JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 39, NO. 1, P. 159–165
FIGS. 1–5, MARCH, 1969

DIFFERENTIAL SORTING OF PELECYPOD VALVES IN THE SWASH ZONE[1]

E. WILLIAM BEHRENS AND RICHARD L. WATSON
Marine Science Institute and Department of Geological Sciences
University of Texas

ABSTRACT

Differential sorting of right and left valves of pelecypods was found to be common on Mustang and Padre Island beaches, Texas. Determination of stable orientations of valves in unidirectional flume currents enables one to predict their behavior on a beach washed by obliquely approaching waves. The valves become initially stable with respect to the oblique swash and then are sorted by the backwash. The following swash tends to re-enforce this sorting. Further observations on the beach confirm that opposing valves behave as predicted. The sense of sorting is correlated to the direction of wave approach and hence with the direction of longshore drift. Interpretations of paleodrift directions from R-L sorting may be possible, but the narrowness of the inter-tidal zone in which the sorting takes place, and the rapidity of resorting, plus uncertainties in the hydrodynamic behavior of fossilized material, dictate extreme care in attempting such analyses.

INTRODUCTION

Several workers have noted that pelecypod valves on recent beaches may be highly sorted with either right (R) or left (L) valves predominant (Muelen 1947, Martin-Kaye 1951, Boucot 1953, Kornicker, Wise, and Wise 1963, Nagle 1964, Lever 1958, Lever and others 1964, and Craig 1967). Several authors suggest that the sorting takes place because of different hydrodynamic properties resulting from mirror symmetry of the two valves, but they describe no specific process. Kornicker and others (1963) substantiated this hypothesis by finding that in well sorted groups of *Dinocardium robustum* there were no discernible differences between opposing valves with respect to weight, shape, or size.

Lever (1958) and Nagle (1964) explain the sorting somewhat more explicitly as an effect of longshore current and the oblique approach of waves. According to Nagle, the valves are transported and rotated by the backwash until the beaks point seaward. When the next wave approaches obliquely, the beak of one valve points into it and this valve is easily moved away. The beak of the other valve points away from the uprush, and is stable. The valve being carried away is carried up the beach and deposited near the berm crest. The valve remaining behind is left at the toe of the foreshore in the breaker zone. In studies of the right and left sorting of *Donax*, Lever (1958) found that the valves turn in opposite directions with each wave. Lever suggests that the valves are oriented by the swash and then selectively removed by the backwash if the waves approach the shore obliquely. His experiments (1958, 1964) show that sorting takes place on the first offshore bar as well as on the beach. He concludes that sorting actually takes place in somewhat deeper water on the seaward slopes of bars "by the interplay of currents and the subsurface effect of waves, while the breaking of waves, washing up and down on the slopes, carries up the result of this sorting" (1958, p. 49).

These mechanisms seem to involve the sort of obliquely approaching waves which would cause longshore sediment transport. Thus paleo-longshore drift directions may be preserved as sorted sets of pelecypod valves. For this reason we decided to investigate the mechanism of shell sorting on Texas beaches and to test both the theoretical and actual correlation between sorting and longshore drift.

EXTENT OF SORTING

To determine the extent of sorting we made over 200 counts of 15 or more each of right and left valves on Mustang and Padre Islands and applied a χ^2 test to each count (fig. 1). The χ^2 test assumes a normally distributed population and tests the probability that this assumption is false, that is, that the valves of each count are really sorted. If they were not sorted a frequency plot of the χ^2 values would form a bell-shaped curve around the low probability values in a histogram. Figure 1 shows that about half of the samples showed no evidence of sorting and the other half are very significantly sorted.

[1] Manuscript received April 26, 1968.

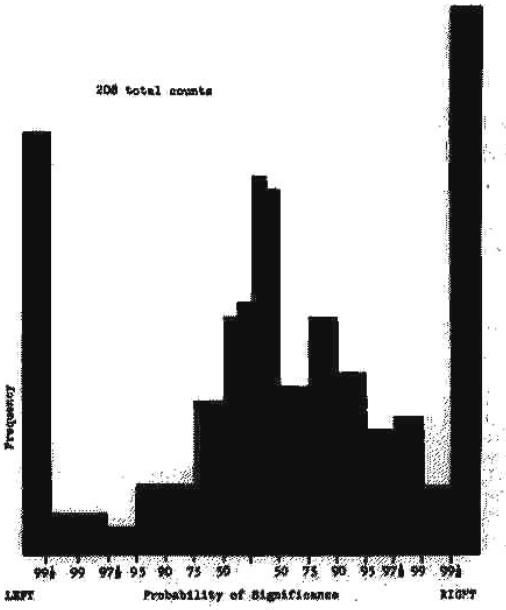


FIG. 1.—Histogram of the frequency distribution of χ^2 values for 208 counts of R-L sorting of pelecypod valves on Texas beaches. The χ^2 test assumed equal probability of finding a R or L valve and tested the significance of unequal counts.

LOCALITY OF SORTING

Because the organisms whose shells we found sorted live from the beach to the offshore barrier shoreface, the sorting must take place somewhere within these environments. The oblique waves suggested to be sorting agents by both Lever and Nagle are most effective on the beach foreshore. The effect within this zone was tested by sampling at the top of the berm and in the shell step at its base (fig. 2). Counts of right and left valves at these locations show significant and opposite sorting at greater than 99½% confidence. Thus we conclude that the R-L sorting we observed takes place in the swash zone.

The tidal range along the Texas coast is smaller than it is along the Dutch North Sea coast where Lever performed his experiments. Thus while the offshore bars referred to by Lever are exposed during low tide and actually become beaches with regular wave swash and backwash, those along the Texas coast are continuously submerged, and wave swash and backwash are restricted to the beach foreshore. Hence the mechanism operating on the beach foreshore and investigated herein may apply equally well farther offshore in areas of greater tidal range. It may be effective on submerged offshore bars too, because water movement in the two places has many similarities. However, there are no shell concentrations on or between these bars along the Texas coast, and thus no samples were taken there.

STABLE ORIENTATIONS

In order to be able to evaluate the action of the complex system of currents acting to produce sorting in the swash zone, we first attempted to determine the behavior of the commonly sorted species in a simple unidirectional current. Numerous valves of each species were placed in either random or oriented positions on the sand bed of a 20 ft. flume. The pump was operated briefly so that a single wave moved down the flume. If the current was initially very fast, the valves rolled. As the current slowed, the valves slid and rotated into a stable position. Once the stable orientation was assumed, the valves continued to slide down the flume in that position until the depth and (or) velocity of the flow was reduced sufficiently for the valve to be deposited. The results of the tests are plotted in figures 3a and 3b.

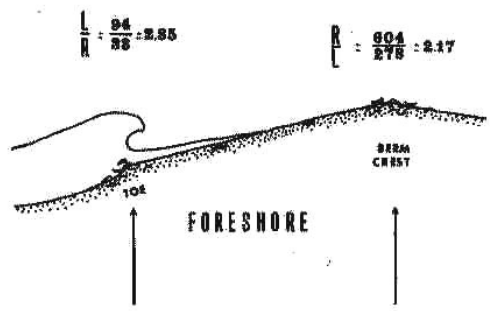
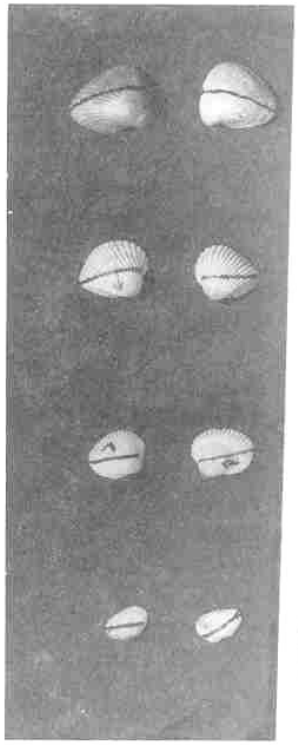
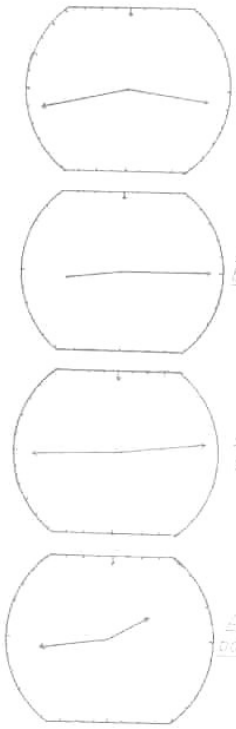
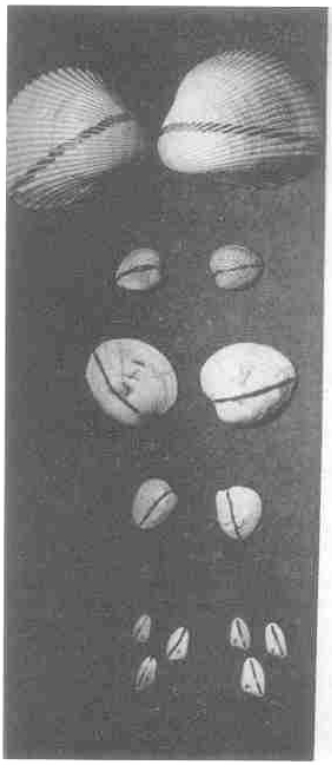


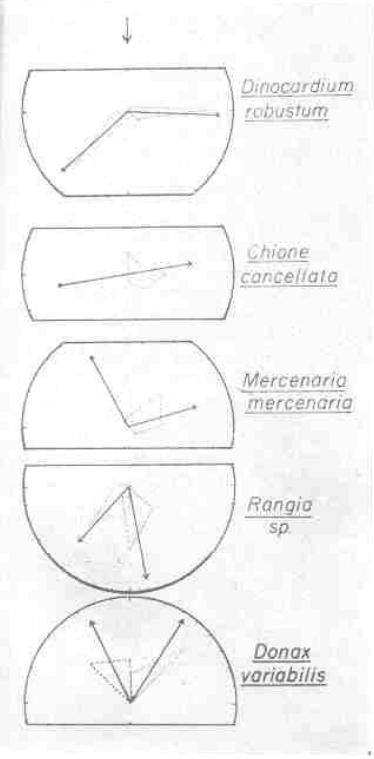
FIG. 2.—Sorting on the foreshore. Opposite ratios of valves in the toe and berm crest are significant at greater than 99½% confidence.

FIG. 3.—Orientation of valves in unidirectional flow. The lines painted on each shell are the arbitrary axes used. Their orientations measured during several tests are plotted at the right. Each valve is oriented with the arbitrary axis parallel to the resultant vector of each series of tests. The current is from the top to the bottom of the illustration. The valves of the *Anadara* group range from three to five cm across.




Eontia ponderosa
Anadara brasiliana
Anadara ovalis
Anadara baughmani




Dinocardium robustum
Chione cancellata
Mercenaria mercenaria
Rangia sp.
Donax variabilis

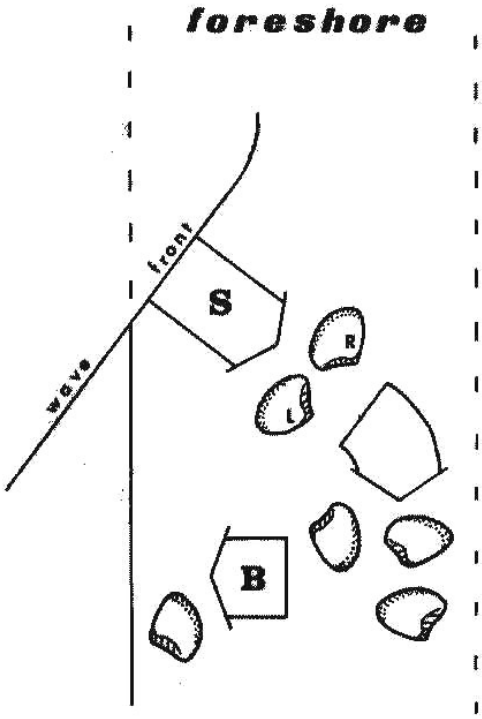


FIG. 4.—Differential sorting mechanism. The stippled portion of each valve is the broad, gently sloping edge that faces the current when the valve is in a stable orientation. In this position the valve is moved only by strong currents. However, when the steep-sided beak (vertically lined) faces a current the valve is unstable and may be rolled or rotated and transported by a relatively weaker current. Thus the oblique swash (S) approaching from the right as one faces the sea orients the valves so that the R valve is relatively stable with respect to the backwash (B), but the L valves tends to be carried back down the foreshore. Furthermore, as a result of backwash orientation the beak of the R valve points into the next oblique swash which will thus be able to carry it further up the foreshore. Oblique waves approaching from the left would sort the valves in the opposite manner.

The majority of species studied may be considered to have triangular, wedge-shaped valves. Those that are equant behave like imbricate plates in a stream and assume a position with their broadest, most gently sloping edge facing into the current. This group includes *Dinocardium robustum* and three species of *Anadara*. The direction of orientation of *Anadara* is the same as found by Trusheim (1931) and Nagle (1967), but the consistency during our experiments was greater (fig. 3a).

Shells of *Mercenaria* and *Chione* are flatter and less triangular but rounder. Their orientation is similar to, but less consistent than, the above group. More elongate plates such as *Donax* orient with their long axis parallel to the current as described by several other workers (Trusheim 1931, Lever 1958, Seilacher 1960, Kelling and Williams 1967, Nagle 1967, and Wobber 1967). *Rangia* has especially heavy beaks which cause it to behave like a short cone (Trusheim 1931, Nagle 1967), that is, with the heavy, broad end into the current and the lighter wing trailing behind (fig. 3b).

Both Lever (1958) working with *Donax*, and Kornicker and Armstrong (1959) working with *Dinocardium* and *Anadara*, claim that R and L valves rotate differently in coming to a stable position. In our experiments both valves were

FIG. 5 (top).—Rose diagram of valves oriented by one wave. The resultant orientation of the longest axes of both R and L valves is shown for a single wave. The solid arrows show the current direction in which the valves are stable. They point seaward; thus the valves were deposited in a stable position relative to the backwash.

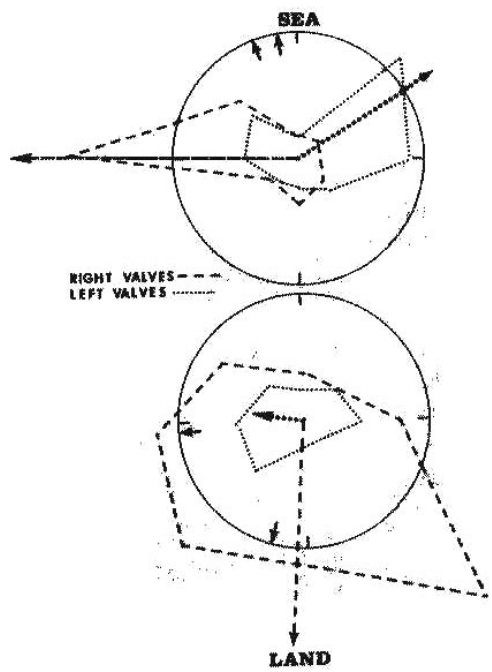


FIG. 5 (bottom).—Rose diagram of the orientation of valves naturally deposited near the top of the foreshore. The solid arrows indicate the current direction in which the valves are stable. Preceding and at the time of measurement the swash approached the beach obliquely from the right as the observer faces the sea. These valves deposited high on the beach are stable with respect to this swash.

TABLE 1.—*R-L sorting of pelecypod valves*

Date	Direction from which the current comes as the observer faces seaward: Preceding four days	Immediate current	Number of counts	Number of valves: L	R	Confidence level	χ^2
9/11/66	1 1 1 L	L	37	660	*1144*	99½	130
9/20/66	r 1 1 1	L	1	*22*	6	99½	9.1
10/2/66	1 r r L	L	5	*120*	84	97½–99	6.3
10/11/66	1 1 1 1	L	8	*133*	29	99½	67
10/15/66	r r r r	L	18	*237*	*303*	99½	8.1
10/16/66	r r r L	L	12	*336*	126	99½	9.5
10/17/66	r r L L	R	3	32	*78*	99½	19.3
	r r L L	L	6	*125*	70	99½	15.5
10/21/66	L L L L	R	23	*551*	346	99½	47
	high beach		13	*331*	109	99½	112
	low beach		10	220	*237*	50–75	0.63
10/22/66	L L L R	R high	2	*64*	20	99½	23
		low	2	45	*51*	25–50	0.38
10/23/66	L L R R	L	6	*155*	124	90–95	3.45
10/24/66	L R R L	L	32	339	*617*	99½	81
12/7/66	1 r r r	R	16	318	*757*	99½	187
12/8/66	r r r R	R	3	121	*313*	99½	81
	r r r R	L high	18	318	*480*	99½	33
		low	10	220	*338*	99½	25
1/12/67	1 1 1 1	L	2	*40*	14	99½	12.5
1/13/67	1 1 1 L	L	5	*295*	211	99½	14

For this portion of the Texas coast, a current from the right, as the observer faces seaward, should result in an excess of right valves on the upper foreshore where most of the counts were made. A current from the left will result in an excess of left valves. On some days, counts were made both high and low on the foreshore as indicated in the table. Currents on preceding days were observed directly (capital letters) or deduced from wind direction (lower case letters).

observed to rotate in both directions depending on the initial orientation. Furthermore, Kelling and Williams (1967, p. 253) point out that there are several principal methods of shell reorientation other than rotation.

SORTING MECHANISM

We can now develop a hypothetical set of movements for valves subject to oblique waves on a foreshore. As a wave breaks at the base or toe of this zone, the water becomes very turbulent and picks up some of the coarse shells that are concentrated there. They are at first tumbled rather violently up the slope until the rush of water slackens and the shells fall to the bottom and slide into a stable orientation (fig. 4). They are stable with respect to the current of the swash, which may be either diagonally up the slope or actually parallel to the shore due to a lateral swing at the climax of the wave. In these orientations one valve has a portion of its gently sloping ventral margin while the other has the steep sided beak facing into the subsequent backwash. The former then tends to remain high on the beach while the latter is picked up by the backwash and returned to the shell step at the base of the swash zone. In addition, when the valves are deposited in a stable position relative to the backwash, the one that tends to be left higher on the beach is less stable with respect to the next oblique swash, and the one washed back down the beach is more stable. Thus we agree with Lever (1958) that swash and backwash are complementary in producing the sorting phenomenon. The mechanism described by Nagle (1964) is a part of this process.

EXPERIMENTAL RESULTS

This hypothesis for the R-L sorting was tested by field measurement of orientation by single waves, orientation of valves deposited on the beach by normal processes, and correlation of the sense of sorting with the direction of swash approach.

In order to determine the effect of single waves, we released right and left valves of *Eontia ponderosa* in the path of incoming waves and measured the orientation after the valves were deposited. The majority of shells were observed to be transported by both swash and backwash in that order. Thus their orientation should be stable with respect to the latter, and in fact it was (fig. 5a).

In order for a valve to be semipermanently deposited, rather than just dropped between

TABLE 2.—*Summary of counts from Kornicker and others (1963)*

Year	Month	Sense of Sorting	Right	Left	Neither	χ^2	Confidence Level
			Summer Regime				
1959	Apr.	R					
1959	Apr.	R					
1959	May	R					
1959	Jun.	R					
1959	Jun.	R					
1959	Jul.	L					
1959	Aug.	—	10	3	1	3.5	90–95%
1959	Aug.	R					
1959	Aug.	L					
1959	Sept.	R					
1960	May	L					
1960	Jun.	R					
1960	Jul.	R					
1960	Aug.	R					
			Winter Regime				
1959	Sept.	L					
1959	Sept.	L					
1959	Oct.	L					
1959	Nov.	L					
1959	Dec.	L					
1959	Dec.	L					
1958	Dec.	L					
1960	Jan.	L	2	12	1	7.7	99–99½%
1960	Jan.	L					
1960	Feb.	R					
1960	Mar.	—					
1959	Jan.	L					
1959	Feb.	R					
1959	Feb.	L					
1959	Mar.	L					

waves, it must be deposited high on the foreshore. This requires that it be carried to the upper limit of the swash so that the backwash does not have enough power to move the valve again. Thus naturally deposited valves should be stable relative to the swash or the lateral swing at its peak. The orientations of 868 valves found deposited on the upper foreshore were measured (fig. 5b). Although the orientation patterns for these valves are not as consistent as the patterns developed by single waves, these valves are generally stable with respect to the incoming swash as expected.

All preceding examples and measurements were made with the oblique waves approaching from the right as the observer faces the sea. This is from the south or southeast on Mustang and Padre Island beaches. With this direction of wave approach, right valves should be carried to the berm crest while left valves remain at the toe of the foreshore (fig. 4). An oblique approach from the left should produce the opposite sorting. The relative numbers of right and left valves on the upper foreshore were counted on several subsequent occasions under various directions of swash approach. The counts were correlated with direction of wave approach and longshore drift (table 1). All counts except one agree well with the sense of sorting predicted from the current direction either on the day of measurement or shortly preceding it. After a change in the direction of wave approach, the resorting from dominant left valves to dominant right valves and vice versa can occur in a period of from a few hours to a few days.

Data for Kronicker's (1963) counts do not include notes on the direction of wave approach or longshore drift at the time of counting, but the sense of sorting may be predicted on the basis of the time of the year each sample was taken. During the fall and winter months abundant northerly winds make it likely that waves will approach from the left as one faces the sea and that left valves will be deposited high on the berm. During the summer months strongly predominant south-southeasterly winds cause waves to approach from the right and right valves should be found high on the berm. Variation in the wind direction and thus sorting changes may occur in any season, but the close correlations between the predominant wind directions and the sense of sorting (table 2) is further supporting evidence for the mechanisms proposed.

CONCLUSIONS

We conclude that our evidence strongly supports the mechanism for R-L sorting of pelecypod valves suggested by Lever (1958) and Nagle (1964). The chief agent in this mechanism is oblique wave approach, which also causes longshore drift. The correlation between the mechanism and the results is well supported by field evidence. However, the sorting changes rapidly from R to L dominated, and the two sets of sorted valves are concentrated very close together at opposite ends of the swash zone. Thus very close control and very extensive counts are probably necessary in order to apply these findings to paleocurrent analysis. Furthermore, the valves of every species are somewhat different; and any additional species studied should be tested to determine their hydrodynamic behavior. Extinct species should be used with even more care, because, as Trusheim (1931) pointed out, the behavior of their valves may be altered by fossilization or diagenesis. Finally, the mechanism of differential sorting seems to restrict the phenomenon to the intertidal zone, and thus the effect may be used as an indicator of this environment.

ACKNOWLEDGEMENTS

We acknowledge with thanks Mr. J. S. Nagle for his discussions and criticism of the manuscript, and the Padre Island National Sea Shore Rangers for use of their cabin during part of the field work.

REFERENCES

Boucot, A. J., 1953, Life and death assemblages among fossils: Am. Jour. Sci., v. 251, p. 25–40.

Craig, G. Y., 1967, Size-frequency distributions of living and dead populations of pelecypods from Bimini, Bahamas, B. W. I.: Jour. Geology, v. 75, p. 34–45.

Kelling, Gilbert, and Williams, P. F., 1967, Flume studies of the reorientation of pebbles and shells: Jour. Geology, v. 75, p. 243–267.

Kornicker, L. S., and Armstrong, Neal, 1959, Mobility of partially submersed shells: publ. Inst. Mar. Sci., Univ. Texas, v. 6, p. 171–185.

Kornicker, L. S., Wise, C. D., and Wise, J. M., 1963, Factors affecting the distribution of opposing mollusk valves: Jour. Sedimentary Petrology, v. 33, p. 703–712.

Lever, J. A., 1958, Quantitative beach research I. the "left-right phenomenon": sorting of Lamellibranch valves on sandy beaches: Basteria, v. 22, p. 21–51.

Lever, J. A., van den Bosch, Marlies, Cook, H., van Dijk, T., Thiadens, A. J. H., and Thijssen, R., 1964, Quantitative beach research III, an experiment with artificial valves of *Donax vittatus:* Neth. Jour. Sea Research, v. 2, p. 458–492.

Martin-Kaye, P., 1951, Sorting of Lamellibranch valves in beaches in Trinidad, B. W. I.: Geol. Mag. [Great Britain], v. 88, p. 432–434.

Muelen, H. V. D., 1947, Nieuwe Gezechtspunten: Tet Zeepard, v. 7, p. 10–12.

Nagle, J. S., 1964, Differential sorting of shells in the swash zone: Biol. Bull., v. 127, p. 353.

———, 1967, Wave and current orientation of shells: Jour. Sedimentary Petrology, v. 37, p. 1124–1138.

Seilacher, Adolf, 1960, Stromungsanzeichen im Hunsruckschiefer: Wiesbaden, Notizbl. hess. Landesamtes Bodenforsch, v. 88, p. 88–106.

Trusheim, F., 1931, Versuche uber Transport und Ablagerung von Mollusken: Senckenbergiana, v. 13, p. 124–139.

Wobber, F. J., 1967, The orientation of *Donax* on an Atlantic coast beach: Jour. Sedimentary Petrology, v. 37, p. 1233–1235.