EVOLUTIONARY CLASSIFICATION OF COASTAL SEDIMENTS

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ABSTRACT

One of the most successful ways of classifying coastal environments has been to employ the dominant coastal process variables as discriminating parameters. This approach has been previously applied to deltas and continental shelves using the three parameters of waves, tides and rivers and to tidal inlets using only waves and tides. We suggest that a three parameter triangular classification can be extended to all coastal environments and enables a division into the primary categories of deltas, estuaries, barriers and tidal flats. Although combinations of coastal processes may remain constant through time on any coast, the coast itself undergoes continuous evolution. This necessitates the inclusion of time as a fourth parameter to satisfy an evolutionary coastal classification. If we adopt a sequence stratigraphic view of coastal evolution, then we may place most coastal sediments within either the transgressive or highstand systems tracts, undergoing either progradation (regression) or flooding (transgression). If we assume that all temporal evolution between sedimentary environments within the coastal system takes place during either a regression or transgression then we can substitute regression/transgression for time as the fourth parameter. Using this approach we see that all environments may occur in the general case but that at times of (maximum) flooding, estuaries predominate and that as sediment continues to be supplied during progradation, deltas, barriers and tidal flats expand at the expense of estuaries. At any one time, each depositional environment may be further subdivided using wave, tide and river process domination.

INTRODUCTION

Numerous authors have shown that deltas and barrier coasts can be classified on the basis of the relative influence of river outflow, waves and tidal currents, because these processes control the morphology and facies distribution (Coleman and Wright, 1975; Galloway, 1975; Hayes, 1975, 1979; Coleman, 1976; Zaitlin and Shultz, 1990). We believe that estuaries can be treated similarly.

Figure 1 attempts to combine the process and temporal aspects conceptually, to give an evolutionary classification of coastal systems. Following Coleman and Wright (1975) and Galloway (1975), the relative importance of river outflow, waves and tidal currents may be represented by a triangle, while the evolutionary aspect can be portrayed by adding a third dimension, *relative time*, to form a triangular prism. In the context of coastal evolution, including estuary creation and infilling, relative time may be best expressed in terms of transgression and progradation (depositional regression) as the direction of shoreline movement, and is one of the major controls on coastal morphology (Curray, 1964; Kraft and Chrzastowski, 1985; Nummedal *et al.*, 1987). Thus, changes which occur during progradation (estuary filling) are shown by movement toward the back of the prism, whereas changes associated with transgression (progressive flooding) are represented by movement toward the front face (Fig. 1). The rate at which different systems progress in either direction is not constant in real time, however, because the rate of filling (or flooding) is dependent on the ratio of sediment supply to the size of the paleovalley, other variables being constant. As a result, individual systems will be spread out within the volume of the prism at any instant in real time (*e.g.*, today).

Although the choice of axes for the coastal classification

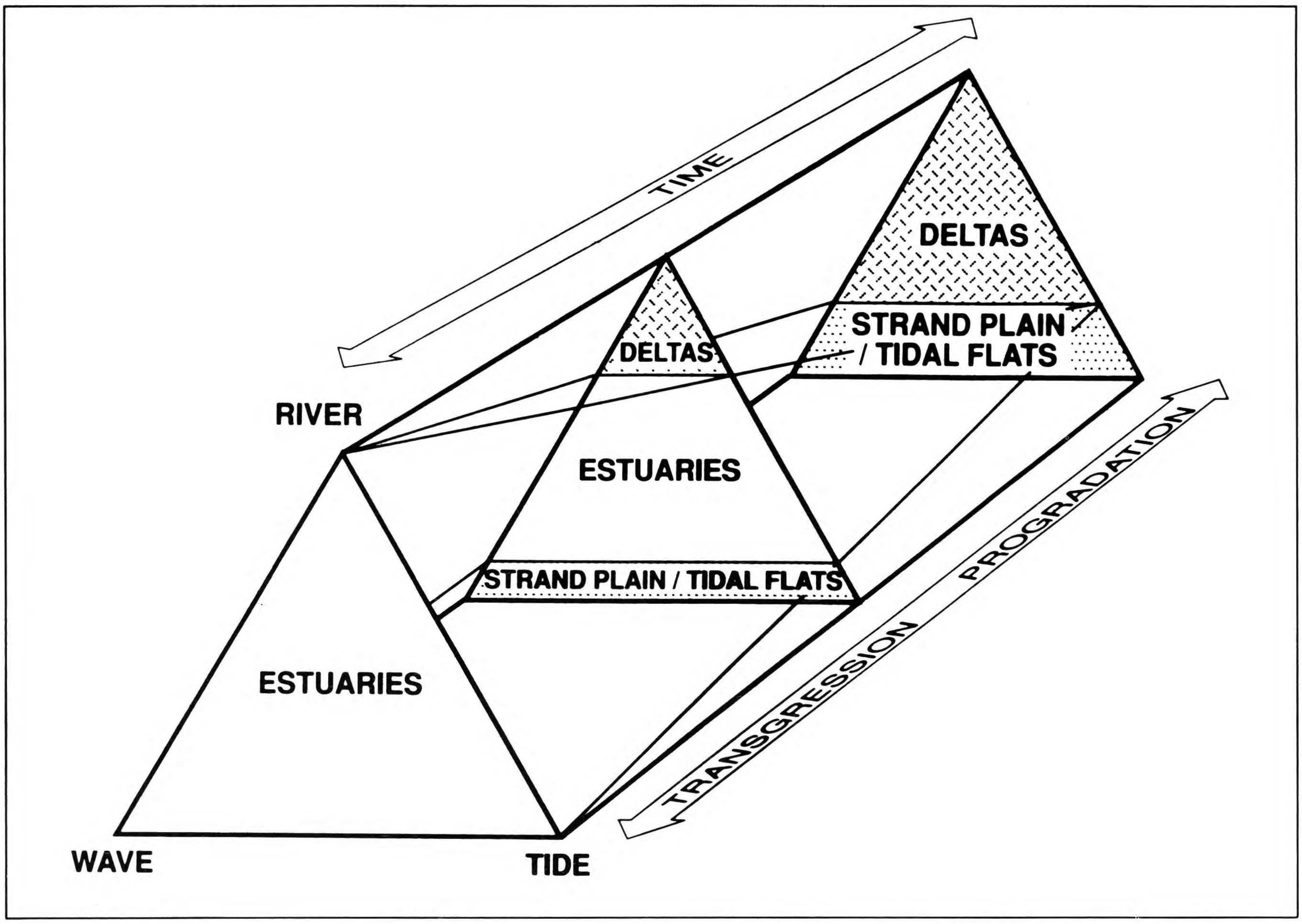

Figure 1. Evolutionary classification of coastal environments. The long axis of the three-dimensional prism represents relative time with reference to changes in relative sea level and sediment supply: transgressions are shown by movement toward the front of the prism, whereas progradations are represented by movement toward the back face. Following Galloway (1975), the three corners of the triangular prism correspond to depositional conditions dominated by fluvial, wave and tidal processes; mixed energy conditions are indicated by points within the prism. Deltas occupy the uppermost area; the intermediate, wedge-shaped space contains all estuaries; and the bottom wedge represents non-deltaic prograding coasts. During a sea level cycle, a coastal area will track forward and backward through the prism by an amount determined by the interplay between the rate of relative sea level change, the sedimentation rate and basin size. It will maintain a constant position relative to the corners if the controlling process variables remain unchanged.

prism (Fig. 1) is obvious, the positioning of the environmental fields within the prism is not, because there is no one-to-one correlation between the relative intensity of the three processes and a particular evolutionary state. The situation at two temporal extremes is clear, however. If a transgression is sufficiently rapid, no river will be able to offset sea-level rise, and the seaward end of all valleys will be converted into estuaries (*e.g.*, the Mississippi River during the early Holocene; Boyd *et al.*, 1988). Such a condition is represented by the front face of the prism (Fig. 1). At the other extreme, if progradation has continued sufficiently long, all the estuaries will cease to exist and the entire triangle will consist of either deltas or prograding coasts; this situation is shown by the back face of the prism. Between these extremes, we have shown both the delta and prograding coast fields expanding at the expense of estuaries as progradation progresses (Fig. 1). This organization has two primary advantages: the relative abundance of the three coastal systems changes in the expected manner along the length of the prism; and the three coastal environments are correctly positioned relative to the process(es) which are responsible for supplying sediment: deltas–a fluvial sediment source dominates; prograding, non-deltaic coasts (strand plains and tidal flats)–sediment is moved onshore by waves and/or tides; and estuaries have a mixed sediment source (Fig. 2).

The coastal classification prism (Fig. 1) can also be sectioned longitudinally and transversely to illustrate the temporal and process relationships between systems. A representative cross section of the prism is shown in Figure 2;

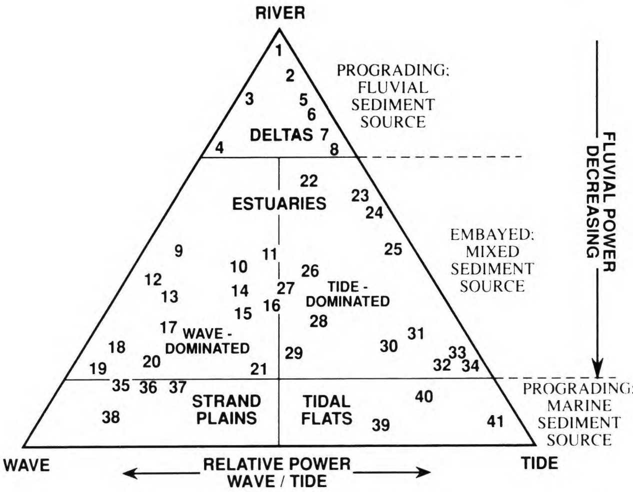

Figure 2. Section through the coastal classification prism (Fig. 1) showing the location of representative modern systems (see Table 1 for the key to the numbers). The uppermost triangle is the delta field, the middle trapezoid is the estuary field, and the lower area contains a spectrum of prograding, straight coastlines, ranging from tidal-flats to strand (beach ridge) plains.

see Zaitlin and Shultz (1990, Fig. 15-2) for an earlier version. In this figure, the upper triangle is equivalent to the delta classification triangle of previous authors (*e.g.*, Galloway, 1975; Wright, 1985), whereas the narrow band at the base is conceptually similar to the bivariate (wave/tide) classification of barrier coasts developed by Hayes (1975, 1979). The trapezoidal area in the center provides a framework for the process classification of estuaries. Following Hayes (1975) we have subdivided them into wave- and tide-dominated types, with the degree of river influence varying from weak to strong in each category. Estuaries are unlike other coastal systems, because of their very ephemeral nature. Thus, any estuary which is created by a transgression will begin to fill when sediment supply exceeds the rate of relative sea-level rise. If sea level remains stationary for long enough relative to the rate of sediment supply and valley size, the estuary will fill and cease to exist; it then becomes either a delta, if the sediment is supplied directly by the river, or a non-protruding, prograding coast (which includes a spectrum of settings ranging between beach-ridge plains and open-coast tidal flats), if the sediment is delivered to the coast by marine processes (waves and/or tides respectively) from sources elsewhere along the coast or on the adjacent shelf.

When constructing Figure 2, data points for the systems listed in Table 1 have been projected horizontally into the plane of the figure. As a result, systems which are at different stages of infilling are plotted side by side. Potential overlap between the three main fields has been minimized to simplify presentation by shifting points slightly to keep them within their proper field; such overlap was not major, however, perhaps because of the short time (4-6000 years) available for progradation since the post-glacial sea-level rise slowed in many areas (*e.g.*, Belknap and Kraft, 1977; Clark *et al.*, 1978; Woodroffe *et al.*, 1989).

An all inclusive model of coastal variability would also need to include locally important modifying variables such as paleotopography and sediment supply. However, the model presented here provides a logically useful way of ordering the natural variability of coastal environments and indicating their inter-relationships. In addition, it provides a coastal classification based on the concept of geological evolution.

CONCLUSIONS

1) Coastal sediments can be classified using the four parameters of river outflow, waves, tidal currents and relative time (expressed in terms of transgression and progradation).

2) This classification provides a logically useful way of ordering the natural variability and inter-relationships of coastal environments, based on the concept of geological evolution.

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Table 1. Summary of representative depositional systems shown in Figure 3.
Relative intensity of tide, wave, and river processes estimated from published literature or personal observations.
Mod = moderate; Ext = extreme.

NUMBER	LOCATION	TIDE	WAVE	RIVER	REFERENCE
DELTAS					
1	Mississippi Delta, USA	Low	Low	High	Coleman 1976; Wright 1985
2	Chang Jiang Delta, China	Mod	Mod	High	Chen *et al.* 1982
3	Ebro Delta, Spain	Low	Mod	High	Maldonado 1975
4	Sao Francisco Delta, Brazil	Low	High	Mod	Coleman & Wright 1975
5	Mahakam Delta, Indonesia	Mod	Low	High	Allen *et al.* 1979
6	Klang-Langat Delta, Malaysia	High	Low	Mod-High	Coleman *et al.* 1970
7	Fly River Delta, New Guinea	High	Low	High	Harris & Baker in press
8	Colorado Delta, Mexico	High	Low	Mod-High	Meckel 1975
WAVE-DOMINATED ESTUARIES					
9	San Antonio Bay, USA	Low	Low-Mod	Mod	Donaldson *et al.* 1970
10	Raritan River, USA	Low-Mod	Low-Mod	Low-Mod	Ashley & Renwick 1983
11	Gironde River, France	Mod-High	Mod-High	Low-Mod	Jouanneau & Latouche 1981; Allen 1991
12	Hawksbury Estuary, Aust.	Low	High	Low-Mod	Roy *et al.* 1980; Roy 1984
13	Lavaca Bay, USA	Low	Low-Mod	Low-Mod	Wilkinson & Byrne 1977
14	Ogeechee River, USA	Mod	Mod	Mod	Dorjes & Howard 1975; Greer 1975
15	Delaware Bay, USA	Low-Mod	Low-Mod	Low-Mod	Knebel *et al.* 1988
16	Chesapeake Bay, USA	Low-Mod	Low-Mod	Low-Mod	Biggs 1967; Ludwick 1974; Coleman *et al.* 1988
17	Miramichi River, Canada	Mod	Mod	Low	Reinson 1977; unpubl. observ.
18	Lake Macquarie, Aust.	Low	Mod-High	Low-Mod	Roy *et al.* 1980; Roy 1984
19	Mgeni Estuary, S. Africa	Low	High	Low	Cooper 1988
20	Eastern Shore estuaries, Nova Scotia, Canada	Low	High	Low	Boyd *et al.* 1987; Honig & Boyd in press
21	Willipa Bay, USA	Mod	High	Mod	Clifton 1983; Clifton *et al.* 1989
TIDE-DOMINATED ESTUARIES					
22	St. Lawrence River, Canada	Low-Mod	Low-Mod	High	d'Anglejan & Brisebois 1978
23	Cook Inlet, Alaska	High-Ext	Low-Mod	Mod	Bouma *et al.* 1980; Bartsch-Winkler and Ovenshine 1984
24	Ord River, Australia	Mod-High	Low-Mod	Mod-High	Wright *et al.* 1973, 1975; Coleman & Wright 1978
25	S. Alligator, Daily and Adelaide Rivers, Aust.	High	Low	Mod	Woodroffe *et al.* 1989
26	Humber River, GB	Mod-High	Mod	Low-Mod	unpublished observations
27	James River, USA	Low-Mod	Mod	Mod	Nichols *et al.* in press
28	Oosterschelde Estuary, The Netherlands	Mod	Low-Mod	Low	Yang & Nio 1989
29	Corio Bay, Australia	Mod	Mod	Low	unpublished observations
30	Moreton Bay, Australia	Mod-High	Low-Mod	Low	Harris 1988
31	Severn River, GB	H-Ext	Mod	Low-Mod	Hamilton 1979; Harris & Collins 1985; Allen & Rae 1988
32	Broad Sound, Aust.	H-Ext	Low	Low	Cook & Mayo 1977
33	Cumberland Basin, Canada	Ext	Low-Mod	Low	Amos & Zaitlin 1985; Amos *et al.* 1991
34	Cobequid Bay-Salmon River & Avon River, Canada	Ext	Low	Low	Lambiase 1980b; Dalrymple & Zaitlin 1989; Dalrymple *et al.* 1990
PROGRADING STRAND PLAINS					
35	Senegal "Delta"	Low	High	Mod	Coleman & Wright 1975; Wright 1985
36	Shoalhaven River, Aust.	Low	High	Low	Roy *et al.* 1980; Wright 1985
37	Yaquina Bay, USA	Low-Mod	High	Low	Kulm & Byrne 1967
38	Nayarit, Mexico	Low	High	Low	Curray *et al.* 1969
PROGRADING TIDAL FLATS					
39	Mont St. Michel Bay, France	High	Mod	Low	Larsonneur 1988
40	Head of the German Bight	High	Low-Mod	Low-Mod	Reineck & Singh 1980
41	East coast, Taiwan	High	Low	Low	Reineck & Cheng 1978

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