# SYMPOSIUM ABSTRACTS

## KEYNOTE ADDRESS:

## ACHIEVEMENTS AND PROSPECTS IN FLUVIAL SEDIMENTOLOGY

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Our present knowledge and understanding of the sedimentology of fluviatile deposits has been obtained through the combined efforts of geologists, geomorphologists, and hydraulic engineers. Useful future advances will depend on the continued close collaboration between these workers.

*Channel pattern and process.* Channel pattern and interconnectedness vary widely in contemporary streams but can be regarded as functions of stream power, bank erodibility, and time. The pattern of a river reach may change with time, and different reaches on the same river may differ strongly in pattern at a given time. If a satisfactory basis for palaeohydraulic interpretation is to be obtained, the attack on the question of the dependence of channel geometry on hydraulic and drainage-basin controls must be renewed in a wider and more vigorous manner than hitherto. There is a fair understanding of meandering stream processes, obtained through a combination of theoretical, experimental and field studies of contemporary rivers, but an inadequate knowledge of the processes operating in streams of low sinuosity, where secondary flow may not be important. Our inadequate knowledge of the time scales appropriate to river processes, particularly of channel-shifting and bar-building, is holding back understanding of the full implications of channel facies encountered in the older geological record. Knowledge of the processes affecting the overbank is particularly inadequate and retards appreciation of the corresponding facies.

*Bed forms.* In the analysis of fluvial channel facies, bed forms and their dependent internal structures afford potential information about transport directions, hydraulic conditions and regime, and channel pattern and connectedness. Extensive data have been obtained experimentally on the characteristics and hydraulic limits of the common one-way bed forms in sand-sized sediments. There is little corresponding data on bed forms in gravel, and our knowledge of bed forms in silts also cannot be described as satisfactory. Efforts are, however, being made to remedy these defects. These experiments, almost without exception, were carried out under conditions of steady-state equilibrium (flow quasi-uniform and quasi-steady). Flows in real rivers are non-uniform and unsteady, and field studies show that many bed forms display lag effects in relation to the patterns of hydraulic conditions. Are bed forms which differ geometrically necessarily different hydrodynamically, or can operational differences be explained by lag effects? How might lag affect our judgement of regime from the deposits which chance to be preserved? What are the bed forms of gravel-bed streams?

*Facies and facies models.* A combination of studies of contemporary fluvial deposits with the older geological record has led to the presentation of general facies models for the deposits of meandering and a variety of low-sinuosity streams. In refining and applying these models in the future, their limitations should not be overlooked. Firstly, the models are of local relevance, for what may be true of a stream or fluvial sand body at one restricted site may not necessarily be true either overall or even at sites close by. A lateral change of facies may be expected in point bars, for example, because of the influence of local channel curvature on local processes. Secondly, these models emphasize the facies originating in channels. Just as overbank processes are ignored in comparison with channel processes, so the relatively fine-grained sediments of the overbank are neglected at the expense of the more immediately attractive channel sands and gravels. Overbank facies are the more important volumetrically in many alluvial suites and are the "matrix" in which the channel sand-bodies lie. A better understanding of overbank facies, particularly those dependent on pedogenic and other superficial processes, would greatly assist our understanding of how alluvial suites are put together by the flows in and emanating from channels, under the influence of subsidence, base-level change, and climatic variation. A future emphasis on this aspect of fluvial deposits would go far towards bridging the present gap between the traditional stratigrapher's treatment of alluvial suites on the macroscale and the sedimentologist's perhaps undue concern to date with the microscale aspects of channel facies.

# PRESERVATION POTENTIAL AND BEDDING FEATURES IN VARIABLE DISCHARGE STREAMS

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Construction and application of actualistic sedimentological models for coarse-grained fluvial sediments must address the preservation potential of features observed in modern streams. Effective evaluation of preservation potential requires a detailed comparison of modern fluvial bedforms, barforms, and hydraulic parameters with the sedimentary structures, clast size, and vertical/lateral variability of ancient fluvial sediments.

Comparative study of the Platte River system, Great Plains, U.S.A., with fluvial sediments of the Oligocene White River Group has shown the utility of discharge and preservation potential in interpreting gravel and sand-size fluvial sediments. Results of this study include a revision of the classic Platte model for braided stream sedimentation based on discharge fluctuation data, aerial photography at high discharge, and a historical analysis of the effects of human modification on the Platte.

Application of the Platte model to Oligocene bed configuration reconstruction indicates that some widely held concepts of longitudinal and transverse bars need revision to adequately describe modern barforms and provide a workable model for recognition of ancient barforms. Vertical and lateral sequences of White River Group sedimentary structures indicate high discharge bed configuration may have a great preservation potential in variable discharge streams.

# VERTICAL ACCRETION DURING HIGH-GRADIENT PROGRADATION OF FLUVIAL SYSTEMS

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Vertical accretion of fluvial conglomerate and sandstone units is common in tectonically active and rapidly subsiding basins. In such basins it is common to find coal or wind blown tuff interlayered with coarse conglomeratic deposits. Simple vertical sequences of grain size and sedimentary structures are difficult to establish. Upward-coarsening and upward-fining cycles coexist. The most characteristic features of these progradational fluvial successions are sole marks similar to flute casts which seem to have formed when pulses of coarse material scoured into finer deposits of lowland swamps. Examples of this type of environment are known in the Eocene and Oligocene of the northwestern Canadian Cordillera. Recent examples should be expected in areas where swampy lowlands are close to tectonically active mountain fronts and where alluvial fans cannot develop due to rapid subsidence.

# UPPER DEVONIAN OF SOUTH-EAST IRELAND — ANATOMY OF A CONSTRICTED ALLUVIAL FAN

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Three dimensional cross-sections permit detailed evaluation of this localised sand-deficient alluvial fan sequence. In bulk terms three valley fill episodes are recognised. Initially an 8 km wide NE-trending feeder canyon, some 150 m deep, was partially plugged by proximal gravelly material deposited by debris flows and sheet floods. This resulted in a broader, shallower canyon profile. Plugging was completed by conglomerates dominantly deposited by sheet and streamflood action.

Overstep onto lateral divides resulted in the third phase valley fill on a larger scale (> 20 km width) in the context of a stable distal fan - flood plain setting. Fine grained members, in part possibly wind transported, comprise some 50% of this 200+ m thick fill, with immature caliche profiles locally developed. Interleaved gravel deposits occur as thick braid bars, sheetflood crevasse splay units, and

low sinuosity channel fills from ephemeral rivers. Low palaeocurrent variance and facies associations are considered suggestive of continued lateral constriction. Localised ponds with associated vegetation are interpreted to have been present in the central parts of the fan fringe.

The geometry and facies of this sequence is contrasted with other known alluvial fan models. The constricted model recognised here may prove to be relatively common in post-orogenic alluvial retreat situations.

## BED FORMS AND STRATIFICATION TYPES OF MODERN GRAVEL MEANDER LOBES, NUECES RIVER, TEXAS

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All major streams draining the southwestern flank of the Edwards Plateau in south-central Texas transport large volumes of gravel and sandy, muddy gravel and are developing meander lobe sequences consisting predominantly of coarse gravel. The largest of these streams, the Nueces River, has a sinuosity index of 1.3 and a water surface slope of 1.8 m/km in the study area. Stream discharge is variable and has ranged from no flow to more than 17,000 $m^3/s$.

Mean clast b-axis length for the 10 largest clasts at 13 sample sites ranged from 2.5 to 10.8 cm. Velocities of 2.7 to 4.4 m/s 1 meter above the streambed are required to transport these clasts. Stream velocities of these magnitudes occur about once in 8 years when discharge of the Nueces River exceeds 3,000 $m^3/s$. Mean grain size of Nueces River alluvium ranges from 1.2 to 3.4 cm. At a flow depth of 1 m sediment of this size has a critical erosion velocity of 1.8 to 3 m/s. Velocities of this magnitude occur about once in 2 years when discharge exceeds 340 $m^3/s$. Under these conditions flow is subcritical, with critical shear stresses on depositional surfaces ranging from 6.4 to 12.7 $kg/m^2$.

Gravel clasts are imbricated and channel bed forms are predominantly transverse gravel bars with slip faces ranging up to 2 m high and wavelengths in excess of 100 m. Stratification includes graded planar crossbeds and horizontal beds. Lower lateral accretion face sediments are also predominantly transverse bars; upper lateral accretion face deposits occur as longitudinal gravel ridges deposited in the lee of vegetation and, less commonly, as chute bars. Near the upper limit of meander lobes where vegetation is heavy, mud and muddy sand occur as overbank deposits; in these deposits sedimentary structures other than desiccation cracks are rare.

Sedimentary sequences in gravel meander lobe systems deposited by low sinuosity streams are graded or nongraded horizontal beds and planar crossbeds overlain by mud and muddy sand interbedded with horizontally bedded gravels. These deposits in turn are overlain by overbank deposits of mud and muddy sand. Similar sedimentary sequences occur in the extensive Quaternary terraces that parallel the Nueces River.

## FLUVIAL MODELS IN COAL AND HYDROCARBON EXPLORATION

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Channel and levee deposits are important components of fluvial-deltaic sequences and are economic factors in the exploration and exploitation of oil and gas in the Tertiary deposits of the Gulf Coast and of coal in the Carboniferous of the Appalachians.

In the transitional zone between lower and upper delta plain sequences of the Tertiary deposits, infrequent, laterally migrating, meandering channels developed. Fine-grained point bar deposits accumulated in single-storied sequences within these channels. Associated with these deposits are brackish to marine shales and siltstones with good source quality organic matter, and because of this, these channels become reservoir targets.

However, producing hydrocarbons from fine-grained reservoirs can be difficult. Within the point bar sequences individual sandstone beds may be separated and sealed by thin shale beds. Selected

multiple perforations must be made for the individual sandstone lenses or much of the hydrocarbons in the reservoir will be left untapped.

In the Carboniferous, channels that occurred directly over a coal often scoured downard onto the coal reducing its thickness and, in some instances cut it out entirely. The sandstones of channel deposits that rest directly on coals can provide excellent roof rock in mines, but when slump blocks that accumulate most abundantly on the "cut bank" side of channels are encountered, severe roof problems develop.

Levee deposits can cause splits in coal seams that reduce coal thickness below minable minimums and increase the percent rejects above tolerable limits. Where extensively rooted levees occur directly over a minable coal, severe roof problems are encountered.

Because of their effect on economic parameters of hydrocarbons, channel and levee deposits must be considered during the exploration phase with respect to drill hole spacing in order to delineate these features. In addition, these deposits must be taken into account during the exploitation phase to provide the maximum development of reservoir potential for oil and gas and during the mine planning and development for coal because of potential roof problems they may cause.

## GENESIS OF FLUVIAL BEDFORMS

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Bedform genesis is doubly germane to fluvial sedimentology. Not only do streams display a complex variety of bedforms, despite simpler gross-flow conditions than in other environments, but bedforms are also an important component of existing facies models. This paper presents some recent findings on the origin of fluvial bedforms.

Three classes of bedforms are defined on the basis of formative factors and physical scales. The class of largest bedforms, macroforms, includes those bedforms which do not depend upon local flow conditions but which instead respond to long-term hydrological and geomorphological factors. Fluvial macroforms include alternate bars, point bars, scroll bars, and pool-and-riffle sequences. Their wavelength scales with stream width. Mesoforms include those bedforms that respond directly to flow conditions of the outer zone of the local boundary layer of the flow system. Their wavelength scales with boundary-layer thickness (= flow depth in streams), and their lifetimes are commensurate with the duration of individual hydrological events. Fluvial mesoforms include dunes, Coleman's large-scale lineation, and antidunes. The smallest bedforms, microforms, respond to flow conditions of the inner zone of the turbulent boundary layer and thus scale with wall variables. Fluvial microforms include current lineation and small scale ripples.

The conceptual simplicity of this classification is realized incompletely in fluvial streams, owing to the poorly understood bedforms variously referred to as braid bars, linguoid bars, spool bars, unit bars, etc. Theoretical models of the braiding mechanism suggest that these "braid" bars are macroforms, but observations of their behavior in natural streams show mesoformal and macroformal traits.

A new approach to bedform genesis involves the concept of flow structures. Recent laboratory experiments indicate that turbulent shear flows contain one or more inherent structures, each consisting of a more-or-less deterministic secondary flow superimposed upon the prevailing unidirectional mean flow. The main microscale structure is the wall streaks of the turbulent boundary layer, which govern the formation of microforms. Mesoscale structures include the bursting phenomenon, longitudinal roll vortices, in-phase waves, and possibly transverse roll vortices. Wavelength of mesoscale flow structures is proportional to boundary-layer thickness. A speculative explanation of the well documented sequence of bedforms with increasing flow regime involves the successive domination of microscale structure (producing ripples), bursting (dunes), longitudinal roll vortices (upper flat bed and large-scale lineation), and in-phase waves (antidunes).

Other flow structures, possibly width dependent, are associated with macroforms. Examples include spiral motion in bends, which maintains point bars, and obscure long-period oscillations in flow velocity, which may be associated with alternate bars and initiation of meandering.

There remains a critical need to test further these proposals.

# EVOLUTION OF SOURCE-DISTAL TO SOURCE-PROXIMAL FLUVIAL REGIMES IN THE HIMALAYAN MOLASSE

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The record of Himalayan tectonism is preserved in a 7000 m sequence of molasse represented by the Neogene and early Quaternary Siwalik Group. Fining upwards sedimentary cycles from strata of the Upper Siwalik sub-Group generally reflect the transition from streams having high sinuosity, well-developed meander-belt structure typical of much of the Siwalik Group, to low-sinuosity and braided stream regimes during the late Pliocene and early Pleistocene (ca. 2.5 m.y. to 0.5 m.y. B.P.). In significant fashion, this transition in sedimentary style of the Himalayan molasse is not an isochronous event but rather a variable response to the morphogenesis of the adjacent schuppenstruktur of the Outer Himalaya, syndepositional deformation of the Himalayan foredeep margin and proximity to major antecedent stream courses which flow from these regions into the foredeep basin.

Constraints on the chronology of these events is provided by a magnetic polarity reversal stratigraphy which is established for the Upper Siwalik sub-Group. This is coupled with radiometric age determination of several volcanic ashes. The events discussed cover the entire Pliocene and Pleistocene record of the evolution of this fluvial molasse in a region of northern Pakistan.

# A FLUME STUDY OF FLUVIAL GRAVEL FABRIC

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Gravel-sized sediment has not shared in the rapid expansion of experimental sedimentology since 1960. In terms of the sedimentary structure hierarchy, it is considered that 'rank 6', and to a lesser extent 'rank 5', structures embrace the possible range of conglomerate features amenable to a laboratory study. Gravel fabric appears to be a more profitable line of inquiry in view of its common usage in paleocurrent studies, and because of the low preservation potential and/or difficulty in recognising small-scale bedforms.

The laboratory flows were steady-state and spanned the lower- and upper-flow regimes. Clasts isolated on a sandbed undergo combined rotation and translation in response to current-crescent scour. In general, motion is dependent both on the degree of form roughness associated with migrating sand bedforms as well as on the geometric properties of the clasts. Imbrication to moderate angles and current-normal orientation are the dominant responses. Optimum stability of imbricated clasts is attained at the regime transition where flows best approach a steady and two-dimensional character, and is described by a simple power function of projection area versus nominal diameter. The ellipsoidal tendency of the clasts was utilised in the calculation of projection areas.

Since the sandbed co-existing with gravel deposition would likely be in the transition or upper-flow regime, where a stable clast configuration is rapidly attained in response to vigorous current-crescent scour, it follows that the 'equilibrium area' concept is a potentially useful tool for the investigation of matrix-supported gravels.

# DEPOSITS OF FINE GRAINED MEANDERING RIVERS, WITH LARGE DISCHARGE VARIATIONS, IN THE CARBONIFEROUS OF THE MARITIME PROVINCES, CANADA

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A series of fining-upward sequences, up to 11 m thick and interpreted as point bar deposits, occur in the lower part of the Shepody Formation (mid-Carboniferous) in the Chignecto Bay area of New Brunswick and Nova Scotia. The sandstones are predominantly of fine to very fine sand grade but have a maximum grain size of medium sand grade. Plane parallel lamination and ripple lamination are the dominant sedimentary structures in the sandstones. The sandstones pass upward into siltstone with climbing ripple or parallel lamination and clay mudrock. Small, steep-sided channels, infilled with rippled sandstones and siltstones, cut into the upper parts of the fining-upward sequences. These are interpreted as chute-fill deposits. Desiccation features occur in the upper third of the fining-upward sequences and in the chute channels. The presence of chute channels in such a fine-grained sequence and the desiccation structures suggest rivers with considerable stage fluctuations.

In the underlying Maringouin Formation, fining-upward sequences are similar to those in the Shepody but are thinner (up to 5 m) and finer (virtually all very fine sandstone or finer). Ripple lamination is the dominant sedimentary structure. Desiccation features are seen throughout most of the fining-upward sequences and it is probable that many of the river channels were ephemeral.

## BEDFORMS FROM ABANDONED FLUVIAL CHANNELS, CARBONIFEROUS, MARITIME PROVINCES

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Fining-upward fluvial sequences in the upper Shepody and Boss Point Formations (mid-Carboniferous in the Chignecto Bay area of New Brunswick and Nova Scotia) are in the order of 25 m thick. Several sequences are incomplete with the fining-upward sequence truncated by a mudrock bed. The truncation of these sequences was probably produced by abandonment of the channel by meander neck cutoff or avulsion. In a few places the mudrock drape has been removed leaving surfaces, up to 300 $m^2$ in area, covered with bedforms present in the river when it was abandoned. Preservation of the bedforms is excellent and even individual avalanche lobes can be seen.

Ripples, sandwaves, dunes and longitudinal bars have been recognized. The larger bedforms show evidence of falling stage modification: small dunes are washed out; ripples in the troughs of larger bedforms indicate a low stage runoff; and the crestlines of some sandwaves and longitudinal bars have been rounded or modified by minor lobes. The preservation of the bedforms allows a far better understanding of the stratification within the fining upward sequences than would otherwise be possible.

## EPSILON CROSS-STRATA IN THE ATHABASCA OIL SANDS

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The Lower Cretaceous McMurray Formation oil sands contain solitary sets of cross-strata up to 25 metres thick, with cross-stratal dips of 8 to 12 degrees. In all essential regards, these sets conform to Allen's definition of epsilon cross-strata.

The principal characteristics of a typical set are as follows: the lower bounding surface is erosional, and on the scale of a single exposure is essentially planar and horizontal; the cross-strata, which discordantly overlie the basal surface, consist of decimetre to metre thick beds of fine sand, separated by thin partings of argillaceous silt; individual beds are remarkably continuous and uniform from the base to the top of the set and, in sections normal to depositional strike, they characteristically exhibit a straight line profile; subtle fining-upwards within the set is manifest largely by an upwards increase in the proportion of silt and clay rather than as a decrease in mean sand size; depositional strike is generally consistent in any given exposure, but adjacent outcrops commonly show wide divergence in attitude.

Single beds within an epsilon set characteristically exhibit the following sequence: on a sharp base lie essentially structureless sands, followed upwards by trough cross-bedded sands (only sporadically developed) overlain by ripple-bedded sands, grading into laminated silt and clay. Preliminary paleocurrent analysis on the trough sets and the ripples indicates unidirectional flow approximately parallel to depositional strike. Common in the silt partings, and characteristically penetrating down into the underlying sands, are tubular walled burrows up to 5 mm in diameter, exhibiting a form very

similar to polychaete burrows found in the fresh water portions of some present-day estuaries. Microflora within the silts is also of fresh water origin.

Details of the depositional environment of the epsilon cross-strata have yet to be established, but it is proposed that they originated as lateral accretion deposits, laid down on the sloping inner banks or point bars of deep sinuous channels. The falling flow regime indicated in the sands suggests that sand deposition may have taken place only during waning of the flood stage, with fines accumulating during the remainder of the cycle.

## COMPARISON OF LABORATORY AND NATURAL MEANDERING

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Both the processes of meander initiation in laboratory flumes, and the maintenance of bed geometry in flumes with imposed meandering banks bear a close resemblance to the field situation. However, it has not proved possible to model, for example, the process of formation, cutoff, and reformation of large loops in the laboratory. Clearly laboratory meandering provides only a partial model of the field case. A lack of awareness of the extent of correspondence between the two has led to applications of laboratory results that are in some cases unduly broad and in some cases unduly narrow. For example, a major difference between natural sand-bed rivers and laboratory meandering in self-formed sand channels is the fact that no suspension can occur in the laboratory case, ruling out vertical accretion on the floodplain and bar. This fact has important implications as regards to the inability of laboratory streams to form coherent meanders of large amplitude. On the other hand, the correspondence between natural meandering in coarse gravel and laboratory meandering in coarse sand, where suspension is precluded in both cases, is perhaps better than is generally recognized. It can be demonstrated that the concept of pseudomeandering, long used to distinguish the laboratory and field cases, must apply to field meandering in coarse gravel, making the concept essentially meaningless.

## SEDIMENTOLOGY OF A PALEOVALLEY FILL: PENNSYLVANIAN KYROCK SANDSTONE IN CENTRAL KENTUCKY, U.S.A.

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What are the characteristics of the fill of a basal Pennsylvanian paleovalley in central Kentucky, how homogenous is it, what was its depositional environment, and how was it connected, if at all, with the Appalachian Basin to the east?

The paleovalley is about 200 feet (66 m) deep, about 3 miles (5 km) wide and has several sharply defined benches along its sides. Its fill is almost entirely sandstone and consists of two major sandstone bodies: a lower medium to coarse grained, crossbedded body and an upper, fine to medium grained crossbedded, but less homogenous body that contains some shale. The lower sandstone is interpreted to have been deposited by a low sinuosity braided stream; the upper unit was deposited by a series of small high sinuosity meandering streams 20 to 30 feet (6 to 10 m) deep. The upper unit has more variable paleocurrents and extends somewhat beyond the limits of the erosional valley.

The internal facies of the sandstone fill suggest deposition by a stream of perhaps about the size of the Wabash River (in southwestern Indiana) on an alluvial plain in a tropical climate. The change from braided to meandering pattern is probably related to lower gradients as alluviation encroached up paleoslope into the Illinois Basin in early Pennsylvanian time. There are several different ways to connect this paleovalley to the Appalachian Basin, none of which can be well established. East of the study area the sandstone becomes totally decemented and only scattered quartz pebbles and cobbles mark its former presence.

## FLUVIATILE DEPOSITS OF THE ATHABASCA FORMATION OF NORTHERN SASKATCHEWAN

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Analysis of over 3000 paleocurrent measurements in association with sedimentological data and measured sections indicate the presence of several deposystems in the eastern and central Athabasca Basin. The eastern systems derive from the Wollaston Fold Belt and form broad fans with coarse gravels at their apices that grade into sands within a short distance. Silts and clays are notably scarce. Thickness of the sedimentary cycles, variance in current direction, and the type and frequency of sedimentary structures vary down-current. The sequence is interpreted as a group of broad, coalescing alluvial fans grading into a plain traversed by shallow braided streams and subject to strong eolian influence.

## PARTICLE SIZE SORTING IN SUBGLACIAL ESKERS

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Glaciofluvial deposits in subglacial eskers consist of two groups, those deposited during (1) free-surface flow and (2) full-pipe flow. Hydraulic sorting during free-surface flow is no different from that in open-channel eskers, and consequently structural assemblages are similar. Under full-pipe flow there are only minor differences in primary structures and size sorting in sand sizes. Thus, ripple, dune and plane bed attributes are found in both supraglacial and subglacial environments during free-surface flow and during subglacial, full-pipe flow.

Near and above the limit deposit condition, at Froude numbers ranging from about 3 to 10, particle sorting becomes distinctively different under full-pipe flow than in free-surface flow. At a velocity slightly less than the limit deposit velocity, the whole bed slides along the invert of a pipe. Inside this sliding bed, particle sorting is probably restricted to that produced by particle collisions and dilation of the sediment mix caused by strong seepage flow through the bed. At flow velocities higher than the limit deposit velocity, heterogeneous and homogeneous suspension occur, but all of the sediment in the pipe is in suspension and no bed forms can be preserved. A poorly sorted sand and gravel facies of probable sliding bed origin is abundant in several eskers near Guelph and Orangeville, Southern Ontario. Beyond the inferred exits of these eskers, more effective size sorting has produced well-defined bedding in fans and deltas.

## EXPERIMENTAL STUDIES OF FLUVIAL PLACERS

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Experimental studies of channel incision reveal that heavy minerals are concentrated on the bedrock floor of valleys by reworking of valleyfill sediments. Inner channels formed by scour into bedrock are especially favorable locations. These deeper parts of the valley floor are located at both the inside and outside of valley bends, depending on the nature of the sediment load. Pauses in deposition and renewed scour permit heavy mineral concentrations to form within the valley-fill.

Arid alluvial fans rarely contain economic concentrations of heavy minerals, and yet the large fluvial fans of Ghana and South Africa contain important gold concentrations. During experimental studies of the growth of a fluvial or wet fan under conditions of perennial flow, fan-head trenching occurred repeatedly, and this reworking of the fan-head deposits plus rejuvenation of the source area streams remobilized and concentrated heavy minerals in the fan head and mid-fan. This process was not influenced by external variables but rather it reflected the natural morphologic and sedimentologic development of a fluvial fan.

Valley-fill, bedrock and fluvial fan placers may in many instances reflect the behavior of a complex geomorphic system, rather than the influence of external variables.

## DOWNSTREAM GRAIN-SIZE CHANGES IN ALBERTAN RIVERS

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Detailed lithologic and grain-size analyses of 174 samples collected along 12 rivers in Alberta were carried out by L. B. Halferdahl. This set of data is used to illustrate downstream changes in the bed material of these rivers. Each of the major rivers can be sub-divided into three reaches on the basis of downstream change in grain-size. The Mountain reaches show highly variable grain-size characteristics with a tendency to increasing size downstream. Through the Foothills and Western Plains plots of grain-size, D, against distance, x, follow the relationship $D = D_0 e^{-ax}$. Where $D_0$ is the grain-size at $x = 0$ and a is a diminution coefficient. D and $D_0$ are given as $D_{50}$ or $D_{90}$ obtained from cumulative grain-size curves. Bed material is predominantly gravel in the above two reaches. At the beginning of the third reach the rivers become sand bedded and there is no significant decrease in grain-size with distance downstream.

The reach characteristics can be explained qualitatively in terms of their geomorphic history. The Mountain reaches include numerous lakes and infilled lakes of glacial origin. These act as sediment traps and cause the burial of coarse material. In addition much of the present supply is from periglacial environments in which the bedrock is heavily fractured. The Foothills and Western Plains reaches have been degrading since deglaciation and are expected to show grain-size changes according to Sternberg's relationship. The Eastern Plains reaches were affected by isostatic adjustment to the Wisconsin, Laurentide Ice Sheet. Simplifying assumptions of the isostatic effect on stream slopes leads to the conclusion that, following initial degradation, these streams should now be aggrading. Aggradation accounts for the abrupt change from gravel-bedded to sand-bedded streams.

Abrasion coefficients from laboratory experiments and diminution coefficients from rivers are compared. Laboratory experiments greatly underestimate diminution coefficients for rivers, and aggrading rivers show higher diminution coefficients than degrading rivers. The diminution coefficient, a, can be divided into three components: $a_t$, the component of abrasion during transport; $a_v$, the component of *in situ* abrasion; and $B$, the component of differential transport. The value of the diminution coefficient for limestone is obtained using the bed material samples, and also using the diminution coefficient for quartzite and an experimentally derived ratio of the abrasion coefficients for quartzite and limestone. The second derivation of the diminution coefficient for limestone includes an assumption that $B = 0$. As the two coefficients are similar this assumption is accepted, and the ratio of abrasion in transport to abrasion *in situ* is calculated for quartzite as

$$\frac{a_t}{a_v} = 0.1$$

This result explains why laboratory experiments, which do not include $a_v$, greatly underestimate abrasion coefficients in rivers.

## SCALE MODELING OF BED FORMS

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Experiments were made in a small flume to test the validity of scale-model parameters describing transport of loose sediment. Using seven variables to characterize flow and sediment transport (mean flow depth d, mean flow velocity U, fluid density $\rho$ and viscosity $\mu$, sediment size D and density $\rho_s$, and gravity g), dimensional analysis provides four model parameters: Reynolds number $\rho Ud/\mu$, Froude number $U/(gd)^{0.5}$, size ratio d/D, and density ratio $\rho_s/\rho$. Two scaled runs were made in the ripple regime at a scale ratio of about 1.7 to 1 using sand and water with appropriate grain sizes and viscosities. Frequency distributions of ripple height, spacing, and migration rate were determined for 100 ripples; the test for scaling is whether the two curves for each of these variables coincide when

the appropriate scaling factor is applied. In each case the curves are closely coincident, indicating that scale modeling of sediment transport by variation of grain size and water temperature is feasible. This technique should be valuable in studying bed forms and transport rates in small to medium-sized rivers by means of scaled hot-water runs in laboratory flumes.

A pilot study was made in an insulated flume 0.9 m wide and 11 m long with water temperatures up to 80°C (providing a scale model ratio of up to 2.3) with sand sizes ranging from effectively 0.11 mm to 0.30 mm and a flow depth of up to effectively 0.5 m. Sand waves are present at flow velocities intermediate between those for ripples and for dunes, with heights comparable to those of ripples but with significantly longer spacings. Dune spacing increases with increasing flow velocity; dune height increases with increasing flow velocity, then decreases as velocities for upper flat bed are approached. The velocity interval for stable sand waves and dunes decreases with decreasing sand size, and disappears at about 0.11 mm.

## DENSITY SORTING OF SAND-SIZE SPHERES DURING TRACTION TRANSPORT: AN EXPERIMENTAL STUDY

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It is well known that sediment sorting according to size, shape and density takes place but it is not known just how it takes place. To assess the effects of size and density sorting, sand-size spheres of different density were transported under controlled flume conditions. Observations on the motion of discrete grains show that grains smaller than the roughness elements move continuously and have the same velocities regardless of density. For grains near and slightly larger than the roughness, movement is intermittent and, for a given size, heavy particles move more slowly than lights. For grains much larger than the roughness, movement is once again continuous over the rough surface and light and heavy grains move at nearly the same velocity.

Bulk samples containing spheres of a range of sizes and two densities were also studied. Analyses of grain size for the two densities show that for planebed transport, the size of heavies decreased with respect to that of lights with distance transported. For ripple-bed transport however, the size relations between associated light and heavy grains remained essentially unchanged for the duration of transport. These results indicate that the specific process of sediment sorting is a function of the exact mechanism of sediment motion.

## ANATOMY OF AN ARKANSAS RIVER SAND BAR

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Detailed relationships between cross-bed measurements and shifting channel patterns will be demonstrated, and grain size analyses showing a wide variety of distributions will be presented.

The sand bar is located in the Arkansas River valley approximately 10 miles upstream from Tulsa, Oklahoma. From aerial photo sequences, plus discharge and river stage records, it was determined that the entire sand bar (600,000 cubic yards) was deposited in 156 hours. Deposition occurred during two floods, May 19 to 22, 1957 (60 hours) and October 3 through 6, 1959 (96 hours).

The sand bar was studied in detail along a natural cubank (500 feet long) parallel to the valley axis and in a trench (700 feet long by 15 feet deep) dug perpendicular to the cutbank. Sand peels and box cores were taken, and cross-bed types were recorded. Closely spaced cross-bed measurements ($N = 210$) recorded at 12 vertical sections, and grain size analyses were performed on 210 samples from the same sections.

Results show that the highly variable patterns of cross-bed dips match the erratic and changing flow directions prevalent during flood stages. In some of the vertical sections, cross-bed dip directions are at all angles to the overall east-west orientation of the Arkansas River valley. Mean grain size ranges from $0.07\phi$ (0.95 mm) to $4.44\phi$ (0.05 mm), and standard deviation ranges from $0.26\phi$ to $1.48\phi$. At most of the vertical sections, grain size distributions show no systematic change from bottom to top.

# THE FORMULATION OF FLUVIAL FACIES MODELS: POSSIBLE "END MEMBERS" AND THE SPECTRUM OF TYPES BETWEEN END MEMBERS

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The wide range of different river types (meandering, straight, braided; coarse, fine) has spawned a wide range of possible facies models. The best known end member — the meandering fining-upward sequence — is itself a composite model involving facies sequences for active lateral accretion, neck cut-off, and chute cut-off. The philosophy and ultimate usefulness of "splitting" existing models will be examined in the lecture. Models for braided systems, especially the emerging models of sandy and gravelly systems, will be developed, compared, and contrasted. The possible spectrum of types from meandering to braided sandy systems will be emphasized, within the context of what a good model should do, namely 1) act as a *norm* for purposes of comparison, 2) act as a *guide* for future observations, 3) act as a *predictor* in new situations, and 4) act as a *basis* for an overall interpretation.