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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 29, NO. 4, PP. 596–601
FIGS. 1–3, DECEMBER, 1959

ANALYSIS OF FACTORS AFFECTING QUANTITATIVE ESTIMATES OF ORGANISM ABUNDANCE[1]

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ABSTRACT

Examination of the physical relationship between weight and volume sediment samples, and comparison of estimates of organism abundance obtained from equal volume and equal weight samples of recent sediment show that kinds of minerals forming the sediment have little effect on abundance distribution patterns determined by counting the number of specimens in samples of a given weight or volume, and that variation in sediment porosity probably is the major factor responsible for differences between organism counts based on equal weight samples and those based on equal volume samples.

Consideration of the diagenetic processes of compaction and cementation that affect organism abundance shows that for sediments, which have not been materially changed by processes such as intrastratal solution, replacement, and recrystallization, abundance counts from recent and ancient sediments are more comparable if clays and shales are reported on the basis of equal weight samples, and unlithified and lithified sands are reported on the basis of equal volume samples.

INTRODUCTION

Analyses of the distribution of the remains of dead organisms in recent sediments is strongly influenced by the method used to establish and report abundance counts. Comparisons of abundance counts from recent and ancient strata are affected by the composition of the sediment, its history, and the type of sample upon which counts are based.

The abundance of dead forms in recent sediments may be used to interpret past environments (Kornicker, 1957), to estimate relative sedimentation rates (Walton, 1955) and may serve as a basis for making comparisons with the abundance distribution of fossil organisms. Horizontal or vertical variation in fossil abundance may be useful in stratigraphic correlations (Ellison, 1951), and can be utilized in reconstructing conditions attending the depositional environment (Imbrie, 1955).

Counts of abundance of the remains of dead organisms from recent sediments usually have been expressed in terms of equal weight, equal dry volume, and equal wet volume samples (Schott, 1935; Parker, 1948; Said, 1950; Walton, 1955). Most abundance counts from ancient strata have been made on a weight basis (Ellison, 1951; Imbrie, 1955; Echols and Gouty, 1956).

[1] Manuscript received May 21, 1959.

This paper presents an attempt to explore the general relations between weight and volume sediment samples in order to determine the advantages and disadvantages of each type sample.

COMPARISONS OF ABUNDANCE COUNTS BASED ON VOLUME AND WEIGHT SAMPLES OF RECENT SEDIMENTS

The absolute density of minerals forming the major part of marine sediments does no vary greatly, and therefore mineral density has little effect on abundance distribution patterns determined by counting the number of specimens in samples of a given weight or volume. For example, if a sediment sample composed entirely of aragonite grains (specific gravity 2.94 gm/cc) contains the same number of organisms as a sample composed entirely of montmorillonite (specific gravity 2.4 gm/cc) and both samples have the same porosity and volume, the number of organisms recorded in the two samples would differ by only about 14 percent, providing the counts were made from equal weight samples (See table 1 for additional examples). Mineral density would have no effect on abundance estimates made from equal volume samples.

Porosity (volume percentage of pore space) of recent marine sediments varies considerably. Porosity is dependent on pack-

TABLE 1.—*Comparison of the number of specimens from equal volume and equal weight hypothetical sediment samples composed of different minerals*

Composition of sediment	Mineral density grams per cc	Number of specimens per cc[a]	Number of specimens per gram[b]	Difference in number of specimens
Aragonite	2.94	100	34	66
Calcite	2.72	100	37	63
Dolomite	2.87	100	35	65
Montmorillonite	2.4	100	42	58
Illite	2.6	100	38	62
Average clay	2.7	100	37	63
Quartz	2.66	100	38	62

[a] One hundred specimens per cc is hypothetical and chosen only for the purpose of the table.
[b] Number of specimens per one gram was obtained by dividing the number of specimens per cc (100) by density of mineral composing the sediment. Calculation based on hypothetical porosity of 0 percent.

ing, shape and uniformity of grains, and grain size. The porosity of coarse sand is usually 35 to 40 percent, whereas freshly deposited clay may have a porosity of 50 percent or higher (Pettijohn, 1949, p. 69, 277). Mississippi delta mud, according to Meinzer (1923, p. 8), has a porosity ranging from 80 to 90 percent. Shaw (1915, p. 1415) found the porosities of mud deposits on the sea coast to range from 40 to 90 percent. Terzaghi and Peck (1948, p. 29) reported a soft slightly organic clay having a porosity of 66 percent and a soft very organic clay with a porosity of 75 percent. Walton (1955, p. 992) collected a sediment from station B-45 in Todos Santos Bay having only 4.28 grams total dry weight in a volume of 10 cubic centimeters of wet sediment. If a density of 2.7 grams per cubic centimeter is assumed for the solids in this sample, the porosity would be roughly 84 percent.

The relationship between the number of organisms per dry weight of sample and per volume of sample is shown by the following equation:

$$X_{dw} = \frac{100\, X_v}{\rho(100-P)} \qquad (1)$$

where X_{dw} is the number of organisms per gram of dry sediment, X_v is the number of organisms per cubic centimeter of sediment, P is porosity of sediment, ρ is the grain density in grams per cubic centimeter. The sample may be in dry or wet state when volume is determined, but dry porosity must be used with dry volume and wet porosity with wet volume. By using the above equation a graph was constructed from which the number of organisms per gram of dry weight may be determined directly from the number of organisms per cubic centimeter of sample, providing the grain density of the sample is 2.7 grams per cubic centimeter and the porosity of the sample is known (fig. 1). The number of individuals per sample are identical when based on either weight or volume only when the porosity of the sediment is 63 percent. If the porosity of a sediment is above 63 percent, counts based on weight are higher than counts based on

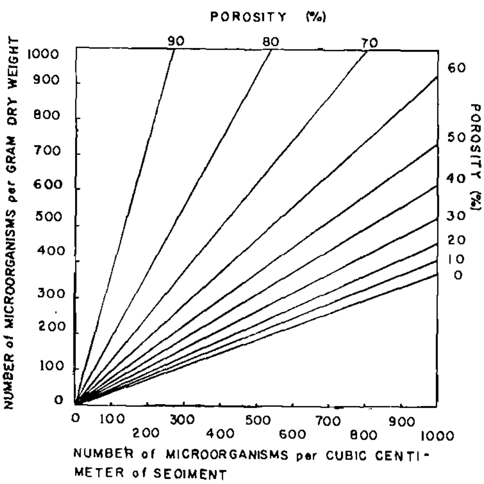

FIG. 1.—Theoretical relationships between the number of organisms per cubic centimeter and gram dry weight of sediment. Wet porosity is used with samples based on wet volume. Dry porosity is used with samples based on dry volume. A density of 2.7 gm/cc has been assumed for sediment grains in the construction of this graph.

TABLE 2.—*Comparison of abundance counts based on volume and dry weight hypothetical sediment samples having different porosities*[a]

Porosity of sediment %	Number of organisms per 1 cc[b]	Number of organisms per 1 gram dry weight[c]
30	500	265
50	500	370
84	500	1150

[a] Absolute density of 2.7 grams per cc is assumed for mineral composing sediment.
[b] Number microfauna per cc is hypothetical and assumed expressly for the purpose of this table.
[c] Values obtained from figure 1.

volume. If porosity is below 63 percent, counts based on weight are lower than counts based on volume.

Variation in sediment porosity probably is the major factor responsible for differences between organism abundance counts based on equal weight samples and those based on equal volume samples. Hypothetical microorganism counts based on volume and dry weight sediment samples having different porosities are compared in table 2.

COMPARISON OF ABUNDANCE COUNTS BASED ON WET AND DRY RECENT SEDIMENT SAMPLES OF EQUAL VOLUME

The volume occupied by a given weight of a sediment is affected by the manner of packing of the grains. Clays, or clayey sediments shrink upon drying and, therefore, the volume of a given weight of dry clay is less than the volume when the clay was in a wet state. However, if the dried clay is pulverized, its volume is likely to increase. Athy (1930) and Frazer (1935) have demonstrated that the volume of some sands deposited in water can be reduced 11 to 13 percent by compaction and jarring.

The relationship between the number of organisms in wet and dry samples of equal volume is shown by the following equation:

$$X_d = \frac{X_w(100-P_d)}{(100-P_w)} \quad (2)$$

where X_w is the number of organisms per cubic centimeter of wet sediment, X_d is the number of organisms per cubic centimeter of dry sediment, P_d is the porosity of the dry sediment, and P_w is the porosity of the wet sediment.

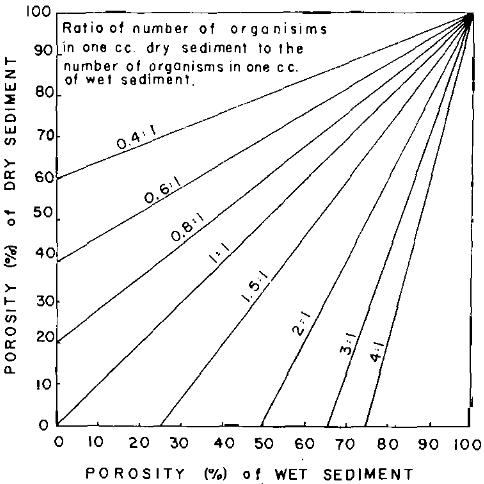

FIG. 2.—Theoretical relationship between the number of organisms in a unit volume of wet and dry sediment.

This equation has been plotted graphically in figure 2. From this graph the number of organisms per cubic centimeter of wet sediment may be obtained from the number of organisms in one cubic centimeter of dry sediment, providing the wet and dry porosities are known. Organism abundance from hypothetical wet and dry samples of equal volume are compared in table 3.

TABLE 3.—*Comparison of organism counts based on wet volume and dry volume hypothetical sediment samples having various wet and dry porosities*

Wet porosity (%)	Dry porosity (%)	Number organisms per 1 cc wet volume[a]	Number organisms per 1 cc dry volume[b]
30	30	500	500
30	15	500	605
30	10	500	650
50	50	500	500
50	25	500	750
50	10	500	900
84	42	500	1800
84	10	500	2800

[a] Five hundred specimens per one cc is hypothetical and chosen only for the purpose of the table.
[b] From figure 2.

DIAGENETIC PROCESSES AND THEIR EFFECT ON ABUNDANCE COUNTS

Diagenetic processes that lead to lithification are compaction, cementation, intrastratal solution, authigenesis and metasomatism (Pettijohn, 1948, p. 477).

Compaction.—As soon as sediment is buried it is subjected to compaction and attendant water loss. According to Athy (1930, p. 8) clay probably assumes an average porosity of about 50 percent after the accumulation of an overburden a few tens of feet in thickness although the surface clays may vary from 50 to 90 percent in porosity.

Compaction of sand is relatively small (see Pettijohn, 1948, p. 69; Athy, 1930, p. 8; Trask, 1931, p. 274; Fraser, 1935, p. 942). Calcareous or sandy shale compaction is comparable with pure shales (Athy, 1930, p. 9). Weller (1959) has pointed out that the uncrushed condition of empty shells in limestones indicates that very little compaction occurs in limestones. Trask (1931, p. 274) has shown experimentally that colloids are compacted more than clays, clays more than silts and silts more than sands.

Compaction will have little effect on abundance counts reported from equal weight samples. Compacted sediment will contain more specimens than the same volume of uncompacted material. An approximation to the number of specimens per sample present on ancient depositional surfaces may be realized from determinations of the abundance of fossil organisms in compacted sediments providing initial and present porosities are known (equation 1).

$$x = \frac{y(100-P)}{(100-P_c)} \quad (3)$$

where y is the number of specimens in unit volume of sample of compacted sediment, P_c is the porosity of compacted sediment, P is the original porosity of sediment, and x is the number of specimens in the same unit volume of sediment when in previous position on the sea floor.

Example: If

$y = 500$ Foraminifera per 10 cc of compacted sediment

$P_c = 10\%$

$P = 50\%$ (estimated)

then

$$x = \frac{500(100-50)}{(100-10)}$$

$= 278$ Foraminifera per 10 cc of sediment before compaction

In general, the porosity of clay and shale is a function of depth of burial. Athy (1930, p. 13) has related porosity and depth of burial in equation (4).

$$P = p(e^{-bx}) \quad (4)^{2}$$

where P is porosity, p is the average porosity of surface clays, b is a constant, and x is the depth of burial.

As the decrease in porosity is principally the result of a decrease in volume, it is possible to predict the theoretical increase in number of specimens per unit volume due to compaction at depth (fig. 3). According to these data, the number of specimens of microfauna per unit volume of clay at the surface would increase by 40% at a depth of 1000 feet and 80% at a depth of 6000 feet as a result of compaction.

Porosity has been found to decrease when a sediment is deformed. Rubey (1930, p. 36) expressed the relationship of porosity and deformation in equation (5).

$$P_u = 100 - \cos d(100 - P_p) \quad (5)$$

where P_u is porosity of untilted rock, d is present angle of dip, and P_p is present porosity.

The number of specimens per unit volume of sediment would theoretically be increased about 8 percent in rock dipping 4–5 degrees, and as much as 20 percent with steeper dips.

Cementation.—Although compaction of sands is negligible, cementation, caused by the addition of a cementing material in pore spaces, is commonplace. As an illustration the average sand has a porosity of 35 to 40 percent, whereas the average sandstone has a porosity of 15 to 20 percent (Pettijohn, 1948, p. 69). In contrast relatively little cementation occurs in shales (Athy, 1930, p. 9). According to Weller (1959) the consolidation of most limestones is probably the result of cementation. Pore filling by a secondary mineral that causes a decrease in rock porosity increases the weight per unit volume. Therefore the number of specimens will be lower in a unit

[2] For recent discussion of this equation, the reader is referred to Weller (1959).

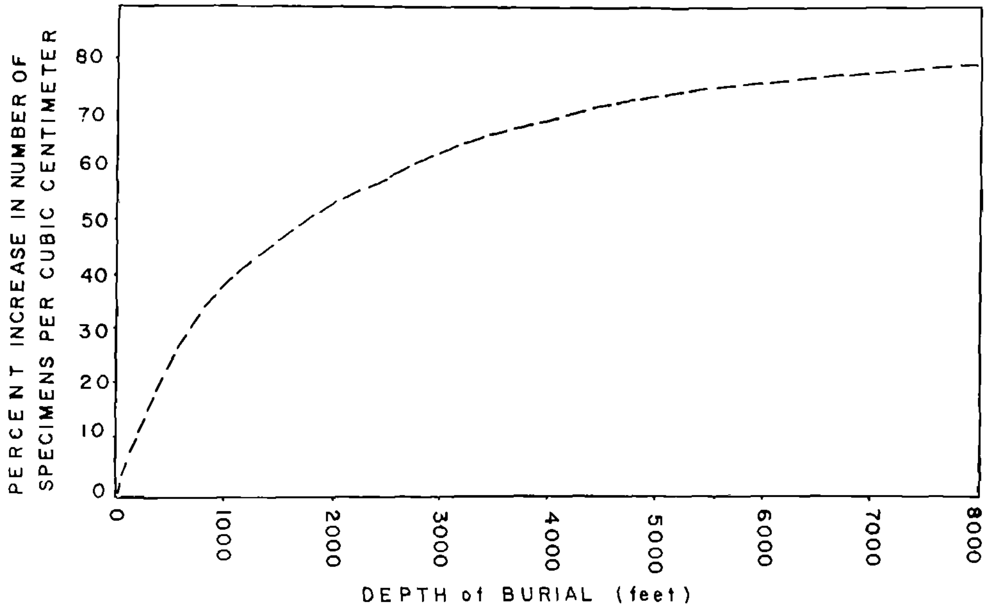

FIG. 3.—Theoretical increase in the number of organisms per unit volume of clay caused by compaction at depth. The curve is based on porosity changes at depth given by Athy (1930).

weight of cemented sediment than in a unit weight of uncemented sediment.

Intrastratal Solution.—Intrastratal solution will generally decrease the number of microorganisms per sample regardless of the sample base because the fragile carbonate shells of Foraminifera and Ostracoda are destroyed quite easily. Siliceous Foraminifera, conodonts, and fish remains may be more resistant. In the Florena Shale of Kansas, for example, only siliceous Foraminifera are found in the upper part of many vertical sections, although both calcareous and siliceous forms occur in the lower part. This distribution may be partially the result of intrastratal solution in the upper part of the sections. Occasionally, siliceous minerals are dissolved and replaced by calcite, but this is considered exceptional (Pettijohn, 1948, p. 492).

Authigenesis.—The formation of new minerals in place is usually termed authigenesis (Pettijohn, 1948, p. 478). Aragonite deposited on the sea floor usually converts to calcite in a relatively short time with a decrease in density from 2.94 to 2.72 grams per cc. Montmorillonite is converted to illite with an increase in density from 2.4 to 2.6 grams per cc. Replacement and recrystallization may or may not destroy all or part of the organisms. However, assuming that the organisms are not destroyed, the number of specimens per sample, on a weight basis, will be affected only slightly by change in density of the enclosing sediment (*see* table 1).

Where deformation, recrystallization, replacement, or intrastratal solution have removed some of the organisms, reliable reconstruction of the original number of individuals is not possible unless special conditions of preservation are known to have occurred such as preservation within chert nodules.

CONCLUSIONS

1. A study of the quantitative distribution of dead organisms in recent sediment is strongly influenced by the method used to establish and report abundance counts, unless the porosity of the sediments in the sampling area is fairly uniform or unless the areal variation in abundance of individuals is sufficiently large to minimize porosity variation.

2. Abundance counts from shale will be more comparable with counts from recent clays if both are reported from equal weight samples. Abundance counts from cemented sand will be more comparable with counts from recent sands if both are reported from equal volume samples. The tendency for limestones to become consolidated by cementation rather than by compaction suggests that abundance counts from limestones will be more comparable with counts from recent carbonate sands if both are reported from equal volume samples.

3. The difference between the volumes occupied by sediment in a wet or dry state may be inconsequential for sands but considerable for clays and other fine grained sediment. The impracticality of basing abundance counts on wet samples of ancient strata makes the wet volume sample, which is currently being used extensively as the basis for abundance counts of dead microorganisms in recent sediments, least useful for comparing recent and fossil abundances.

ACKNOWLEDGMENTS

This study was made as part of a research program on the living ostracodes in Texas bays which is being supported by a grant (NSF-G 5473) from the National Science Foundation. The manuscript has been criticised by Drs. Samuel P. Ellison, M. Hanna, K. T. Turekian, C. H. Oppenheimer, and Edward G. Purdy.

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