scale and column using the procedure given in Figure 1. Calculations of flow regimes necessary for rapid deposition were done. All care was taken to ensure that the equations used are either derived from general principles of physics or from curve fitting of parameters that are measurable in the range we wish to use them. Many equations[3,4] were rejected because they required extrapolation well out of the range they had been calibrated for if used to predict catastrophic flow regimes.

The accepted equations are modifications of the Bagnold[5] and Ackers and White[6,7] sediment transport equations. The modifications to the Ackers and White equation were done by the authors themselves. The constituent variables of the equations were varied through reasonable ranges and their effect on transport rates were noted. A calculation procedure for determining deposition times for strata and geological basins dependent on chosen flow regimes was produced, while relevant constraints evident from bedform analysis were determined. Fine particle deposition rates were calculated using settling velocities, since the transportation rate of fine particles is much higher than their deposition rate in catastrophic conditions.

Flow regimes necessary for deposition of the Palaeozoic and Mesozoic parts of Australia within the time given in the Bible for the Genesis Flood were estimated using these sediment transport equations. Flow regimes necessary for generation of the various bedform structures prevalent in the Hawkesbury Sandstone were used to calculate how long each lithosome of the Sandstone took to form.

Some proposed causes for Genesis Flood flow regimes are briefly discussed.

SYMBOLS AND DEFINITIONS

Sediment transport symbols —

$i = gj(\sigma-\rho_l)/\sigma$ (the transport rate of solids by immersed weight and per unit width)

(kg $m^{-1}s^{-1}$)
j = j_{total} or transport rate of solids by dry mass per unit width (kg $m^{-1}s^{-1}$)
σ = density of solids (kg m^{-3})
ρ_1 = density of fluid (excluding sediment) (kg m^{-3})
g = acceleration due to gravity (ms^{-2})
$\bar{u}$ = mean flow velocity (ms^{-1})
$e_b/\tan\alpha$ = a factor controlling the bedload transport rate
e_b = efficiency of bedload transport
$\tan\alpha$ = dynamic bedload friction coefficient
e_s = a factor controlling the suspended load transport rate
ω = $\tau\bar{u}$ or stream power per unit boundary area
τ = $\rho\bar{u}^2f/8$ (the unit fluid shear stress)
ρ = $(1-C)\rho_l + C\sigma$ (the density of the fluid-sediment mix)
C = the fractional volume concentration of grains
f = the Darcy Weisbach friction coefficient at the bed
R_h = hydraulic radius
$\approx$ average water depth h for planar flow
h = average water depth (in cases where significant density stratification has occurred in the water, for example, turbidite deposition, h = the distance between the bed and the lowest plane of significant density contrast).
V = settling velocity of an array of particles or solids (ms^{-1})
V_0 = settling velocity of isolated particles (ms^{-1})
n = an exponent related to the particle Reynolds number
R_e = $\rho DV_0/\eta$ (the Reynolds number)
D = grain diameter in metres
η = viscosity (Nsm^{-2})
T = stress tangential to the bed
Ar = Archimedes Number
G = Reynolds criterion for granular shear

Strata deposition symbols —
thick = the average thickness of a stratum that is being deposited
tfill = Time required to fill a basin or stratum
w = the width of a stratum being deposited in the direction of water flow
d = distance between source and deposition sites

Name	Grade limits stated as particle diameters in millimetres
very coarse sand	1–2
coarse sand	0.5–1
medium sand	0.25–0.5
fine sand	0.125–0.25
very fine sand	0.0625–0.125
silt	0.00195–0.0625
clay	<0.00195

Bagnoid's 1966 Total Sediment Transport Equation

Bagnoid's total sediment transport equation[8] and the Ackers and White equations,[9,10] which have been derived from Bagnoid's equation, appear to be about the most rigid published equations for high flow regimes. Demonstrating this, Bagnoid's equation has even been successfully applied to deposition of sand in dust storms.[11] Many alterations[12,13] to the equation since 1966 have improved its performance at low flow regimes rather than at high flow regimes, so they are not applicable to catastrophic flood deposition. A brief explanation of the equation is given in Appendix 1.

Ackers and White Revised and Updated Total Sediment Transport Equations

Ackers and White have produced equations[14,15] that are in some ways superior to Bagnoid's equation for particles of diameters less than or equal to 1 mm. The equations use physical arguments for deriving their form, and dimensional analysis of over 1,000 flume experiments and some river data for calibration. The effect of sediment concentration is taken into account by the equations, which were used here to check for agreement with the high flow regime part of the Bagnold equation graph that has not been tested by experiments. Details of the rearrangement of the equations for the purpose of calculating transport rates are given in Appendix 2.

Predicted Transport Rates and Consideration of Uncertainty

In order to observe the performance of the transport equations in high flow regimes, transport rates for a range of velocities and grain diameters were graphed in Figure 2 using the Bagnold equation, and in Figure 3 using the revised Ackers and White equations. Individual variables were then changed and the effects noted. The variables were given values as specified in Table 1.

The solutions of the Bagnold equation were partially corrected for sediment concentration through iteration. Figures 2 and 3 clearly show that only a small change in water velocity causes a very large change in the sediment transport rate.

Comparison of Figures 2 and 3 shows good agreement at flow velocities over 1 ms^{-1}, except for particles of fine sand size and smaller. For such small particles, the Ackers and White equation should be considered to be more accurate, due to equation revisions that they have made to adjust for effects operating on such particle sizes.

Figure 4 shows sediment concentrations calculated from the Bagnold equation for various suspended sediment transport rates. Sediment concentration significantly affects settling velocities, and the effect of concentration on suspension becomes unknown when concentration rises

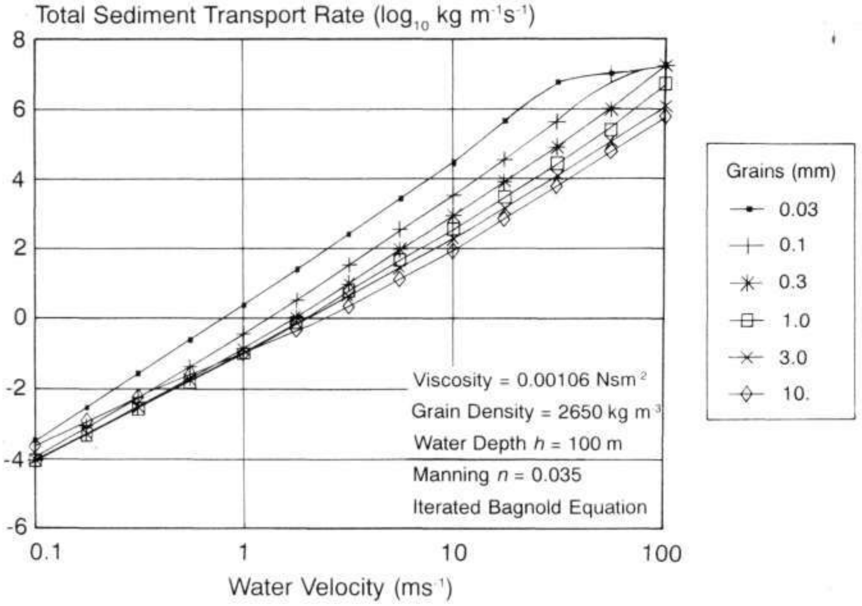

***Figure 2.** Sediment transport rates calculated using Bagnold's equation for various grain sizes and water velocities.*

Further graphs were produced to analyse the effect of viscosity, water depth, Manning '*n*', iterative concentration corrections, and grain density. The graphs show that none of these variables has anything like the effect on sediment transport that water velocity has. Sediment transport rates are approximately proportional to the fourth power of water velocity, the square of the Manning V, and inversely proportional to the cubed root of water depth for velocities we are concerned with here and according to Bagnold's equation.

For water velocities between 8 ms^{-1} and those where sediment concentration approaches the sand packing factor of 0.65, changing the following variables as specified caused the following effects:

Water depth *h* — changing it from 10 m to 10,000 m reduced the transport rates by

above 0.1, that is, at flow velocities over 35 ms^{-1} (for 0.1 mm sand). Using the Ackers and White equation for 0.1 mm sand, a much lower flow velocity of 8 ms^{-1} corresponds to a concentration of 0.1. The flow concentration becomes the packing factor of consolidated sand which equals 0.65, which it cannot exceed, even at velocities greater than 60 ms^{-1} (for 0.1 mm sand, the packing factor is reached at this velocity). Once that packing factor is reached, and at velocities just lower than where it is reached, the equations are totally untested and may be very inaccurate — physical processes may operate that we do not know about under such conditions.

For velocities in excess of 10 ms^{-1} the bedload transport rate was noted by the author to be insignificant when compared to the suspended sediment transport rate even for 10 mm particles.

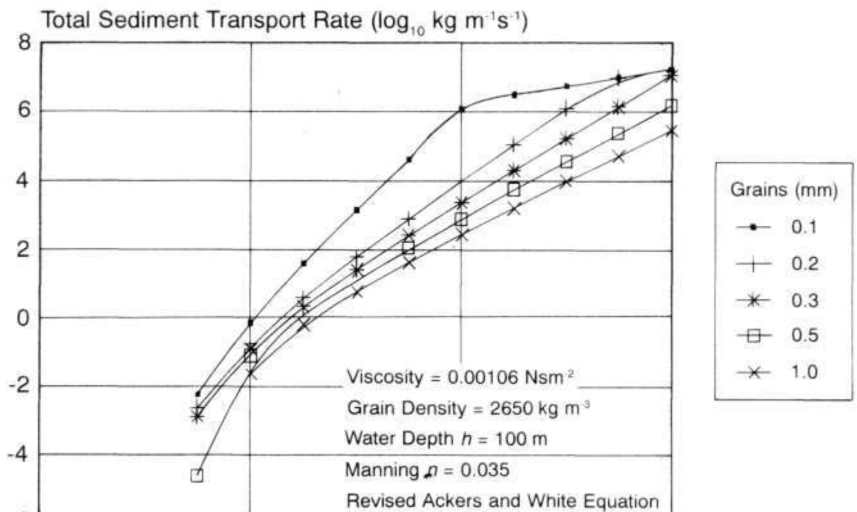

***Figure** 3. Sediment transport rates calculated using Ackers and White's revised equation for a range of grain sizes and water velocities.*

Water depth, '*h*'	=	100 m. Genesis 7:20 tells us that the Flood waters covered the tops of the mountains to a depth of at least 7 m (the draught of the Ark). We have no indication of the size of the mountains that existed before the Flood, so initially h = 100 m has been used.
Water temperature	=	18° C This gives a water viscosity of 1.06 x 10^{-3} Nsm^{-2} (see Vennard and Street, Ref. 16).
Grain density, σ	=	2,650 kg m^{-3} (for quartz density particles).
Fluid density, ρ_1	=	1,000 kg m^{-3}
Acceleration due to gravity, *g*	=	9.8 ms^{-2}
Manning *n*	=	0.035 (common for large rivers — Ref. 16) It is anticipated that this value would be appropriate for flood-scoured plains expected to exist under a catastrophic flood (see Vennard and Street, Ref. 16).

***Table 1.** The values given to the variables needed to calculate sediment transport rates in the Genesis Flood.*

about an order of magnitude.

Manning *'n'* — changing it from 0.035 to 0.022 decreased the sediment transport rates by about 20 per cent *(n* = 0.022 for clean planar earth).[16] Bed forms were noted to increase *'n'* by several times its planar surface value.

Water temperature — decreasing it from 18° to 5°C caused viscosity to increase 50 per cent,[17] but made very little change to the sediment transport rates, while increasing the water temperature up to 60°C similarly caused very little change to the transport rates.

Clay content — in flood conditions, a high concentration of clay-sized particles can be kept in suspension almost effortlessly. Assuming that much clay has been entrained in the water, and considering the clay to be part of the fluid rather than the sediment, it was considered possible that an increase in viscosity could arise from an increase in clay content, so calculations were based on the water having the viscosity of crude oil (10^{-2} Nsm^{-2}).[18] [Crude oil has a viscosity about ten times the viscosity of plain water at 18°C. For comparison, fluidised sand has a viscosity of 1 Nsm^{-2}.[19]] These calculations produced sediment transport rates an order of magnitude higher for 0.03 mm diameter particles, but did not significantly change the transport rates of 10 mm diameter particles. Considering that the Yellow River (China) contains up to 40 per cent sediment by weight[20] (20 per cent by volume), we can be certain that clay content would have affected sediment transport in the conditions of a global Flood.

Grain density — σ has some effect on transport, however densities of common minerals do not vary much; that is, quartz 2,650 kg m^{-3}, feldspars 2,550-2,760 kg m^{-3}, calcite 2,710 kg m^{-3} (minerals uncommon as grains: hornblende 3,000-3,470 kg m^{-3}, mica 2,800-3,400 kg m^{-3}, pyroxene group 3,200-3,550 kg m^{-3}). The resulting sediment transport rates for the different grain densities were observed to be very similar.

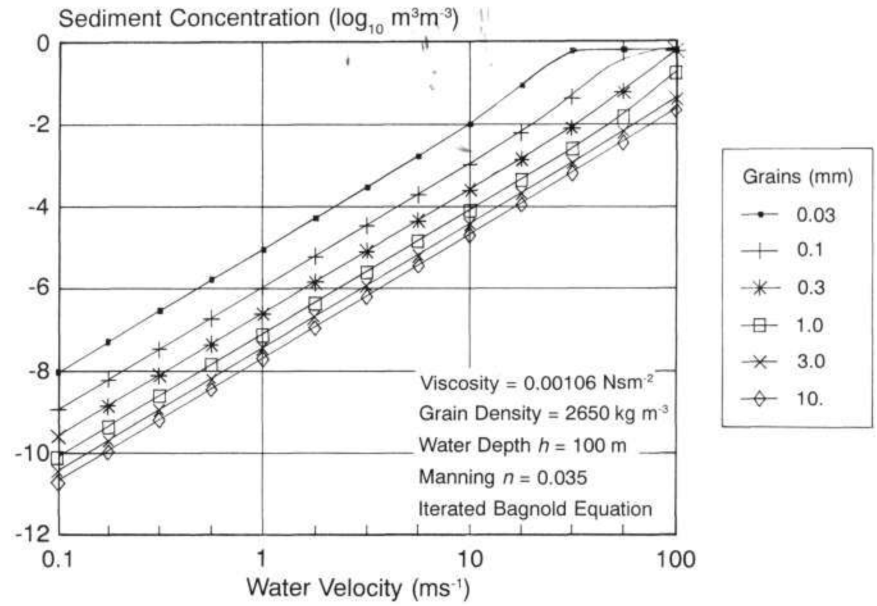

Figure 4. *Sediment concentration calculated using Bagnold's equation for various grain sizes and water velocities.*

Summary of the Effect of Variables

Noting that a three times increase in water velocity causes a two orders of magnitude change in the sediment transport rate, any reasonable variation in viscosity, Manning '*n*', grain density or water depth will not significantly change the water velocity required to produce a particular sediment transport rate.

Grain size is observed to greatly influence sediment transport rates, especially as particle size decreases. Coarse particles are observed to be largely transported as bedload, and therefore their sediment transport rates vary only slightly with respect to grain size. For very fine sediment, even at low water velocities sediment transport rates are very high, thus the problem of sediment transport diminishes and the problem of how to stop sediment transport arises.

Summing up, for high flow regimes the factors that have by far the greatest effect on sediment transport rates when varied through the range anticipated to be reasonable for them, are water velocity and grain diameter.

TRANSPORT OF CLAY AND SILT-SIZED SEDIMENT

The Bagnold equation, the Ackers and White equation and other conventional sediment transport equations are not appropriate for clay transportation. However, more problems arise when considering deposition of clay and silt in catastrophic conditions than with entraining and transporting it. A clay-sized spherical particle (diameter = 1 μm) has a terminal fall velocity of $10^{-6}ms^{-1}$, and a silt-sized spherical particle (diameter = 10 μm) has a terminal fall velocity of 10^{-4} ms^{-1}.[21] Particles of these sizes would take 3.2 years and 120 days respectively to fall 100 m in still water. Furthermore, clay and silt particles are typically not spherical but platy, so their settling velocities are overestimated here.

A special factor such as flocculation or pelletisation by zooplankton may greatly reduce the fall velocity of clays — such factors cause increased rates of deposition of clays and silts today at some locations.[22] Flocculation is the result of congregation of clay particles because of electrical attraction. It is largely affected by the salinity of water, as shown in Table 2.

Table 2 also gives typical floc sizes which are much bigger than the 1 to 2 μm size of individual grains of clay. Because these large flocs can settle faster than individual

Phyllosilicate	Settling Velocities cm/yr			Floc sizes in seawater (μm)
	Salinity (ppt)			
	0.9	10.9	32.5	
Illite	0.89	1.10	1.10	14.2
Kaolinite	0.80	0.081	0.81	12.2
Montmorillonite	0.0023	0.041	0.088	4.0

Table 2. *Flocculation and settling velocities (cm/yr) in quiescent water (see Weaver, Ref. 2, Table 4-4).*

clay grains, and because of the additional effect of binding of flocs by bacteria, rapid deposition of clay is possible as in the following example from Wells.[23] In a coastal barrier island setting (Cape Lookout Bight, North Carolina, USA), mud was accumulating at the rate of 10 cm/yr, despite the fact that the particle density in the overlying water was low and the current velocity was high. Large (up to 1 cm) agglomerates of marine 'snow' bound by bacterial mucilage settled. The mucilage also glued the agglomerates to the bottom, limiting the amount of resuspension. Turbulence not only does not break up the agglomerates of floc, but allows them to grow by coming into contact with other particles that can be entrapped by the mucilage.

Catastrophic formation of orderly layers of sorted silts, sands and clays has been recorded near Mt St Helens, Washington, USA as a result of catastrophic mud-flows activated by explosive volcanic activity. In this case, however, sediment did not have to settle before forming layers of sediment, as the sediment was fluidised rather than suspended.

Supercharging of flood waters with sediment may occur as the result of explosive volcanism in some situations. In periods of tranquillity, this phenomenon could cause rapid formation of mudstone layers made up of very slightly reworked and weathered volcanic detritus which may, after landing on flood water, have sunk as clumps of ash rather than as individual particles.

If mafic igneous rocks are rapidly weathered, many olivine and pyroxene grains are created that could be of sand-sized diameters. These grains could be deposited, then rapidly weathered by entrapped water, forming clays and silts as part of the geological column. Such rapid weathering has been noted when olivine-rich rocks were used to form a sea-wall at Sydney airport. The blocks showed severe signs of weathering after two weeks in salt water and had to be replaced. However, because there is not much known evidence of remnant grain textures in mudstones, this mode of deposition probably does not account for much of the mudstone in the geological column.

ORIGIN OF LIMESTONE AND CHALK

Much of the geological column is composed of limestone and chalk. Because limestone and chalk are usually assumed to be deposited due to biological factors, they cannot be analysed using the equations used in this paper, except where a limestone was originally deposited as lime sand. Under such circumstances limestone deposition can be analysed with the equations in the same way as sandstone deposition is analysed. Otherwise, those interested in catastrophic deposition of chalk and non-reefal limestone are referred to an article by Snelling[24] and to later articles from the same source.

CORRELATION OF TRANSPORT RATES WITH BEDFORM STRUCTURES

Sand-waves (anti-dunes), dunes, plain beds and ripples have been correlated with flow regimes to some degree, and the remnant structures therefore place constraints on flow regimes at deposition. The main transition of interest in high flow regimes is the transition between lower and upper flow regimes in which the various structures in Figure 5 form.[25] As shown in Figure 5, these regimes are determined by the Froude number:-

$$Fr = \frac{u}{\sqrt{gh}}$$

There is a definite limit *(Fr* = 1) where dunes and upper stage plain beds stop forming and anti-dunes start forming. Empirically, Allen[26] has shown that the probable range of the value of the Froude number is between 0.3 and 0.7 for dunes. Using this relationship, probable limits to current velocities can be obtained once flow depth is determined.

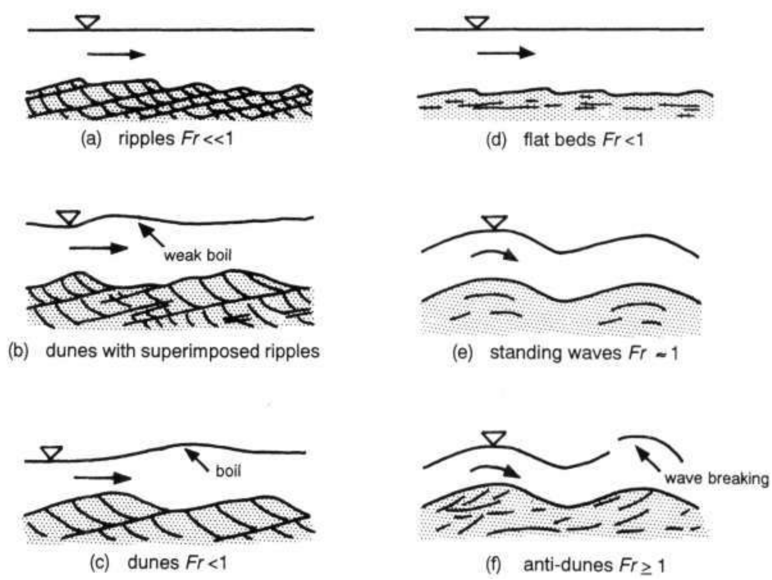

Figure *5. Bed forms that occur at different Froude numbers.*

The upper limit for dune formation has also been very roughly determined by Hill *et al.*[27] to occur when non-dimensional shear stress reaches 0.58, although many dunes are known to have formed at shear stresses in excess of this limit. Non-dimensional shear stress is defined as:

$$\theta = \frac{\tau}{(\sigma - \rho_1)gD} = \frac{\rho \bar{u}^2 n^2}{(\sigma - \rho_1)Dh^{1/3}}$$

The relationship between water depth and sand-wave dimensions has been calculated using experimental and field measurements that range between 0.1 m < h < 100 m, and is given by:

wavelength = $1.16h^{1.55}$ and

dune height = $0.086h^{1.10}$

although there is much scatter about the regression lines.[28]

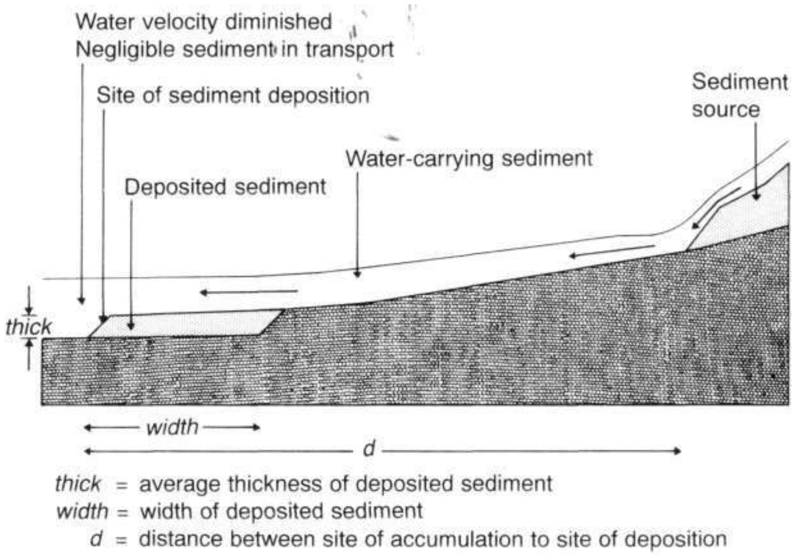

***Figure** 6. Basin or strata formation diagram.*

Dunes and ripples cause formation of foresets, which are layers of sediment with lamination that dips at an angle to the true bedding plane. Anti-dunes can produce weak laminae which usually dip gently upstream.[29] The dunes that produced the foresets are equal to the height of the foreset for critical cross-stratification[30] (no net transfer between suspended and bedload sediment), but are usually twice the height of the foresets[31] (cases of sub-critical cross-stratification).

Finely laminated sediment is often considered to be derived from periodic variations of flow regime, thus suggesting very slow deposition rates. However, this has been proved to have not always been the case by Julien *et al.*[32] Further consideration of such lamination in determining deposition environments for examples given later will therefore not be made.

DETERMINATION OF DEPOSITION DURATION OF STRATA

Methodology: consider Figure 6. For initial simplified calculations let us consider the following. Sediment is removed from a source and transported a distance *'d'* to a site of deposition. Source and deposition site widths '*w*' and '*ws*' respectively are considered to be small in comparison to *'d'*. However, this assumption becomes unnecessary when *j/thick* is small, because the time required for the sediment to get from the source to the site of deposition becomes much smaller than the time required to fill the basin. It is assumed in the following calculations that *j/thick* is small.

tfill = time required to fill a basin or stratum

= time for sediment to initially travel from source to sink + time for the basin or stratum to be deposited

= (*w* x *thick* x particle density x packing factor)/j_{total} + d/(average sediment velocity)

Neglecting the time required for the sediment to get from the source to the site of deposition, and inserting a particle density and packing factor,

tfill = (*w* x *thick* x 2,650 x *0.65*)/j_{total}

DETERMINATION OF FORMATION TIME FOR THE WHOLE GEOLOGICAL COLUMN

Eastern Australian Section

An approach to calculating sediment cross-section area that does not require information on stratigraphic thicknesses of folded strata will be taken for Eastern Australia. Sediment deposited from the beginning of the Cambrian to the end of the Palaeocene in Eastern Australia is largely included in the Tasman Fold Belt, which has an average width of about 1,000 km.[33] The Tasman Fold Belt runs right down the eastern side of Australia. The required sediment transport rate for this belt has been calculated assuming it was all deposited during the Genesis Flood (1.25 years), and that the depth of the sedimentary layers is about 16 km. Evidence for this depth comes from seismic wave transmission velocities, which change at about 16 km depth in continental crust indicating that granulitic type rocks exist below 16 km.[34] It will be assumed that 50 per cent of the rock above 16 km is rock of igneous origin (that is, mafic rocks and I-type plutonic rocks), as many igneous intrusions exist in the fold belt even at ground level. Thus we are left with a cross-section of sediment that is 8 km deep and 1,000 km wide. About 5 per cent of this would be limestone. About 20 per cent may have come from deposition resulting from explosive volcanism. Let us assume that the remainder is equally divided so that half is very fine and the transport of it is negligible, and that the other half has a grain size of 0.3 mm. (This is actually assumed to be the 35 per cent percentile of the grain diameters in this half of the strata [D_{35}]). The sediment transport rate then required for the sediment with D_{35} = 0.3 mm would be

$$\frac{1{,}000{,}000 \times \left(8{,}000 \times 0.75 \times 0.5\right) \times 2{,}650 \times 0.65}{1.25 \times 365 \times 24 \times 3{,}600} = 130{,}000 \text{ kg m}^{-1}\text{s}^{-1}$$

Using Figures 2 and 3, calculated water velocities required to maintain this sediment transport rate are 34 ms^{-1} and 28 ms^{-1} respectively.

Clark states that

'Indirect but convincing evidence indicates that fragmented or continuous Precambrian continental crust underlies the Tasman Fold Belt at least as far east as Canberra and the Snowy Mountains'.[35]

Because of this, the average depth of the Tasman Fold Belt may well be less than suggested above, thus the sediment transport rates required for deposition during the Genesis Flood could be down to a quarter of the transport rate given above. Corresponding water velocities from Figures 2 and 3 would be 24 ms^{-1} and 18 ms^{-1} respectively.

Northern Hemisphere Sections

Using the same method as for the Eastern Australian Section, sediment transport rates have been calculated for the interior of the USA above a latitude of 35°N. The depth to Precambrian basement of platform deposits was digitised off the USA tectonic map,[36] as was topography. These were used to calculate the volume of the platform sediment. A representative cross-section was then determined by dividing the volume by half the sum of the lengths of the boundaries between source and deposition areas (that is, ½ x 4,500 km or the length of the highly tectonically deformed area to the east and west of the centre of the USA, plus the length of the edge of the Precambrian block in Minnesota and Wisconsin). The sum of the lengths was halved, as source areas bound both sides of the USA interior, while under total inundation water probably only flowed in one direction at a time. The proportions of rock types in the platform sediments were assumed to be the same as for the Eastern Australian Section, as documentation suggested this assumption was valid.[37] However, negligible igneous rock was assumed to be present in the platform sediments. The results are as follows:

Platform sediment coverage area = 3,280,500 km^2
Platform sediment volume = 7.369 x 10^{15} km^2
Average cross-section area through the sediment in a direction parallel to direction of flow = 3,275 x 10^{12} m^2
Sediment transport rate for D_{35}(0.3 mm) = 54,000 kg m^{-1}s^{-1}

Using Figures 2 and 3, calculated water velocities required to maintain this sediment transport rate are 23 ms^{-1} and 19 ms^{-1} respectively.

Before radioisotopic dating was invented, several geologists attempted to determine the ages of strata using uniformitarianism and observed sedimentation rates. Sollas (1849-1930) wrote that 26 million years would have been required for deposition of all stratified deposits,[38] Wallace wrote that 28 million years have passed since the beginning of the Cambrian,[39] and Mellard Read (1832—1909) wrote that 526 million years would have been required to deposit all the sediments of the crust of the Earth assuming that the crust is all sediment and is 10 km thick.[40] Underestimations of sedimentation rates were made where vertical sediment accumulation rates were measured and horizontal rates, which were several orders of magnitude larger, were ignored.[41] Even so, Haughton (1821-1897) commented:

'The geologists speak of the enormous lapse of time requisite for the formation of exceedingly small quantities of rock in a manner that would almost make us suppose that some miraculous agency was at work to retard the progress of the formation of those rocks.'[42]

With the popularisation of radioisotopic dating, however, the enormous lapse of time became even more popular and sedimentation rates began to be calculated using such dating.

The part of the geological column typically attributed to the Genesis Flood (from the beginning of the Cambrian to the end of the Palaeogene) has its sum of maximum thicknesses of strata calculated for Northern Europe and North America. The total thickness came to 84 km in both locations.[43] A published global sedimentation rate[44] that has been obtained using uniformitarian assumptions and radioisotopic dating of the rocks at those locations is 108 m Ma^{-1}.

For comparison, for the USA dataset just presented, the average sediment thickness is 2.3 km, so if the sediment were deposited during the year-long Genesis Flood, then it would have been deposited at a rate of 2.3 km/per year or 2.3 x 10^9 m Ma^1. Similarly, for the maximum sediment thickness in the dataset, sediment could have been deposited at a rate of 8 km/per year or 8 x 10^9 m Ma^1. These figures are about eight orders of magnitude greater than the figure obtained above using principles of uniformitarianism and radioisotopic dating.

TRANSPORT AND DEPOSITION OF THE HAWKESBURY SANDSTONE

The Hawkesbury Sandstone (see Figure 7) is a flat-lying Middle Triassic quartz sandstone with an areal extent of about 20,000 km^2 and a maximum thickness of 250 m. It contains numerous thin mudstone intervals, but sandstone exceeds mudstone by about 20:1.[45] Conaghan[46] attributes its origin to an environment similar to that which exists in the Brahmaputra River floodplain in Bangladesh. In his more recent work, Conaghan shows that at least the higher flow regime parts of the sandstone resulted from a more catastrophic deposition mechanism.[47] Bedform analysis is done here to show what conditions prevailed during deposition and how long deposition may have taken.

Assuming an average width (parallel to the direction of current flow) of the sandstone of 100 km and a triangular cross-section, the average cross-section area is 12,500,000 m^2.

Detailed information on the sandstone is given in Conaghan.[48] However, a summary is given here with calculations of flow regimes. Three lithosomes occur in the Hawkesbury Sandstone cyclically in the following order of succession:

TOP 3) Mudstone lithosome
2) Sheet sandstone lithosome (see Figure 8)
1) Massive sandstone lithosome.

The succession strongly suggests that unidirectional episodic flooding occurred in which rapidly increasing flow velocities eroded some sediment, and then flow velocity decreased at a decreasing rate before rapidly increasing again.

The sheet sandstone lithosome is commonly <10 m thick, makes up approximately 50 per cent of the sandstone, has a bulk grain size of medium to coarse sand, and contains cross-beds which are typically straight to flexed and ranging in size from 5 m down to 0.2 m thick. Average set thickness will be assumed to be 1 m. Using this information, thicknesses, water velocities and the sediment transport rates were calculated, giving the information in Table 3.

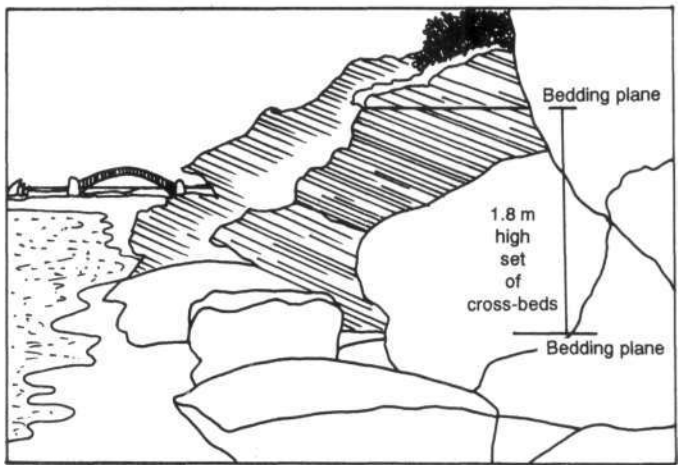

Figure 8. Cross-beds in the Hawkesbury Sandstone, South Head, Sydney, Australia.

Before continuing, let us define 'coverage fraction' as the average fraction of the sandstone area covered by a particular flow regime. Assuming that most of the cross-beds in this unit are around 1m thick, and thus using the sediment transport rate of 100 kg $m^{-1}s^{-1}$, the duration of deposition of all of the sheet sandstone lithosome in the Hawkesbury Sandstone would be very approximately 1,000 days = 2.7 years/(coverage fraction).

The 'massive' sandstone lithosome is commonly <18 m thick, makes up approximately 50 per cent of the sandstone, and has the bulk grain size of medium-fine sand. It contains perfectly massive sandstone, sigmoidal cross-beds up to 1m thick (where fully preserved), crude lamination, and back-set stratification and wave-like structures indicative of anti-dunes. The average flow regime of this unit will thus be assumed to be around that given for a Froude number of 1 for the water depth calculated for the sheet sandstone lithosome cross-beds of maximum size. This Froude number has been assumed

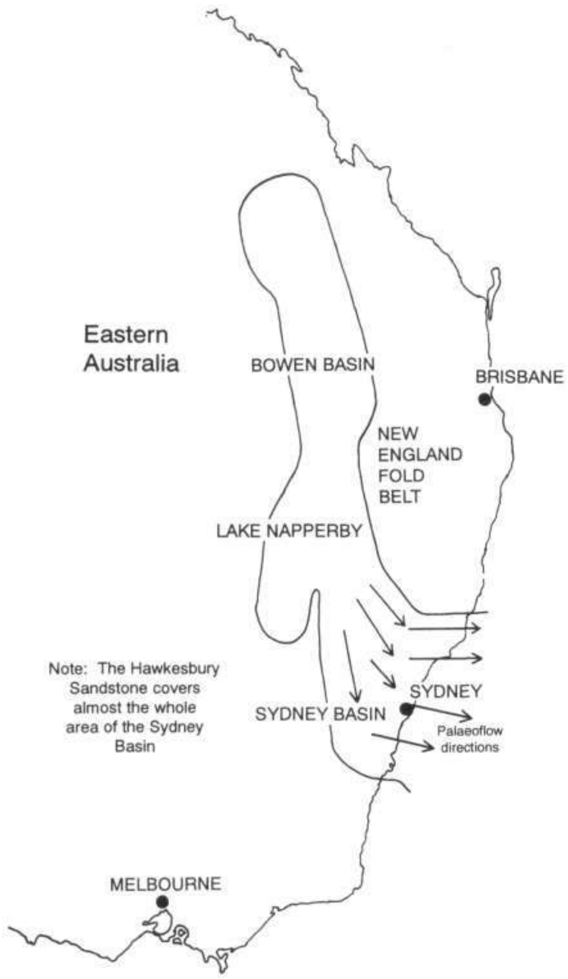

***Figure 7.** Location and palaeoflow directions of the Hawkesbury Sandstone, Sydney Basin, Australia.*

Thickness	Depth	MaxVA	AvgVA	MinVA	MaxVB	TransVel	TransRate	TransRat2
0.2	2	3.1	2.2	1.3	19	4.4	12	100
1	8	6.2	4.4	2.7	24	8.9	100	2,000
5	30	12	8.6	5.1	30	17	2,000	50,000

Thickness	=	Cross-bed thickness (metres).
Depth	=	Water depth calculated from the dune height, which has been assumed to be twice the cross-bed thickness because foreset geometry is straight to flexed (metres).
MaxVA	=	Water velocity (ms^{-1}) assuming the Froude number = 0.7
AvgVA	=	Water velocity (ms^{-1}) assuming the Froude number = 0.5
MinVA	=	Water velocity (ms^{-1}) assuming the Froude number = 0.3
MaxVB	=	Water velocity (ms^{-1}) assuming the non-dimensional shear stress = 0.58 in the non-dimensional shear stress equation.
TransVel	=	Water velocity (ms^{-1}) assuming the Froude number = 1.0
TransRate	=	The sediment transport rate ($kg\ m^{-1}s^{-1}$), assuming that AvgVA is the water velocity and using the Ackers and White formula. This rate should be used for cross-bedded sandstones.
TransRat2	=	The sediment transport rate ($kg\ m^{-1}s^{-1}$), assuming that TransVel is the water velocity and using the Ackers and White formula. This rate should be used as a lower limit for upper flow regime planar beds conformably underlying cross-beds of the corresponding thicknesses.

Table 3. *Water velocities and sediment transport rates for different cross-bed thicknesses and water depths for the sheet sandstone lithosome of the Hawkesbury Sandstone, Sydney Basin.*

because bed forms in this lithosome are those that exist at around a Froude number of 1. Thus, the very approximate sediment transport rate would be 50,000 kg $m^{-1}s^{-1}$, and the very approximate duration of deposition of all the massive sandstone lithosome present in the Hawkesbury Sandstone would be 2 days/(coverage fraction).

The mudstone lithosome is made up predominantly of laminated mudstone. It is commonly between 0.5 and 3 m thick where preserved. It makes up 5 per cent of the sandstone, but much more mudstone must have at some time been deposited because there are signs that much of it has been eroded. The total thickness of 5 per cent of the Hawkesbury Sandstone is 6 m, and the time required for 6 m of silt and clay to settle could be taken for the time required for deposition of the mudstone. However, at one location, the thickness of mudstone is 35 m.[49] Thus the time required for deposition of the mudstone has been taken to be very approximately the time required for enough silt and clay in equal proportions to produce 35 m of mudstone. The concentration of clay and silt in the water would be almost wholly dependent on the amount of clay and silt entrained at the sediment source, as the turbulence created during deposition of the sandstone layers would have prevented much settling of the clay and silt while being transported from its source. The concentration of these particles in the water has been chosen as 0.15, which is considered to be a generous maximum amount (comparable to the maximum reached in the most turbid river today — the Yellow River).[50] The water velocity has been assumed to remain below that required for re-entrainment of the mudstone during settling ($<<0.05\ ms^{-1}$), and at a rate sufficient to prevent the sediment concentration from dropping. Assuming that the clay and silt eventually attain a packing factor of 0.65, clay and silt would be deposited at rates of

$$\frac{10^{-6} \times 0.65^{-1} \times 0.15}{2} = 10^{-7} ms^{-1}$$

and

$$\frac{10^{-4} \times 0.65^{-1} \times 0.15}{2} = 10^{-5} ms^{-1}$$

respectively. Thus, for deposition of 35 m of mudstone, the very approximate minimum time required is

$$\frac{17.5}{10^{-5}} + \frac{17.5}{10^{-7}} = 1.8 \times 10^{8} \text{seconds} = \frac{5.6 \text{ years}}{(\text{coverage fraction})}$$

This time assumes settling of the sediment as individual particles, and without the type of deposition observed, but not understood, at Mt St Helens mentioned above, or flocculation or binding by bacteria. Because of these assumptions, it is unreliable.

The very approximate duration of deposition of the Hawkesbury Sandstone is (2 days + 2.7 years + 5.6 years [minimum]) x the inverse of the proportion of the average area over which sedimentation was taking place to the total area of the Hawkesbury Sandstone. The total time required for deposition of the Hawkesbury Sandstone by a continuously moving cover of water equals about 10 years according to these equations. Continuous coverage has been assumed for computational simplification.

Remains of anti-dunes exist in the Hawkesbury Sandstone, which suggests that shallow, rapidly-flowing water once passed over them. This is contrary to the above scenario. It has been suggested that

'the presence of antidunes under these anomalously

deep palaeoflow conditions may well be explicable in terms of strong density stratification and flow discontinuity phenomena within the moving sediment cloud near the bed.'[51]

These phenomena could alter the transport rates for all of the Hawkesbury Sandstone deposition. However, these phenomena are not well understood as yet.

The probable cause of the deposition in the Sydney Basin is the build-up in, and break-out of, water from back-arc basins. If water built up behind a mountain chain or other obstruction, such as a glacier or cross-cutting mud-flow, in a back-arc basin and suddenly managed to escape as in the manner of dam breaching, then a feature such as the canyon on the Toutle River (Mt St Helens) could form in the obstruction and sediment would be laid out in a huge fan below the breach. If such a phenomenon occurred, it is expected that suitable velocities for transportation of huge amounts of sediment would have occurred for short periods of time and over small areas.

Deposition by explosive volcanism along the north-east edge of the Sydney Basin. Ignimbrites (rhyolitic rocks resulting from outpouring of rock fragments and magma droplets from explosive volcanoes) exist in the southern New England Fold Belt Isismurra Formation.[52] The transition between these ignimbrites and the slightly reworked sands that have formed sandstone in the same formation is gradual, indicating that the sands are of the same origin. If deposited during a global Flood, this reworking could have easily occurred. Similar pyroclastic sediments could have been transported into the approximate location of their deposition in many surrounding areas, and evidence of their origin from explosive volcanism would have been lost. Thus much Sydney Basin sediment (including grains in the Hawkesbury Sandstone) may have been transported part of the way to its sites of deposition through the air, and then reworked slightly once submerged. Bed forms created by such rapidly deposited sediment could thus be those of relatively tranquil flow and thus would incorrectly suggest slow rates of deposition.

OTHER AUSTRALIAN SEDIMENTS

Examples of extensive catastrophically deposited strata similar to the Hawkesbury Sandstone exist in many Australian sedimentary basins, including the Amadeus Basin and Great Artesian Basin.[53] The sedimentary layers of which Ayers Rock (Uluru) and the Olgas are part contain features suggesting much more catastrophic deposition than that which formed the Hawkesbury Sandstone.[54]

TRANSPORT AND DEPOSITION OF THE COCONINO SANDSTONE

The Coconino Sandstone, Colorado Plateau, USA, has been studied by Snelling and Austin,[55,56] who have presented us with the following details:

Average thickness = 96 m
Areal extent (including equivalent sandstone to the east) = 518,000 km^2
Dip direction = South consistently
Distance from anticipated source to site of deposition = 300 to 500 km
Maximum cross-bed set height = 9 m

From this information we can calculate that the water depth over the maximum sized dunes was likely to be around 90 m, and the current velocities for Froude numbers 0.3, 0.5, 0.7 and 1 assuming this depth are 9, 15, 20 and 30 ms^{-1}. If the non-dimensional shear stress = 0.58 for the above conditions, then the current velocity would be 40 ms^{-1}. The sediment transport rate at 15 ms^{-1} is approximately 4,000 kg $m^{-1}s^{-1}$, and at 30 ms^{-1} is approximately 100,000 kg $m^{-1}s^{-1}$.

The cross-section area in the original direction of current flow is 30 million m^2, because the approximate average distance across the sandstone is 300 km. To deposit this cross-section area of sediment using a water velocity of 15 ms^{-1} flowing continuously over the whole area of the sandstone would take 150 days, or using 30 ms^{-1} would take six days. Even when it is assumed that deposition of all of the Coconino Sandstone was as suggested by the few extremely large bed forms found in the Coconino Sandstone, the transport rates suggested above for deposition during the year of the Genesis Flood are just reached.

CONSIDERATION OF POSTULATED SOURCES OF CURRENT VELOCITIES

It has been postulated that water currents that could have transported sediment during the Genesis Flood could have been generated through a combination of some of the following postulated sources. All of the sources appear to be inadequate on their own, and it is thus proposed that while none of them were probably the true primary source of currents generated during the Genesis Flood, several in combination would have been capable of producing the currents necessary for catastrophic sediment transport during the Flood.

Heat-generated currents

If much volcanism was occurring under water, heat from the volcanism would cause water at the site of the volcanism to rise, thus setting up circulation of water in a vertical plane. Such activity is not, however, expected to create adequate currents for the bulk of the sedimentation proposed to have occurred due to the Genesis Flood.

Tides in the Genesis Flood

Tidal forces could have caused currents to rush around the Earth in the absence of continental obstructions, as suggested by Morris and Whitcomb.[57] Sediment transporting power created in this way, however, would not be any greater than it now is, but would only have its effect distributed differently over the Earth, so this theory is not adequate for explaining all the sedimentation caused by the Genesis Flood. Palaeocurrent directions measured all over the world are distributed in all directions, rather than being aligned in a manner expected if tidal forces in a global flood had caused them. Clark[58] gives details on tides in global flood conditions.

High flow regimes generated by the Coriolis force

According to a paper by Baumgardner and Barnette,[59] current speeds of between 30 and 80 ms^{-1} may have been generated by the Coriolis force acting over water which could have covered the continents to depths of between 0 and 1,000 m. These water velocities are quite adequate for transporting all sediment proposed to have been transported during the Genesis Flood, However, it is yet to be determined if the Earth's stratigraphy and palaeoflow directions can be attributed even partly to this mechanism.

Rainfall runoff

It is expected that rainfall runoff could only account for a small component of the sediment transport, largely because it could not cause water to build up to a sufficient depth over an area wide enough to carry the required amount of sediment to deposit the geological column in the time-span of the early phase of the Genesis Flood before everything was completely inundated.

Build-up in, and break-out of, water from back-arc basins

If water built up behind a mountain chain in a back-arc basin or other obstruction and suddenly managed to escape as in the manner of dam breaching, then a formation such as the Grand Canyon could form and sediment would be laid out in a huge fan below the breach. If such a phenomenon occurred, it is expected that suitable velocities for transportation of huge amounts of sediment would have occurred for short periods of time and over localised areas. However, to account for all sediment deposited in a global flood, this type of breach would have to have occurred more than I believe the present-day geological record suggests considering the hydrologic constraints given here. Such breaches need not have been limited to exposed mountain chains as turbidity currents could have breached submerged mountain chains. When relating sand dune heights to water depths of turbidity currents, only the depth of the turbidity current need be related, thus small sand dunes can occur under very deep water.

Comet or meteorite impacts, or other enormous sources of seismic activity

The following is an extravagant and unsupported theory. If a comet or meteorite of large size struck the Earth thus assisting in causing the Genesis Flood, then shock waves of huge proportions would travel around the Earth in a similar fashion to waves dissipating from the site where a pebble was dropped into water. If the impact was great enough, large waves could have travelled around the crust of the Earth displacing ocean water as they went. In the process, very large water velocities would be achieved and much sediment would be transported, especially since the waves in the crust of the Earth would be breaking the rocks of the crust up and liberating them as transportable sediment, and explosive volcanism would be taking place on a huge scale liberating much pyroclastic sediment. Because of the additional water (from the comet) or rock (from the meteorite) added to the Earth, this theory could explain very convincing evidence that exists for expansion of the Earth and increase in surface area (young ocean basins).[60] This theory may include conditions that would have been challenging or detrimental to the survival of Noah's Ark.

Catastrophic plate tectonics

Water currents could have been generated by catastrophic rapid movement of tectonic plates, as suggested by Austin *et al.* in their plate tectonics model for the Flood,[61]

CONCLUSIONS

Using valid sediment transport equations, it is possible to roughly determine what water velocities were required to have caused transportation of sediment into deposits which contain bed forms indicating catastrophic flow regimes. Many variables affect sediment transport rates, however no factor (within its expected range) besides water velocity and sediment grain size very significantly varies sediment transport rates, so very approximate rather than completely unreliable sediment transport rates can be calculated when other inaccurately known variables are fixed at reasonable values.

A flow regime that may have been suitable for deposition of most of the geological section in Eastern Australia, the Tasman Fold Belt, which is considered to be a product of the Genesis Flood by most creationists, was calculated assuming that the deposition duration was one year — the duration of the Genesis Flood. It was predicted that water velocities of about 30 ms^{-1}, but at least in excess of 15 ms^{-1}, would have to have occurred continuously as blanket flow across the length of the fold belt if it was uniformly laid down by a global flood of one year duration.

Analysis of cross-bedding and other bed structures enables very rough calculation of sediment transport rates. Bed structures were analysed in the Hawkesbury Sandstone, a formation suggestive of some of the highest palaeoflow regimes evident in the geological record of the Earth. By defining 'coverage fraction' as the fraction of the Hawkesbury Sandstone covered by water of a particular flow regime, the following can be stated. Bed structures in the Hawkesbury Sandstone suggest that the half of it containing upper flow regime bed forms would have taken about two days/(cover fraction) to form. Flow velocity was calculated as 15 ms^{-1}. Calculations predicted that the rest of the sandstone (cross-bedded sandstone and minor mudstone) was deposited over a period of about 8 years/(coverage fraction). The flow regime responsible for the Hawkesbury Sandstone appears to be similar to, but sometimes greater than, that which exists today in the Brahmaputra River. Due to the extensive coverage, pulsating nature and large magnitude of the palaeoflow regimes, they are possibly the result of successive mountain uplifts, back-arc basin damming (or other forms of damming) and breaching of the resultant dams. Application of known sediment transport equations do not seem therefore to be fully applicable to deposition of the Hawkesbury Sandstone during the Genesis Flood.

Sources of the predicted 30 ms^{-1} flow velocity and 100 m depth flow regime proposed for the Genesis Flood were considered. High flow regimes of 20 to 80 ms^{-1} generated by the Coriolis force acting over mostly, or completely, flooded continents have been modelled. Heat generated currents, intense rainfall and build-up of water in and break-out of water, or turbidity currents, from back-arc basins were considered as possible mechanisms suitable for only part of the deposition during a global flood. Comet capture by the Earth may have played a part in global flooding; however no evidence confirms this and there is a good chance that such an impact would destroy the Earth rather than flood it. There appears to be no postulated single source for the currents that completely explains the geological column in terms of global Flood geology. However, several sources appear to be capable of generating the flow regimes calculated in this paper for the Genesis Flood, particularly if operating at the same time or overlapping with one another.

This paper has set out and used hydraulic equations to test common creationist models for the Genesis Flood. For a significant proportion of the strata of the crust of the Earth, hydraulic equations using measurements of features of sedimentary rocks suggest that popular creationist models for the Genesis Flood require an excessive sedimentation rate. Even so, the equations and measurements show that catastrophic activity, such as is expected to have occurred in the Genesis Flood, almost certainly is responsible for the creation of many of the strata of the Earth. The period (or periods) of catastrophic activity deposited thick strata at a rate nowhere near as slow as currently popular geological time-scales suggest. Additional work may further confirm that the known sediment transport and bedform analysis equations are not fully applicable to catastrophic conditions of deposition.

APPENDIX 1

A Brief Explanation of the Modified Bagnold Equation used in this Paper

$$i = \omega\left(\frac{e_b}{\tan\alpha} + e_s\left(1-e_b\right)\frac{\bar{u}}{V}\right) \quad (1)$$

where / = transport rate of solids by immersed weight and per unit width (kg $m^{-1}s^{-1}$) and

$$i = \frac{gj\left(\sigma - \rho_1\right)}{\sigma}\left(\text{kg m}^{-1}\text{s}^{-1}\right) \quad \mathbf{(2)}$$

$\omega = \tau\bar{u}$ (the stream power per unit boundary area) (3)

$$\text{where } \tau = \frac{\rho\bar{u}^2 f}{8} \quad \mathbf{(4)}$$

and

$$\rho = (1\text{-}C)\rho_1 + C\sigma \quad (5)$$

(the density of the fluid sediment mix).

The other symbols have been defined earlier. Note that on the first pass through the equations, C is set as zero. Later iterations reveal its true value.

The Darcy Weisbach friction coefficient at the bed *(f)* has been obtained from the Manning V friction coefficient and the following equations. Using the Chezy equations[62]

$$C_h = \frac{R_h^{1/6}}{n} \text{ and } C_h = \sqrt{\frac{8g}{f}} \quad (6)$$

where R_h = hydraulic radius (average water depth *h* for planar flow), the following equation has been derived

$$f = \frac{8gn^2}{h^{1/3}} \quad \mathbf{(7)}$$

The terminal settling velocity of arrays of uniform spherical particles is given by

$$V = V_o\left(1-C\right)^n \quad \mathbf{(8)}$$

where n = an exponent related to the particle Reynolds number (R_e),
$R_e = \rho D V_d / \eta$ and
= viscosity (Nsm^{-2})

Bagnold[63] suggests that the average of the settling velocities of the particles in a heterogeneous diameter mixture of grains be used.

The relationship between *n* and R_e is defined graphically by Allen.[64]

C was obtained from the suspended sediment transport rate (j_s) via iteration starting with C = 0. This procedure assumes that sediment concentration does not change substantially with depth, an assumption supported by Luketina[65] and less accurately by Allen.[66]

Bagnold[67] suggests that for the grain diameter (D) the average grain diameter in a heterogeneous mixture of sediment be used.

The fall velocity of isolated particles (V_0) was determined using an empirically derived graph produced by Allen,[68] which is applicable over a wide range of particle diameters and adjusted for viscosity and densities. The denominator on the graph is the cubed root of the Archimedes number (Ar):-

$$Ar = \frac{4\rho_1(\sigma - \rho_1)gD^3}{\eta^2} \quad (9)$$

The efficiency of bedload transport (e_b) is typically around 0.12. It has been related to grain diameter and flow velocity by Bagnold.[69] The relationship developed by Bagnold has been used here.

The dynamic bedload friction coefficient is tan a. In dynamic conditions in fluids, viscous effects in the fluid cause the coefficient to range between 0.37 and 0.75. Tan a has been related by Bagnold[70] to the Reynolds number criterion for granular shear (G):-

$$G^2 = \frac{\sigma D^2 T}{14\eta^2} \quad (10)$$

where T is the stress tangential to the bed and can be replaced with τ for high flow regimes such as what we are concerned with.

The group $e_s(1-e_b)$ has been fixed at a value of 0.01. Bagnold[71] has studied the sources of this coefficient and determined that they do not vary more than 25 per cent for flow regimes ranging up to those of a large river. e_s has been derived by Bagnold theoretically rather than empirically, so its validity in catastrophic flow regimes is not doubtful. The effect of transported solids on e_s has not been determined but simply assumed to be not very significant.

APPENDIX 2

A Brief Explanation of the Ackers and White Equations as used in this Paper

The revisions of the equations done by Ackers and White[72] are used by many civil engineers for drainage design today, so they can be considered to be about the most up-to-date sediment transport equations. The equations used assume a sediment density of 2.65 g cm^{-3} and that the sediment is non-cohesive. The equations use the famous Stokes law for determining settling velocity. Stokes law begins to break down on particles larger than 100 μm and is definitely invalid for particles greater than 1 mm.[73]

A series of equations is presented, each for a particular grain size. The equations take the following form:

$$\bar{u} = C1h^{C2}n^{C3} + C4h^{C5}n^{C6}C_v^{\;C7}$$

The first term is the threshold velocity. The coefficients Cl to C7 are listed in Table 5.

The sediment concentration by volume (C_v), is defined as:

$$C_v = \frac{j_{total}}{\sigma h\bar{u}}$$

The revised equations have been rearranged and converted to give sediment transport rates in kg m^{-1}s^{-1} as follows:

$$j_{total} = 2650h\bar{u}\left[\frac{\min\left(0,\left(\bar{u} - C1h^{C2}n^{C3}\right)\right)}{C4h^{C3}n^{C6}}\right]C7^{-1}$$

Particle diameter d (mm)	Coefficients for Sediment Transport Equations						
	C1	C2	C3	C4	C5	C6	C7
1.0	0.1976	0.116	-0.236	43.1	0.605	-0.116	0.509
0.5	0.0785	0.127	-0.404	14.2	0.540	-0.225	0.443
0.3	0.0399	0.135	-0.526	5.11	0.479	-0.329	0.377
0.2	0.0233	0.142	-0.627	1.95	0.427	-0.426	0.316
0.1	0.0094	0.153	-0.796	0.30	0.341	-0.623	0.217

Table 5. *Coefficients for the Ackers and White sediment transport equations for different particle diameters.*

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Note: A correction has been made to the numerator which contains a typing error. The correct numerator is included in the text on p. 47.
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70. Bagnold, Ref. 5, p. 111.
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