CHAPTER 109

SAND CIRCULATION PATTERN AT PRICE INLET, SOUTH CAROLINA

Duncan M. FitzGerald
Dag Nummedal
Timothy W. Kana

Coastal Research Division
Department of Geology
University of South Carolina
29208

ABSTRACT

A sand circulation pattern has been determined for Price Inlet, South Carolina, using wave refraction diagrams, littoral process measurements, bedform orientations and inlet hydraulic data. The dominant process acting on the ebb-tidal delta is wave swash which impedes the ebb-tidal currents and augments the flood-tidal currents. This produces a net landward transport of sand on the ebb-tidal delta as evidenced by the landward migrating swash bars. Bedform orientations and velocity measurements taken on the swash bars also support this conclusion.

Countering the general landward transport direction is the ebb dominance of the main channel. This dominance can be explained by higher inlet efficiency at low water than at high water. Consequently, bay tide phase lag is larger at high than at low water resulting in a longer flood duration. This causes higher mean ebb-tidal currents and a consequent larger potential net ebb transport of sand. This inlet characteristic explains why little sand is transported inside the inlet, why the throat remains scoured and why sand entering the main channel is carried seaward.

INTRODUCTION

Wave refraction diagrams, littoral process measurement, bedform orientations and inlet hydraulic data were used to determine the pattern of sand movement at Price Inlet, South Carolina. A knowledge of sand transport in the vicinity of inlets is important in understanding ebb-tidal delta morphology and how sand naturally bypasses tidal inlets. This study verified certain conclusions of previous investigations and generated a sand circulation model which is a further development of one proposed by Hine (1975).

Physical Setting

Price Inlet is located 15 km north of Charleston Harbor between two beach-ridge barrier islands of Holocene Age (Fig. 1). The inlet is backed by an extensive system of salt marsh and meandering tidal creeks and is connected to the Intracoastal Waterway. The inlet has no fresh water influx other than local precipitation. The mean tidal range is 1.5 m, and the mean tidal prism is 14 million cubic meters. During spring tides, these parameters may increase to 2.1 m and 20 million m^3, respectively. The dominant annual onshore wave energy comes from a northeasterly direction, (FitzGerald, 1976).

Figure 1. Aerial view and location map of Price Inlet, South Carolina. Note the well-developed ebb-tidal delta.

Review of Previous Work

Detailed field investigations of sediment transport patterns in the vicinity of tidal inlets were initiated by Bruun and Gerritsen (1959). Based on studies at Eyerlandse Gat Inlet on the Dutch coast, they recognized the segregation of flood and ebb channels and the resultant sand transport. Oertel (1972; 1975), working on the Georgia coast, observed the importance of breaking waves on swash bars and the interaction between the wave bore and the ebb-tidal currents. He also recognized that ebb-deltas have separate regions of flood and ebb dominance. Dean and Walton (1975) traced the flow pattern during maximum current velocity through Redfish Pass, Florida, and concluded that the lateral transfer of the expanding ebb jet momentum caused entrainment of adjacent waters. Entrainment, in turn, would explain flood dominance of the marginal flood channels. They also stated that the seaward transport of sand was due to tidal currents; whereas, the landward movement of sand was probably due to wave forces. At the Chatham Harbor estuary, Massachusetts, Hine (1975) demonstrated the seaward transport of sand in the main ebb channel and recognized wave-induced landward migrating swash bars.

Ebb-Delta Morphology

The large intertidal and shallow subtidal accumulation of sand that fronts Price Inlet conforms well to the ebb-tidal delta model developed by Hayes (1975), (Fig. 2). The major components of this model are the following: a *main ebb channel* that ends at the *terminal lobe*, the seaward dipping lobe of sand; *channel margin* linear bars which flank the main ebb channel; swash platforms, shallow subtidal sheets of sand located on either side of the main ebb channel; swash bars, intertidal sand bodies occurring on the swash platforms; and marginal flood channels, located between the swash platforms and the adjacent beaches. At Price Inlet, the northern channel margin linear bar is connected to a number of large coalescing swash bars. On the southern part of the ebb delta, the channel margin linear bar is attached to a series of elongate landward-migrating swash bars that parallel the shoreline of Capers Island for almost a kilometer. The main ebb channel and marginal flood channels are well developed at the inlet (Fig. 1).

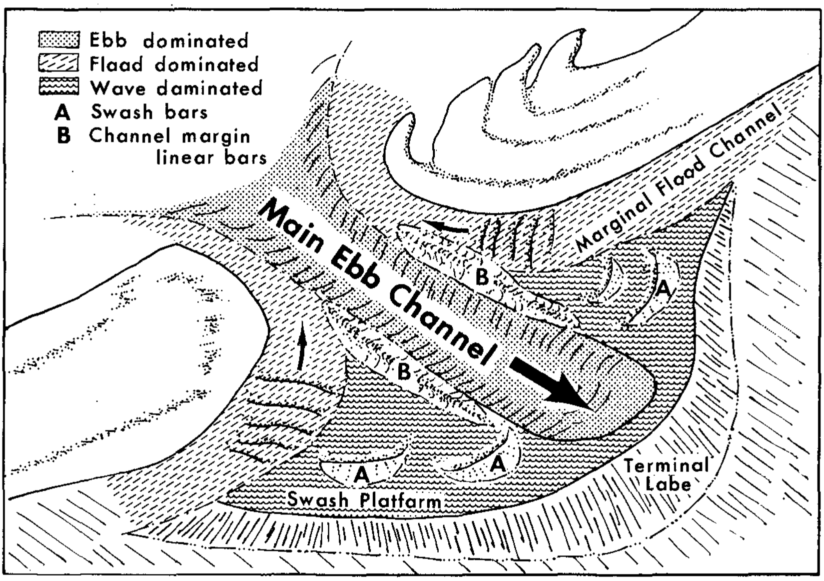

Figure 2. Typical ebb-tidal delta morphology (After Hayes, 1975). The ebb jet maintains a deep central trough, the main ebb channel, flanked by channel margin linear bars and wide arcuate swash platforms. Wave action on the swash platforms generate landward migrating swash bars. Marginal flood channels separate the channel margin linear bars from the adjacent beaches.

Different patterns indicate which areas are dominated by ebb currents, flood currents or waves.

SAND TRANSPORT PATTERNS

Transport to the Inlet

On the central South Carolina coast, there is dominant southward transport of coarse-grained littoral sediment although short term reversals in transport direction do occur. This is determined from wave observations, geomorphic evidence and trends of accretion and erosion (Finley, 1975; Stephens, et al., 1975). Sand enters the ebb-tidal delta complex by longshore transport from the north. Flood-tidal currents and wave bores carry the sand to the marginal flood channels and to the channel margin linear bars. The marginal flood channels constitute pathways for sand transport into the main ebb channel as demonstrated by the flood oriented sandwaves and megaripples which floor these channels. Current measurements in the marginal flood channels also reveal a dominant landward flow (Fig. 3). Wave bores and flood-tidal currents across the swash bar-channel margin linear bar complex probably deliver the bulk of sediment to the main ebb channel. At low tide, wave action transports a portion of the incoming sand in a southerly direction along the periphery of the swash platform.

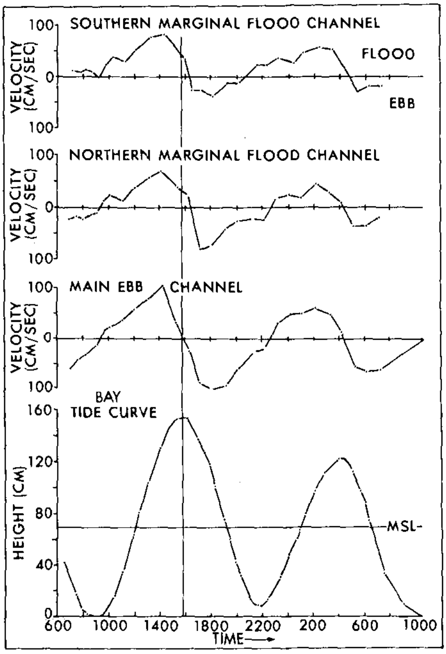

Figure 3. Current velocity curves at Price Inlet, August 15, 1975. Note the dominance of landward currents in the marginal flood channels. Wave bores traveling across the swash bars cause a super-elevation of the water surface in the marginal flood channels, thus augmenting inlet-directed currents.

Transport in the Main Ebb Channel

From high resolution seismic studies of the channel bottom and monitoring of bedform migrations over many tidal cycles, it is evident that no significant amount of sand moves landward through the throat. Therefore, the main channel must be ebb dominated. Seismic profiles made with a 3000 hz EG&G uniboom system, reveal a gently (3 deg.) seaward dipping surface of probably Pleistocene age (Colquhoun, 1976; pers. comm.) underlying the inlet. At the throat, the channel is scoured to this surface; further seaward, the Holocene ebb-tidal delta wedge gradually thickens to reach a maximum of 6 meters (Fig.4). SCUBA-diving has identified a 10-20 cm thick layer of coarse sand and shell fragments at the throat bed. Bottom traces of the main ebb channel made over a complete tidal cycle indicate that no bedforms migrate across the inlet throat. Also, sandwaves and megaripples which floor portions of the channel bottom remain ebb oriented.

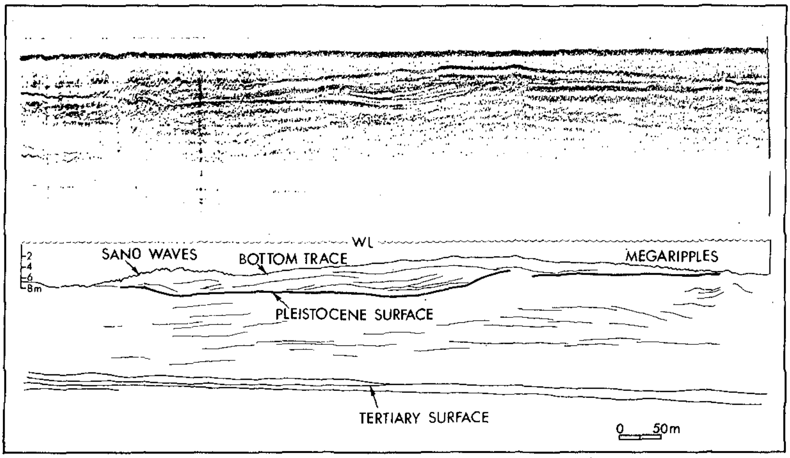

Figure 4. Seismic trace and interpretation through the main ebb channel. The trace runs seaward from the inlet throat (left) where the channel is scoured down to the Pleistocene surface. The Holocene ebb-tidal delta, a wedge of coarse grained clastic sediments, overlies the Pleistocene horizon and reaches a maximum thickness of 6 meters.

It is here proposed that the ebb dominance of the inlet is a function of the hydraulic characteristic of the inlet-marsh system. Keulegan (1967) has defined a repletion coefficient as a measure of the impedance to flow through an inlet. The coefficient is proportional to the quantity A_c/A_b where A_c is cross-sectional area of the inlet throat and A_b is the surface area of the water in the bay. During flooding, A_b increases rapidly as the lower marsh and tidal flats are covered with water. On the other hand, steep banks of the inlet throat cause only minor changes in A_c during the tidal cycle. Consequently, flow through the inlet is much more efficient at low water than at high water, (Table 1).

Table 1

Mean Tidal Range (1.52 m)	A_c	A_b	A_c/A_b
Average low water	1002	2,541,000	.00040
Average high water	1093	6,543,000	.00017
Spring Tidal Range (2.1 m)			
Average low water	994	2,347,000	.00042
Average high water	1110	7,563,000	.00015

Note: Areas in square meters
A_c - inlet cross-sectional area
A_b - bay area

At ocean high tide, there is a substantial landward surface slope through the inlet as a result of the high impedance. Thus, the inlet will flood during early ocean ebb. Inlet impedance is greatly reduced at low tide, and the lag between ocean and bay lows is insignificant (Fig. 5). This inlet characteristic results in a longer flood duration, an average of 44 minutes at Price Inlet. Boon (1975) and Byrne (1976), working at Wachapreague Inlet, Va., have also documented the same trend, and ascribe the cause to distortions of the tidal curve. Due to the diurnal inequality, successive ebb and flood tidal prisms are not necessarily equal, but the mean ebb prism equals the mean flood prism. Because the ebbing period is shorter than the flooding period, the mean ebb currents are stronger than the mean flood currents.

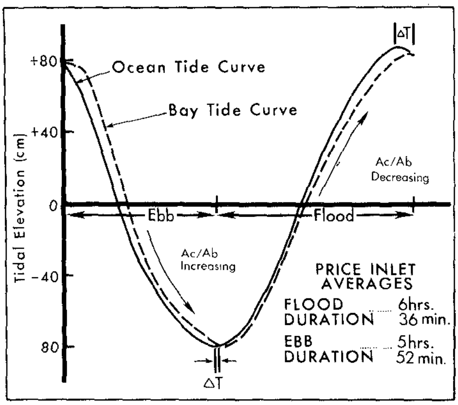

Figure 5. Hypothetical relationship between ocean and bay tides at Price Inlet. As the ocean reaches high water, inlet efficiency, A_c/A_b, the ratio of throat cross-sectional area to the surface area of the bay, is low and the water level inside the inlet lags that of the ocean. Therefore, the inlet floods even after the ocean has begun to ebb. At low tide, inlet efficiency is high, and the bay water level closely follows that of the ocean. This results in a longer flood duration than ebb duration. At Price Inlet, the average difference is 44 minutes.

Maddock (1969), using sedimentation flume data, established that total sediment transport rate is proportional to the cube of the current velocity. His transport equation for a velocity range of .1 to 2 m/sec and a mean grain size range of .3 to .7 mm is:

$$V = 4.03\ (L/\rho)^{1/3}$$

where V is velocity, (m/sec), ρ is mass density of the fluid, (kg/m^3), and L is the total sediment load, kg/m/sec. Assuming the validity of the relationship for tidal inlets, Maddock's formula has been used to determine sand transport rates at Price Inlet. Using hydraulic data measured at the inlet, the weight of sand passing through the inlet throat has been calculated for ebb and flood tidal cycles of varying tidal ranges. It is seen in Figure 6 that a fairly close relationship exists between potential load and tidal range, and that ebb currents will transport far more sand than flood currents.

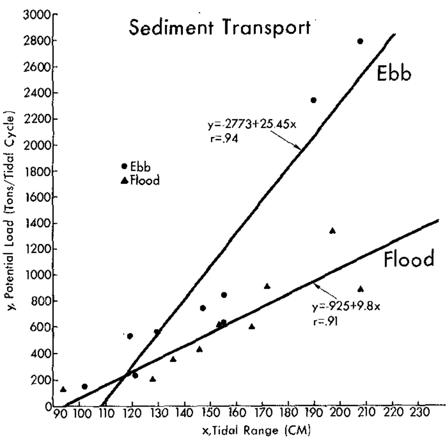

Figure 6. Potential load (tons/tidal cycle) has been determined at the throat section of the main ebb channel using Maddock's (1969) relationship where bedload transport is proportional to the cube of velocity. The individual values were computed from current velocity data measured at Price Inlet for varying tidal phases (neap to spring tides). Except for very low tidal ranges, potential ebb transport predominates.

Sediment transport calculations show a potential net ebb transport rate of 364,000 tons/year through the inlet throat at Price Inlet. A net longshore sand transport rate of 128,000 tons/year toward the inlet was estimated from wave parameters measured on Bull Island just north of the inlet (Kana, 1976).

Consequently, the potential net ebb discharge of sand through the inlet is more than capable of removing sand entering the inlet and keeping the channel scoured.

Effects of Wave Refraction

Sand in the main ebb channel is ultimately carried to the seaward portion of the ebb delta where the mean depth is typically 2 m. The dominant northeast waves breaking in this area at low tide generate a net southward sand transport. Due to wave refraction on the swash platform, a sediment transport reversal occurs just south of the delta. Figure 7 demonstrates a net transport of sediment toward the inlet north of point A regardless of deep water wave approach direction. Inside the swash bars, the transport of sand toward the inlet is augmented by flood-tidal currents. The transport reversal is partly responsible for reintroducing sand into the inlet and in building the beach directly south of the inlet. This mechanism is thought to cause downdrift offsets (Hayes, 1970).

Swash Bar Processes

Swash bar development and migration is a continuous process on the swash platform. Over the past four years, many swash bars have formed in these areas and migrated toward the inlet to form swash bar-channel margin linear bar complexes. Both of these bar complexes have recently increased in volume; the southern one has migrated landward; whereas, the one to the north has remained essentially stable with the bulk of its accretion on the seaward side. During an 8 month period from August 1975 to April 1976, the 1 to 2 m slipface which fronts the entire southern bar complex migrated approximately 100 m. Process measurements on the southern bar complex indicate that its landward migration is related to wave swash (Fig. 8). The bore created by waves breaking on the swash bars impedes the ebb tidal currents but augments the flood tidal currents, resulting in a net landward transport of sand. Bedform orientations, shell alignment and current lineations reflect this landward sand transport (Fig. 9). The most common large scale bedform on the bar complexes are linear and cuspate megaripples. The migration of the bar complex will continue until it welds to the beach, causing an increased downdrift offset at the inlet. Aerial photographs document at least five episodes of bar welding at Price Inlet since 1941. A more complete description of ebb tidal delta morphology at Price Inlet and associated shoreline changes is discussed by FitzGerald (1976).

The momentum of the wave bore across the swash bars causes a water level set-up behind the southern bar system. This causes the water to exit through the southern flood channel even during a portion of the ebbing cycle (Fig. 3). This flood dominance was explained as jet entrainment by Dean and Walton (1975), a process which is believed to be minimal at Price Inlet. There is a smaller water level set-up in the northern flood channel due to the attitude of the bar with respect to the updrift beach and the incoming waves (Fig. 1).

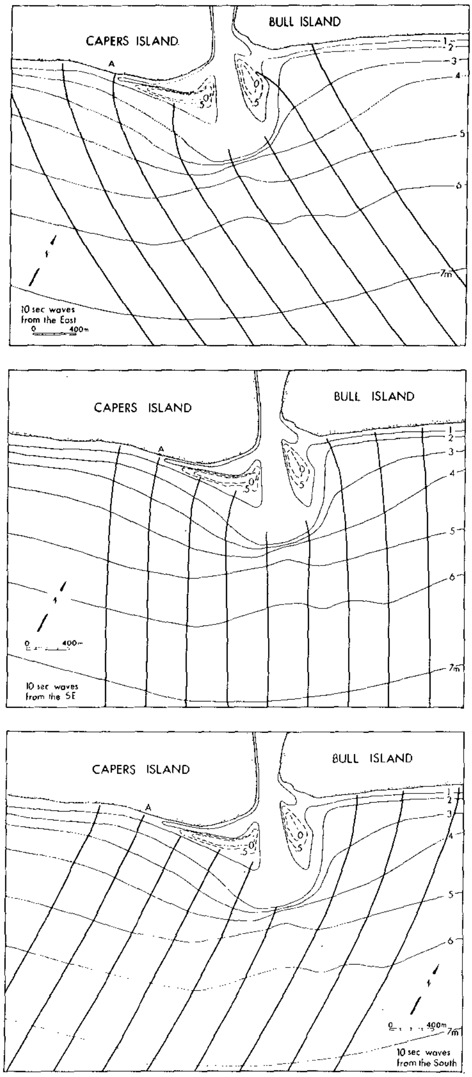

Figure 7. Wave refraction diagrams for 10 sec waves indicate that regardless of wave approach direction, wave refraction around the ebb-delta causes a sediment transport reversal just south of the delta at location A. This mechanism is partly responsible for reintroducing sand into the main channel and for accretion of the downdrift beach.

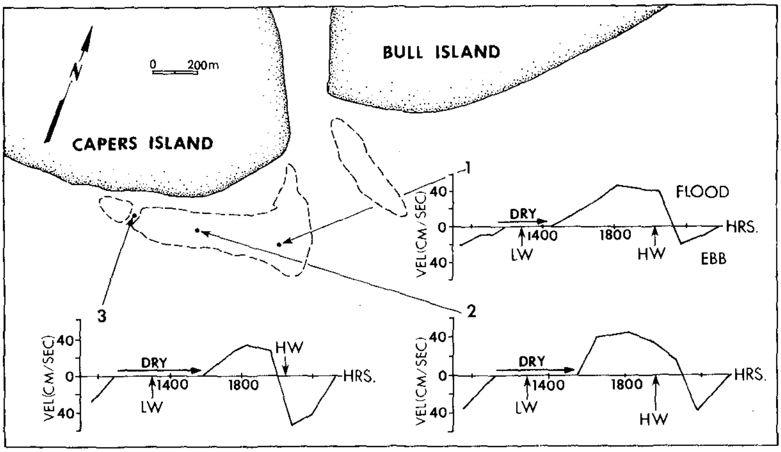

Figure 8. Velocity measurements on the southern swash bar-channel margin linear bar complex on August 20, 1975, show that landward currents predominate. The velocity asymmetry is a result of wave swash retarding the ebb currents and increasing the flood currents.

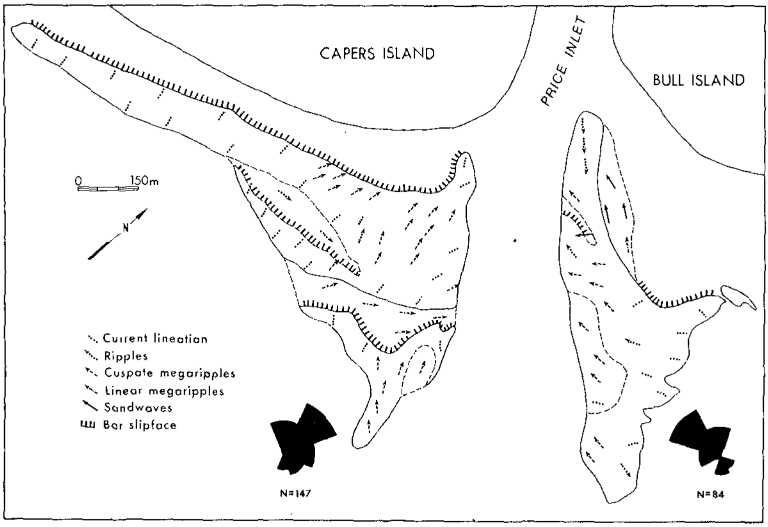

Figure 9. Bedform orientation map of the intertidal portion of the ebb-tidal delta at Price Inlet. Note from rose diagrams that the dominant bedform orientation on either side of the main ebb channel is toward the inlet, indicating landward sand transport.

CONCLUSIONS

1. The sand circulation pattern (Fig. 10) on the ebb-tidal delta of Price Inlet illustrates dominant landward transport except along the periphery of the swash platform where southward transport occurs. Countering this general landward transport pattern is the seaward transport of sand in the main ebb channel.

   The ebb dominance of the main channel is explained as a result of greater inlet efficiency at low water than at high water. Landward currents generated by wave bores dominate the swash platform and the swash bar-channel margin linear bar complex. Wave set-up behind the southern bar system augments the inlet-directed currents in the southern marginal flood channel. This process occurs to a lesser extent in the northern flood channel.

   Assuming that velocity cubed is proportional to total sediment transport, a potential net ebb transport of 364,000 tons per year was determined for the inlet throat. This value, compared with a net longshore transport rate toward the inlet of 128,000 tons per year, indicates that all sand entering the main channel will be carried seaward and the throat will remain scoured.

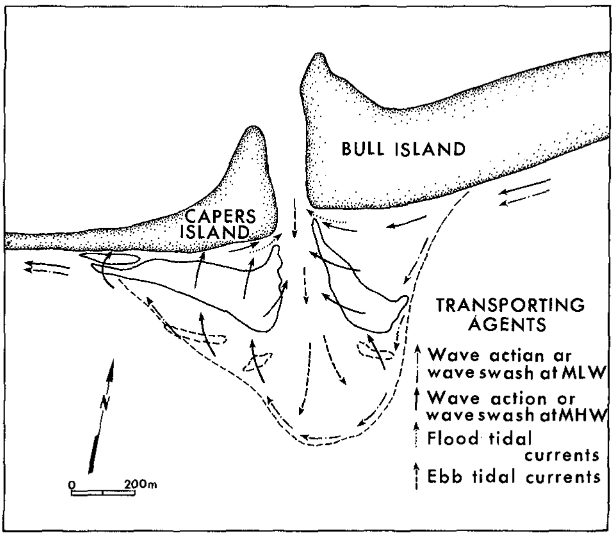

Figure 10. Sand circulation pattern for Price Inlet determined from wave refraction diagrams, littoral process measurements, bedform orientation and inlet hydraulic data. Note the different wave effect at low and high tide, the seaward transport in the main channel due to the dominant ebb-tidal currents, and the landward transport on the ebb delta due to wave swash.

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