JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 45, NO. 1, P. 105–112
FIGS. 1–8, MARCH 1975

UPPER CRETACEOUS RESEDIMENTED CONGLOMERATES AT WHEELER GORGE, CALIFORNIA: DESCRIPTION AND FIELD GUIDE[1]

ROGER G. WALKER
Department of Geology, McMaster University, Hamilton, Ontario, L8S 4M1, Canada

ABSTRACT: A field map and measured stratigraphic sections revise the geology of Wheeler Gorge. There are three layers of conglomerate, each of which passes upward into massive sandstones, classical turbidites, and/or dark mudstones with thin distal turbidites. Clast long axis orientation on conglomerate layers 1 and 3 gives vector means of 282 and 287 degrees respectively. This agrees closely with flutes (285) and grooves (279) on layer 1, and hence gives a paleocurrent direction for layer 3 for the first time.

The conglomerates do not contain as much inverse grading as has previously been suggested, and none of the conglomerates is stratified. Inverse grading was measured in one bed, indicating a continuous upward coarsening of both the smaller and larger clasts in the population. The Wheeler Gorge conglomerates do not fit precisely with the three generalized models of conglomerates recently proposed by Walker, but are closest to the "disorganized-bed" model.

OBJECTIVES

The section of Upper Cretaceous conglomerates and sandstones at Wheeler Gorge, Ventura County, California, has become one of the classic locations for detailed examination of the features of deep-water, resedimented conglomerates and coarse sandstones. This is because of the clean three-dimensional outcrops, easy accessibility, and two excellent published descriptions by Rust (1966) and Fisher and Mattinson (1968).

One purpose of this paper is to present a sketch map of the gorge, together with revised measured sections that indicate fault repetition within the section published by Fisher and Mattinson (1968). I am indebted to Fisher for his help in examining my field sketch map (Fig. 1). He pointed out (personal communication, 1973) that the area near C (Fig. 1) "had a heavy cover of brush and was partly covered with alluvium" in 1967, hence obscuring the stratigraphic relationships. This part of the gorge is now (1974) clean and well exposed.

Another objective is to check the usefulness of clast orientation studies in the determination of paleoflow direction—this is particularly easy because the base of the lowest conglomerate displays flute casts, groove casts, and a well-developed clast orientation. The internal details of the conglomerates—fabric, grading and stratification—are compared with the generalized conglomerate models set up by Davies and Walker (in press) and Walker (in press), and a method for quantifying inverse grading is investigated.

MAP AND MEASURED SECTIONS

A map of Wheeler Gorge is shown in Figure 1. The northern tunnel is 21.2 miles north of the Ventura Freeway exit on California Highway 33, and 7.7 miles north of the intersection of Highways 33 and 150 in Ojai. There is space for parking about one hundred yards north of the northern tunnel, and one can scramble down into the gorge at the parking area, or at the access points shown on the map. Most of the walls of the gorge are nearly vertical, and rise for several hundred feet above the Ventura River. The river is normally little more than a trickle, and all the patterned areas of the map are accessible except in the gorge at the location F. Here, one can either wade, or use the path to the west.

The rest of the map is self-explanatory, except at B, where the 40 degree dip of the fault carries it beneath the overhanging nose of conglomerate.

[1] Manuscript received, May 16, 1974; revised September 4, 1974.

ate Geological Survey
rsity of Kansas, Law-
69–85.
. K. WALTON, 1962,
thems: a quantitative
succession in the East
ientology, v. 1, p. 235-
. K. WALTON, 1967,
Developments in Sedi-
Amsterdam, 271 p.
ical Methods for Re-
and Boyd, Edinburgh,
Statistical Tables for
nd Medical Research,
d, Edinburgh, 146 p.
WN, 1965, The use of
vironmental interpreta-
Geology, v. 73, p. 510-
ific Methods in Anal-
w-Hill, New York, p.
iced Theory of Statis-
521 p.
ultivariate Statistical
New York, 338 p.
ure and sedimentology
erous of the upper
ian Mountains, Spain:
p. 603–703.
TTER, AND R. SIEVER,
nes, Springer-Verlag,
WALLIS, 1956, Statis-
e Free Press, Illinois,
sedimentation of the
e vicinity of Molteno,
Univ. Stellenbosch, v.
origin and deposition
he Indwe area of the
ince: unpubl. M.Sc.
Witwatersrand, 143 p.
application of statisti-
a limestone-shale se-
72, p. 195–213.
tratigraphy and sedi-
Molteno Stage in part
ovince: unpubl. M.Sc.
Witwatersrand, 195 p.
of the Molteno sedi-
on, S. H. (ed.): Proc.
on Gondwana Stratig-
, Cape Town and
Pretoria.
imentation time-trend
ation for correlation
Jour. Geology, v. 69,

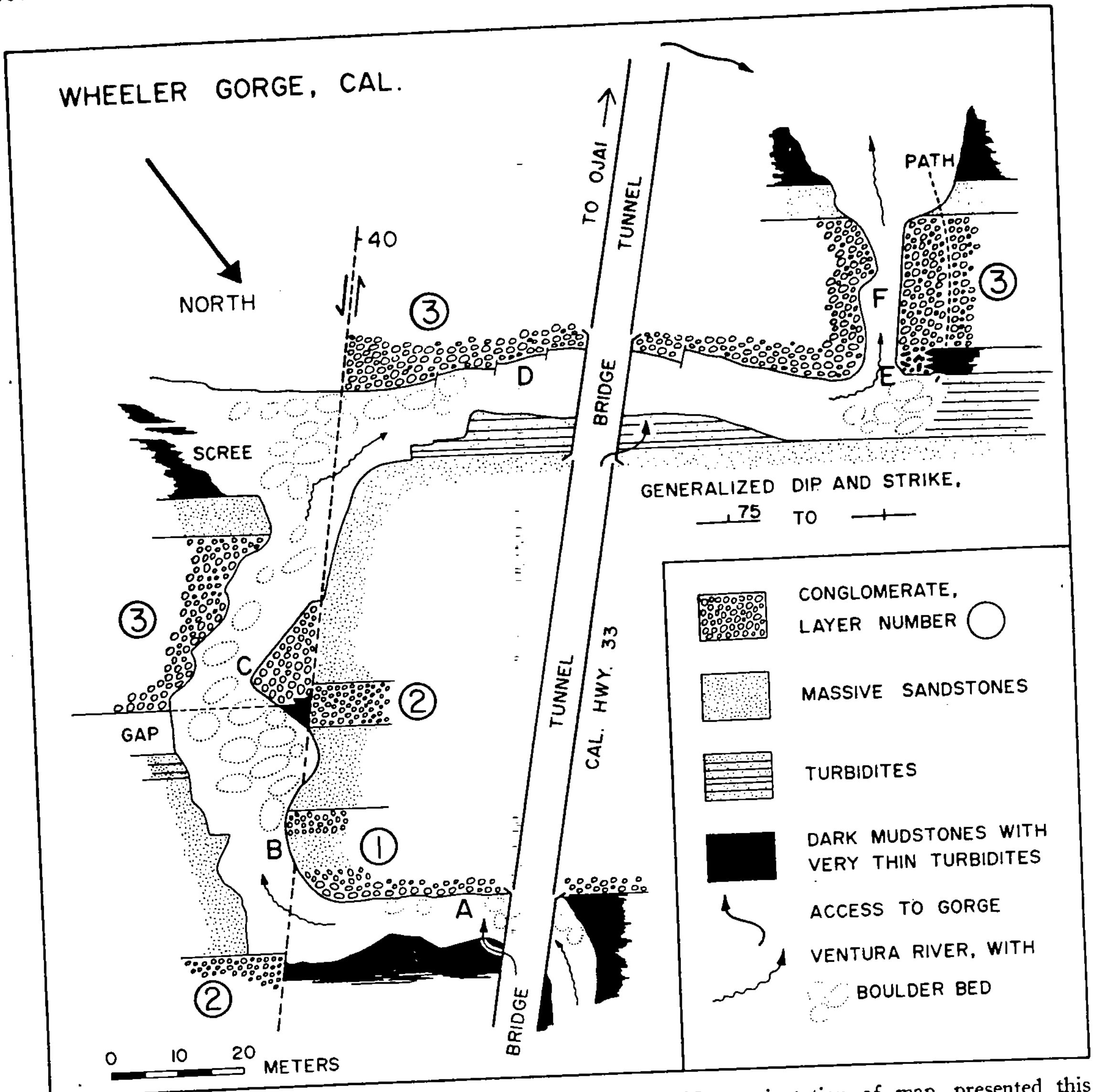

FIG. 1.—Map of Wheeler Gorge, Ventura County, California. Note orientation of map, presented this way for ease of use in the field. Letters and numbers explained in text. At D, base of conglomerate layer 3 is offset by many small faults that trend roughly parallel to the large fault 40 m east of the highway.

Stratigraphic sections were measured wherever possible, and are shown in Figure 2. The long column was measured in the easternmost stretch of the gorge, meters 1–32 on the west bank (B on map), and meters 32–105 on the east bank, from the stream corner at layer 2 to the scree shown on the map. The shorter column was measured below the southern bridge (45–70 m), and along the path south of letter E (70–105 m).

My conglomerate layer 1 is exactly equivalent to Fisher and Mattinson's (1968, Fig. 3) units 1 and 2a. My layer 2 was not recognized by Fisher and Mattinson, and my layer 3 is equivalent to Fisher and Mattinson's unit 4a and b, and also to their unit 6. It is now clear from excellent exposures in the gorge that their unit 6 is a fault repeat of units 4a and b.

The conglomerates appear abruptly as an unnamed 100 m unit within some 700 m of dark mudstones containing distal turbidites. These mudstones are bounded to the north by the Santa Ynez fault, and are overlain unconformably by middle Eocene rocks to the south. The

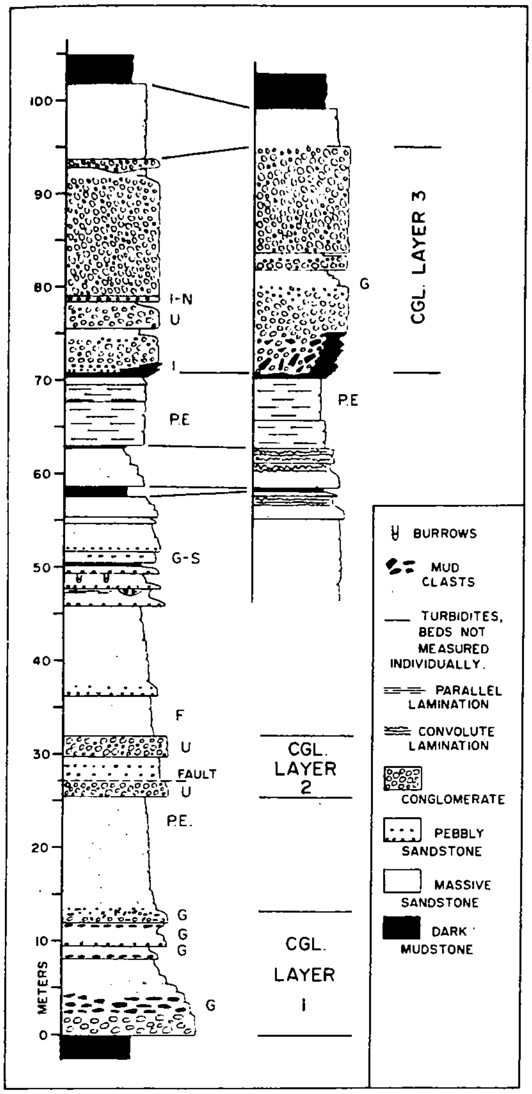

FIG. 2.—Measured sections of the conglomerate-turbidite series in Wheeler Gorge. See text for exact locations of sections. I-N, inverse to normally graded; U, ungraded; I, inverse grading; P.E., poorly exposed; G-S, graded and stratified; F, fractured; G, normally graded.

area has been mapped by Rust (1966), who discusses earlier work in the area.

FACIES

The map and measured sections depict four main facies; conglomerates, coarse massive sandstones, turbidites (alternations of fine sandstones and mudstones), and dark mudstones containing thin graded siltstones (distal turbidites).

FIG. 3.—Basal portion of first bed in conglomerate layer 1, near location A on map (Fig. 1). Note absence of inverse grading. Top to left.

Conglomerates

Conglomerates are essentially restricted to the three layers shown on the map. Layer 1 is composed of four main "beds," but because of amalgamation of units, and abundance of large mudstone clasts, defining "beds" is somewhat subjective. In the beds of layer 1 sketched in Figure 2, there appears to be neither inverse grading, nor stratification other than the sub-horizontal orientation of the mudstone clasts. The basal portion of the lowest bed near A (Fig. 1) is shown in Figure 3. In this part of the gorge, the base can be seen to cut at least 2.25 m into the underlying dark mudstones.

The observation that there is no inverse grading differs from that of Fisher and Mattinson (1968, p. 1014), who note that "each conglomerate bed is inversely graded, starting at the base with a thin basal zone of sandstone or pebbly sandstone which abruptly grades upward to "conglomerate." The difference of opinion may derive from differing definitions of "beds" within the sequence, and differing interpretations of contacts that "abruptly grade

FIG. 4.—Base of conglomerate layer 3 at location E on map (Fig. 1), showing large incorporated mudstone clasts. Photo is taken immediately adjacent to the erosional channel margin (partly under vegetated cover). Top to right.

upward." The problem of inverse grading is discussed in a separate section below.

The conglomerates of layer 2 are not very well exposed. The lower bed (at 26 m, Fig. 2) is brecciated by a small bedding plane fault, and contains rather dispersed, well-rounded clasts, without any sign of inverse or normal grading. The upper conglomerate bed is not graded, except at the very top where there is a rapid passage into coarse sandstones.

Layer 3 contains the thickest conglomerate beds in the section. The base of the layer cuts at least 3 m downward into dark mudstones (71–74 m, Fig. 2), breaking large (1.9 × 0.65 m) mudstone clasts from the wall (Fig. 4), and injecting conglomerate into bedding planes in the mudstone (E, Fig. 1). This contact was excellently described by Fisher and Mattinson (1968, p. 1016–7); the same contact, with at least 1 m of erosion, can be seen near location C, Fig. 1. At this point, inverse grading is well developed and will be discussed below. The layer is 25–30 m thick, but is composite (see Fig. 2). This can be seen along the path (west of F, Fig. 1), and on both sides of the stream at location C. Impersistent sandstone layers at about 78 m can be seen to be eroded by overlying conglomerates. Inverse grading is restricted to the base at location C, and to the layer at 79 m (Fig. 5). Because of poor, mud and slime-covered outcrop, it is not certain whether the conglomerate from 82 to 90 m (long stratigraphic section, Fig. 2) is a single bed. In the short section, the bed from 84 to 95 m appears to be a single bed, without any overall grading.

These three conglomerate layers do not fit very well with the generalized models for resedimented conglomerates recently proposed by Walker (in press) and Davies and Walker (in press). These three models are (a) *disorganized-bed* (no grading, no stratification, normally no strongly preferred fabric); (b) *inverse-to-normally graded*, characterized by inverse and normal grading, without stratification; and (c) *graded-stratified*, characterized by absence of inverse grading, and presence of normal grading and stratification. The Wheeler Gorge conglomerates are not stratified, and in my opinion, only two individual beds have unequivocal inverse grading. The dominant structure is normal grading without stratification, or disorganized-bed (lacking normal and inverse grading, and stratification).

Coarse Massive Sandstones

Above the three conglomerate layers are sequences of coarse, massive sandstone. The conglomerate at 12 m (Fig. 2) grades up into a 7-m thick sandstone—the lower 2 m contains pebble- and granule-grade material, but the upper 5 m is an ungraded medium sandstone. The whole 7 m appears to be one bed, without evident sedimentary structures.

The sandstones immediately above conglomerate 2 are fractured, but the 9-m sandstone from 37 to 46 m is not fractured and appears to be a single bed. The basal 30 cm of the bed contains pebbles up to 2 cm; the bulk of the bed is coarse and medium sandstone without sedimentary structures. The best exposures of

e incorporated mud-
rtly under vegetated

layers do not fit
ed models for re-
ently proposed by
s and Walker (in
are (a) *disorga-*
ratification, nor-
fabric); (b) *in-*
haracterized by
vithout stratifica-
ed, characterized
and presence of
on. The Wheeler
stratified, and in
al beds have un-
dominant struc-
ut stratification,
normal and in-
n).

lstones

ate layers are
sandstone. The
grades up into
er 2 m contains
aterial, but the
dium sandstone.
ne bed, without

above conglom-
9-m sandstone
ed and appears
cm of the bed
he bulk of the
dstone without
t exposures of

FIG. 5.—Inverse to normally graded bed (with notebook) at 79 meters in Figure 2. Face is cut roughly parallel to flow direction—note absence of imbrication. In bed below the inverse to normally graded one, note chaotic fabric with large clasts almost on end.

thick sandstones with sedimentary structures are between 46 and 58 m. These pebbly sandstones are graded, and variously contain parallel lamination, convolute lamination, dubious dish structure, burrows and layers of mudstone clasts. There are no shales between individual sandstones.

The sandstones above conglomerate 3 consist of several individual beds, with well-developed thick zones of parallel lamination (path west of location F). Below the scree (Fig. 1), the same sandstones are in beds 0.60 to 1.50 m thick, and display both parallel and convolute lamination.

Turbidites

The only exposures of "classical" turbidites—alternating graded sandstones and shales—occur between 63 and 70 m, in the stream bed below the southern bridge, and in the steep gully northwest of location E. Individual beds approach 1 m in thickness although most beds are thinner than 0.5 m. Most are graded, and many display parallel and convolute lamination. Grooves oriented 102–282 degrees were observed on the base of one bed.

Dark Mudstones

Dark gray to black thinly laminated mudstones characterize the section above and below the 100-m sandstone-conglomerate sequence, and occur uncommonly within the sequence (Fig. 2). The mudstones contain thin (1–10 cm, average about 2–5 cm) siltstone layers which have sharp bases, and may be either massive and sharp topped, or ripple cross-laminated. The ripples invariably suggest a westward flow direction. The siltstones are extensively bioturbated, with both vertical burrows and horizontal trails and/or burrows. The dark mudstones with thin siltstones are interpreted as a classical distal turbidite facies (Walker and Mutti, 1973).

FINING- AND THINNING-UPWARD SEQUENCES

The entire 100-m interval can be divided into three overall fining- and thinning-upward sequences, 0–25.50 m, 25.50–70.50 m, and 70.50 to 105 m. The first sequence grades from conglomerates to medium sandstone, and although the grain size becomes finer upward, individual beds do not become thinner upward. The second sequence (25.50–70.50 m) is the best developed, with a progressive change from conglomerates upward into thick massive sandstones, thinner massive sandstones, classical turbidites with interbedded shales, and finally into dark mudstones. The third sequence grades from massive conglomerates abruptly into thickbedded massive sandstones, and then abruptly into dark mudstones.

Progressive sequences that thin and fine upward have been noted in other turbidite formations, (Wood and Smith, 1959; Warren, 1963, 1964; Kimura, 1966). The most detailed work has been done in Italy, notably by Curcio, Pranzini and Sestini (1968), Sestini (1970), Mutti and Ricci Lucchi (1972) and Mutti and Ghibaudo (1972). The Italian workers, particularly Ricci Lucchi (personal communication, 1974), emphasize that the fining- and thinning-upward sequences can be seen to occupy broad channels up to 1 km wide, and they relate the sequences to progressive abandonment of channels in the mid-fan areas of submarine fans (Mutti and Ghibaudo, 1972; Walker and Mutti, 1973). Mutti and Ghibaudo (1972, Table II) go as far as comparing the turbidite fining-

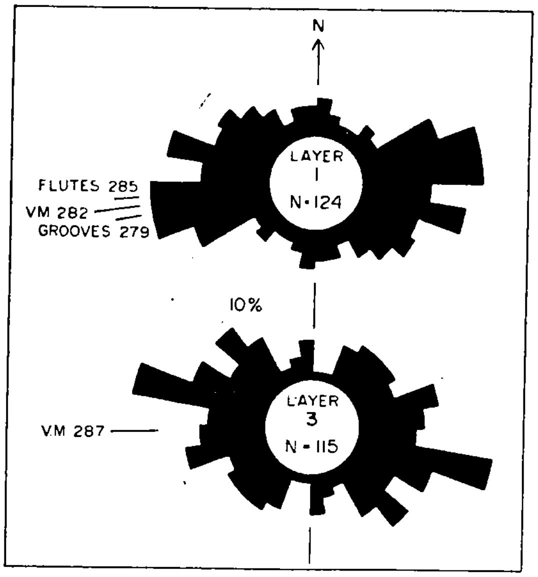

FIG. 6.—Clast long axis orientations on bases of layers 1 and 3. Note the close relationship between clast vector mean and flute and groove directions on layer 1.

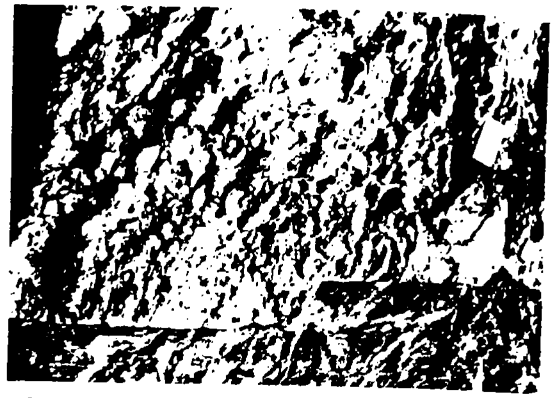

FIG. 7.—Base of layer 3 at location C, Figure 1. Note conglomerate cutting down to left (below note book) and inverse grading (measured in Figure 8).

upward sequence with that of alluvial and delta-plain environments, but I believe this comparison to be misleading. In the fluvial channel, the best developed fining-upward sequences are developed in active channels (as opposed to neck cut-offs), in which progressive lateral migration of point bars, or progressive reduction in flow (chute cut-off) give rise to the sequences. By contrast, on a submarine fan, there is no continuous flow of turbidity currents down the channels, and hence no strong theoretical reason why successive currents using a channel should deposit finer materials in thinner beds. The grain size and current volume will be strongly influenced by events in the source area rather than in the channel.

In the present example, exposures along the Santa Ynez Fault are essentially two-dimensional, and there is no outcrop evidence that the Wheeler Gorge conglomerates are channelized. I do not believe that the turbidite fining-upward sequence is sufficiently well understood to assign the Wheeler Gorge deposits to a channel—the fining-upward could equally well reflect gradual diminution of supply in the hinterland, giving rise to progressively finer-grained and smaller flows.

PALEOCURRENT DIRECTIONS

Rust (1966, p. 1396) has shown that the principal paleoflow direction for the conglomerates (Wheeler Gorge and the area stretching 10 miles to the east) was toward the west and northwest. The base of layer 1 above the northernmost tunnel bears large (up to 1 m long) flute casts indicating flow toward 285 degrees. At location A on the map, grooves with pebbles in the ends indicate flow toward 279 degrees, and in the gully northwest of location E, grooves indicate flow toward 282 degrees.

It has been demonstrated by Davies and Walker (in press) and Walker (in press) that in some resedimented conglomerates, the clasts show a strong preferred orientation, with long axes parallel to paleoflow direction. To check the fabrics on the bases of layers 1 and 3, a series of photographs was taken, and the long axis orientations of clasts were measured. Because of the limited number of clasts showing on the base of layer 1, they could not be measured on traverse lines across the photographs (see Davies and Walker, in press). Instead, the prints were divided into one-inch squares, and each square was carefully searched for *all* elongate clasts.

The results are shown in Figure 6. The vector mean for layer 1 (282 degrees, standard deviation 23 degrees) is very close to the flutes and grooves on the base of the bed, confirming that the clasts are aligned dominantly parallel to flow. Using this evidence, the vector mean of 287 degrees (standard deviation 30 degrees) for layer 3 is interpreted as indicating flow toward 287 degrees for this layer. It is unfortunate that there are no surfaces exposed in the gorge parallel to this flow direction, on which imbrication might have been investigated. The surfaces closest to the ideal orientation are

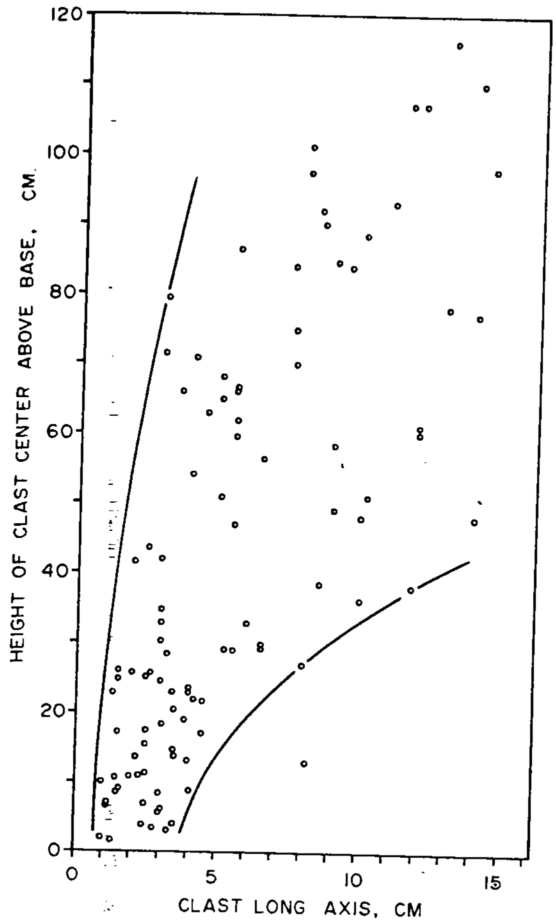

FIG. 8.—Graph of clast long axis (cm) against height of clast center above base of bed, for base of layer 3 at location C (Fig. 1)—see Figure 7. Graph is explained in text.

in layer 3 north of the scree (Fig. 1), but they show no preferred fabric—indeed, many clasts appear to stand sub-vertically (Fig. 5).

The only other orientation observed in Wheeler Gorge was a groove on a turbidite at about 68 m (N.W. of location E). It trended 102–282 degrees, very close to the vector mean clast orientation for conglomerate layer 3 (287 degrees).

INVERSE GRADING

Fisher and Mattinson (1968, p. 1014) noted that "each conglomerate bed is inversely graded, starting at the base with a thin basal zone of sandstone or pebbly sandstone which abruptly grades upward to conglomerate." In my opinion, inverse grading is not as abundant as this statement implies; the difference of opinion may depend upon how "grading" is defined. Grading ideally implies a *progressive* change of size upward from the base of the bed. If there are *abrupt* changes of size, the "grading" may not imply continuous deposition from one flow, but amalgamation of different flows. The interpretation of grading in these two cases would be very different.

It has recently been stressed (Walker, in press) that quantification of grading and inverse grading is important, and an example was given from the Wheeler Gorge conglomerates. Inverse grading was measured at location C, in the lower 1.20 m of layer 3 (Fig. 7), and the results of clast size versus distance of the clast center above the base are shown in Figure 8. The two curves show that inverse grading is present in both the small and large clasts: the use of such a diagram in basin analysis is discussed fully by Walker (in press).

In terms of flow mechanics, the scarcity of inverse grading at Wheeler Gorge implies that flows were not highly concentrated, and that dispersive pressure between the clasts was not important during the last stages of transport (Walker, in press). The implication is that slopes were not very steep at the Wheeler Gorge location, and the prediction is that if the conglomerates could be traced eastward, more beds with inverse grading would appear, and the sandy portions of the section would disappear. This prediction cannot be tested, because the closest Upper Cretaceous outcrops are about 35 miles to the east, in the Simi Hills, where massive sandstones and pebbly sandstones (probably unrelated to the Wheeler Gorge rocks) crop out.

ACKNOWLEDGMENTS

I am indebted to Dick Fisher for examining my field map, and Don McCubbin for helping record the inverse grading data. The work was done whilst I was on sabbatical leave as Visiting Scientist at the Denver Research Center, Marathon Oil Company, and I thank the Company for making their facilities available to me. The work was funded by the National Research Council of Canada, and the manuscript was improved by the comments of Don McCubbin and David MacKenzie.

REFERENCES

CURCIO, M., G. PRANZINI, AND G. SESTINI, 1968, Stratimetria di una serie del Macigno (Oligocene, Appennino Tosco-Emiliano): Boll. Soc. Geol. Italia, v. 87, p. 623–641.

DAVIES, I. C., AND R. G. WALKER, in press, Transport and deposition of resedimented conglomerates: the Cap Enragé Formation, Cambro-

Ordovician, Gaspé, Québec: Jour. Sed. Petrology, v. 44, p. 1200–1216.

Fisher, R. V., and J. M. Mattinson, 1968, Wheeler Gorge turbidite-conglomerate series; inverse grading: Jour. Sed. Petrology, v. 38, p. 1013–1023.

Kimura, T., 1966, Thickness distribution of sandstone beds and cyclic sedimentations in the turbidite sequences at two localities in Japan: Bull. Earthquake Res. Inst., Tokyo, v. 44, p. 561–607.

Mutti, E., and G. Ghibaudo, 1972, Un esempio di torbiditi di conoide sottomarina esterna: le arenarie di San Salvatore (Formazione di Bobbio, Miocene) nell' Appennino di Piacenza: Mem. Acc. Sci. Torino, Classe Sci., Fis., Mat., e Nat., Ser. 4a, no. 16, p. 1–40.

———, and F. Ricci Lucchi, 1972, Le torbiditi dell'Appennino settentrionale: introduzione all'analisi di facies: Mem. Soc. Geol. Italiana, v. 11, p. 161–199.

Rust, B. R., 1966, Late Cretaceous paleogeography near Wheeler Gorge, Ventura County, California: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 1389–1398.

Sestini, G., 1970, Vertical variations in flysch and turbidite sequences: a review: Jour. Earth Sci., Leeds, v. 8, p. 15–30.

Walker, R. G., in press, Generalized facies models for resedimented conglomerates of turbidite association: Geol. Soc. America Bull.

———, and E. Mutti, 1973, Turbidite facies and facies associations: *in* Middleton, G. V., and A. H. Bouma (*eds.*), Turbidites and deep water sedimentation: Soc. Econ. Paleontologists and Mineralogists, Pacific Section, Anaheim, short course lecture notes, p. 119–157.

Warren, P. T., 1963, The petrography, sedimentation and provenance of the Wenlock rocks near Hawick, Roxburghshire: Edinburgh Geol. Soc., Trans., v. 19, p. 225–255.

———, 1964, The stratigraphy and structure of the Silurian (Wenlock) rocks southeast of Hawick, Roxburghshire, Scotland: Geol. Soc. London, Quart. Jour., v. 120, p. 193–222.

Wood, A., and A. J. Smith, 1959, The sedimentation and sedimentary history of the Aberystwyth Grits (Upper Llandoverian): Geol. Soc. London, Quart. Jour., v. 114, p. 163–195.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 47, NO. 2, P. 926–934
JUNE 1977

DISCUSSION

UPPER CRETACEOUS RESEDIMENTED CONGLOMERATES AT WHEELER GORGE, CALIFORNIA: DESCRIPTION AND FIELD GUIDE

HANS NELSON
U.S. Geological Survey, Menlo Park, California
EMILIANO MUTTI
Institute of Geology and Paleontology, Turin, Italy
FRANCO RICCI LUCCHI
Geology Institute, University of Bologna,
Via Zambonia 67, 40127 Bologna, Italy

We wish to comment on a rather minor point in Walker's (1975) paper and clarify some established but misleading terminology exemplified by the paper. Walker (1975) calls thin-bedded turbidites of the "dark mudstone facies" in Wheeler Gorge "classical distal turbidites" even though they are intimately associated with thick-bedded conglomerates that appear to be quite proximal. Such terminology continues an unfortunate convention developed in the 1960's that equated thin-bedded turbidites with distal turbidite environments.

Students of modern turbidites in deep-sea canyons, channels and fans noted the ubiquitous distribution of thin-bedded turbidites in nearly all proximal and distal parts of turbidite systems (Carlson and Nelson, 1969; Griggs and Kulm, 1970; Normark, 1970; Piper, 1970; Haner, 1971). Cases can be documented where correlative Holocene turbidites change from thick-bedded (50 cm) channel thalweg deposits to thin-bedded (3 cm) intrachannel margin and levee turbidite deposits over a distance of less than 5 kilometers, all within an inner fan proximal environment (Nelson et al., 1968; Nelson et al., 1975).

Thin-bedded turbidites ("channel margin silts") that flank proximal channel turbidites (Normark and Piper, 1969; Piper and Normark, 1971) have been recognized in all proximal and distal environments of ancient fans (Mutti and Ricci Lucchi, 1972); these correspond well to those observed in modern systems (Nelson and Kulm, 1973; Nelson and Nilsen, 1974). More detailed paleoenvironmental interpretations of thin-bedded turbidites have subsequently been made, such as the distinction of overbank deposits of proximal intrachannel, levee, and interchannel environments from truly distal turbidites in interlobe and basin plain environments (Nelson et al., 1975; Ricci Lucchi, 1975; Mutti, 1977; Mutti and others, in preparation). Unfortunately the convention of equating thin-bedded turbidites with distal environments still persists and makes paleogeographic reconstructions confusing.

After visiting Wheeler Gorge, we think that the "dark mudstone facies" with interbedded siltstone represents overbank turbidites that are associated with conglomeratic bodies deposited as channel fills in an upper to middle fan environment (Fig. 1). The conglomerates have been injected several meters into the thin-bedded facies, and blocks of thin-bedded facies have slumped penecontemporaneously into channel conglomerates.

Thin sand and silt beds of Wheeler Gorge have similar thickness (Rust, 1966) and good bedding continuity, but with lensing, pinch and swell, and wedging along bed strike (Fig. 2). These are characteristic of proximal overbank beds, whereas variation in total thickness of different beds and extreme parallel continuity typify the thin-bedded distal sand layers (Mutti and Ricci Lucchi, 1972; Nelson

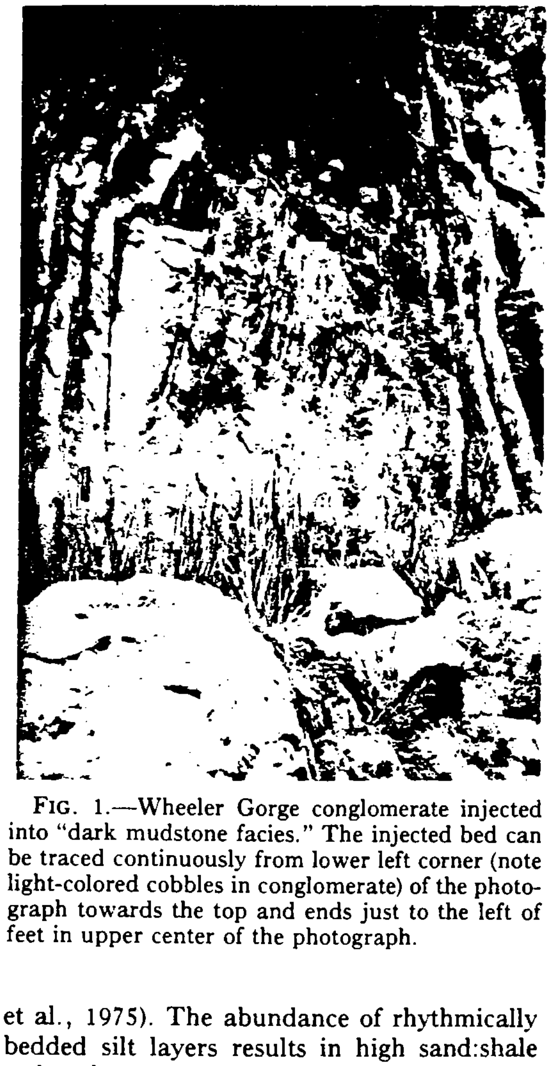

FIG. 1.—Wheeler Gorge conglomerate injected into "dark mudstone facies." The injected bed can be traced continuously from lower left corner (note light-colored cobbles in conglomerate) of the photograph towards the top and ends just to the left of feet in upper center of the photograph.

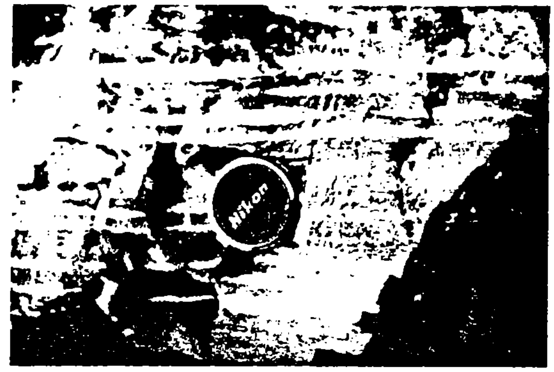

FIG. 2.—Close-up of "dark mudstone facies" of Fig. 1 showing thin-bedded intercalations of sandstone and siltstone (light-colored) that exhibit lenticularity because of predominance of internal rippled structure.

et al., 1975). The abundance of rhythmically bedded silt layers results in high sand:shale ratios that are not found in distal environments where hemipelagic deposits make up a significant portion of the interbeds. The fine-grained interbeds in the Wheeler Gorge "dark mudstone facies" appear to be turbidite mudstone rather than hemipelagic deposits (Rust, 1966). The preponderance of ripple drift cross-lamination and sharp tops that Rust (1966) and Walker (1975) described also appear to characterize interchannel margin and levee turbidites (Fig. 2).

Formation of proximal overbank beds like the "dark mudstone facies" occurs within and alongside thick conglomerate and sandstone beds because major fan valleys and individual thalwegs on valley floors periodically shift. Each new thalweg has overbank flows that create fining-upward sequences in abandoned nearby thalwegs on the valley floor; such flows also deposit thin-bedded overbank deposits with well-developed internal structures (Tc-e) on valley walls and levees alongside the main valley (Nelson et al., 1975). Channelized flows of the thalweg inject (Fig. 1) and cut into adjacent overbank beds (Moore, 1965) causing the ubiquitous slumping observed in ancient proximal thin-bedded turbidites such as the "dark mudstone facies" of Wheeler Gorge (Rust, 1966) and channel margin silts of Doheny Channel (Normark and Piper, 1969; Piper and Normark, 1971).

If no generic interpretation can be made, the term "thin-bedded" turbidites should be used in preference to "distal" turbidites. When beds clearly are associated with channelized facies of the inner to middle fan, such as at Wheeler Gorge, they may be labeled thin-bedded overbank turbidites; when deposited far seaward from the source in interlobe areas of the outer fan or in basin plains, they may be called thin-bedded distal turbidites (Nelson et al., 1975). Should additional details be evident, such as definite pinchout sequences, then thin-bedded turbidites may be defined more specifically into intrachannel margin, channel wall, levee, or interchannel sequences (Nelson et al., 1976; Mutti, 1977; Mutti and others, in preparation). Labeling all ancient overbank deposits as proximal also may be questionable. We would prefer to simply call these overbank deposits of the channelized facies in the inner-middle fan environment because thick channelized gravel beds have been found more than 700 km from continental margin sources (Nelson and Kulm, 1973).

REFERENCES

CARLSON, PAUL R., AND C. HANS NELSON, 1969, Sediments and sedimentary structures of the Astoria Submarine Canyon-Fan system, Northeast Pacific: Jour. Sed. Petrology, v. 39, p. 1269–1282.

GRIGGS, G. B., AND L. D. KULM, 1970, Sedimentation in Cascadia Deep-Sea Channel: Geol. Soc. of America Bull., v. 81, p. 1361–1384.

HANER, B. E., 1971, Morphology and sediments of Redondo Submarine Fan, Southern California: Geol. Soc. America Bull., v. 82, p. 2313–2432.

MOORE, D. G., 1965, Erosional channel wall in La Jolla Sea-Fan Valley seen from the bathyscaph Trieste II: Geol. Soc. America Bull., v. 76, p. 385–392.

MUTTI, E., 1977, Thin-bedded turbidite facies and related depositional environments in the Paleogene Hecho Group (south central Pyrenees, Spain): Sedimentology, v. 24, p. 107–131.

———, H. NELSON, T. H. NILSEN, AND F. RICCI LUCCHI, in preparation, Thin-bedded turbidites and their paleoenvironmental significance.

———, AND F. RICCI LUCCHI, 1972, Le torbiditi dell-Appennino settentrionale: introduzion all'-analisi di facies: Memorie della Societa Geologica Italiana, v. XI, p. 161–199.

NELSON, C. H., AND L. D. KULM, 1973, Submarine fans and deep-sea channels: *in* Turbidites and deep water sedimentation: short course Anaheim, 1973, Pacific Section Soc. Econ. Paleontologists and Mineralogists, p. 39–78.

———, ———, P. R. CARLSON, AND J. R. DUNCAN, 1968, Mazama ash in the Northeastern Pacific: Science, v. 161, p. 47–49.

———, E. MUTTI, AND F. RICCI LUCCHI, 1975, Comparison of proximal and distal thin-bedded turbidites with current-winnowed deep sea sands: Extraits des publications du Congress, Theme 5, Congress International de Sedimentologie, Nice, 1975, p. 317–325.

———, AND T. H. NILSEN, 1974, Depositional trends of ancient and modern deep-sea fans: *in* Dott, R. H. (*ed.*), Modern and ancient geosynclinal sedimentation: Soc. Econ. Paleontologists and Mineralogists Spec. Pub., v. 19, p. 54–76.

———, W. R. NORMARK, A. H. BOUMA, AND P. R. CARLSON, 1975, Thin-bedded turbidites in modern submarine canyons and fans: Am. Assoc. Petroleum Geologists Bull., v. 69, p. 702–703.

NORMARK, W. R., 1970, Growth patterns of deep-sea fans: Am. Assoc. Petroleum Geologists Bull., v. 54, p. 2170–2195.

———, AND D. J. W. PIPER, 1969, Deep-sea fan-valleys, past and present: Geol. Soc. of America Bull., v. 80, p. 1859–1866.

PIPER, D. J. W., 1970, Transport and deposition of Holocene sediment on La Jolla Deep-Sea fan, California: Marine Geology, v. 8, p. 211–227.

———, AND W. R. NORMARK, 1971, Re-examination of a Miocene deep-sea fan and fan valley, Southern California: Geol. Soc. of America Bull., v. 82, n. 7, p. 1823–1830.

RICCI LUCCHI, F., 1975, Depositional cycles in two turbidite formations of northern Apennines (Italy): Jour. Sed. Petrology, v. 45, p. 3–43.

RUST, B. R., 1966, Late Cretaceous paleography near Wheeler Gorge, Ventura County, California: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 1389–1398.

WALKER, R. G., 1975, Upper Cretaceous resedimented conglomerates at Wheeler Gorge, California: Description and Field Guide: Jour. Sed. Petrology, v. 45, p. 105–112.

REPLY
UPPER CRETACEOUS RESEDIMENTED CONGLOMERATES AT WHEELER GORGE, CALIFORNIA: DESCRIPTION AND FIELD GUIDE

ROGER G. WALKER
Department of Geology, McMaster University, Hamilton, Ont., Can., L8S 4M1

I must agree with Nelson et al. (1977) that not all thinly-bedded, fine-grained turbidites are "distal turbidites" and that, in general, it would be preferable to use the more descriptive term "thin-bedded turbidites."

I am not so ready to agree with their suggestion that at Wheeler Gorge my "dark mudstone facies with interbedded siltstone represents overbank turbidites that are associated with conglomeratic bodies deposited as channel fills in an upper to middle fan environment." Below the first conglomerate layer in my measured section there are at least 315 m (Rust, 1966) of my dark mudstone facies (Rust's shale-siltstone or mudstone and siltstone). Above my conglomerate 3, the dark mudstone facies is at least 185 m thick (Rust, 1966). I have not examined these dark mudstone sections in detail except in the immediate vicinity of the conglomerates. Rust (1966, p. 1392) describes the individual siltstones as "remarkably consistent in thickness and character where exposures permit tracing of individual beds along the strike...even the thinnest graded beds, averaging 2 mm in thickness, can be traced throughout the outcrop, and show only insignificant local changes in thickness." The "lensing, pinch and swell, and wedging along bed strike" shown in Fig. 2 of Nelson et al. (1977) indicates partial starvation of sediment supply, a situation that could occur both in overbank turbidites (inner or mid fan), or in classical distal basin plain situations. Thus I am not so confident as Nelson et al. in assigning thin-bedded turbidites that look like those in their Fig. 2 to "overbank turbidites" rather than "classical distal turbidites."

I am also unhappy with some of the other criteria they mention. They suggest that the "abundance of rhythmically bedded silt layers results in high sand:shale ratios" (in proximal overbank beds) "that are not found in distal environments where hemipelagic deposits make up a significant proportion of the interbeds." Surely this depends upon the rate of turbidity-current-supplied silts to distal environments versus the rate of deposition of hemipelagic deposits. Nelson and Kulm (1973, p. 60–61) have discussed overbank spilling versus hemipelagic deposition in levee and interchannel areas. In the levee beds of some deep sea channels (e.g., Surveyor) they note that "groups of interbedded thin turbidites alternate with sections of homogeneous hemipelagic beds." In proximal fan situations, assuming fairly frequent turbidity current flow, we might assume a higher proportion of turbidity current overflow versus hemipelagic deposition. However, I am not sure that we yet have enough evidence from recent or ancient sediments to generalize about sand:shale ratios, proportion of hemipelagics, and environments of deposition in the way Nelson et al. wish to.

Another line of argument that could be used would concern the thickness of the dark mudstones, and whether or not they are homogeneous, or contain thickening- or thinning-upward sequences. Levee deposits shown in many published reflection profiles can be 300 m or so in thickness (i.e., the thickness of dark mudstones below the Wheeler Gorge conglomerates), but there is very little information on how vertically homogeneous these would be, compared with a similar thickness of distal turbidites. This argument is presently inconclusive.

These comments have so far been addressed to the dark mudstones below and above the conglomerates. There is also a 5 m dark mudstone horizon (70 to 75 m on my stratigraphic section; Walker, 1975, Fig. 2) at the top of a 45 m thick thinning- and fining-upward sequence. This sequence contains conglomerates, massive sandstones, classical turbidites and dark mudstones, and possibly represents the gradual filling and abandonment of a channel. If so, the dark mudstones could well represent overbank deposition from an active channel elsewhere, and the thin graded siltstones within the mudstones should indeed be termed "thin-bedded turbidites."

Finally, it is worth emphasizing a point that the proponents of contourites (Bouma and Hollister, 1973) and overbank turbidites (Nelson et al., 1977) tend to ignore—namely that there should be a consistent paleocurrent divergence between downchannel or downslope turbidity current flow, and overbank (or contour current) flow. At Wheeler Gorge, a consistent difference between flow directions for conglomerates and massive sandstones, versus siltstones within dark mudstones, would be a more powerful argument for overbank flow than any of those offered by Nelson et al. (1977) for the thick dark mudstones below and above the conglomerates.

REFERENCES

BOUMA, A. H., AND C. D. HOLLISTER, 1973, Deep ocean basin sedimentation: *in* Middleton, G. V., and A. H. Bouma (co-chairmen), Turbidites and deep water sedimentation: Soc. Econ. Paleontol. Mineral., Short Course Notes (Anaheim), p. 79–118.

NELSON, C. H., AND L. D. KULM, 1973, Submarine fans and deep-sea channels: *in* Middleton, G. V., and A. H. Bouma, (co-chairmen), Turbidites and deep water sedimentation: Soc. Econ. Paleontol. Mineral., Short Course Notes (Anaheim), p. 39–78.

———, Emiliano Mutti, and Franco Ricci-Lucchi, 1977, Upper Cretaceous resedimented conglomerates at Wheeler Gorge, California: decription and field guide—a discussion: Jour. Sed. Petrology, v. 47, p. 926–928.

Rust, B. R., 1966, Late Cretaceous paleogeography near Wheeler Gorge, Ventura County, California: Am. Assoc. Petroleum Geologists, Bull., v. 50, p. 1389–1398.

Walker, R. G., 1975, Upper Cretaceous resedimented conglomerates at Wheeler Gorge, California: description and field guide: Jour. Sed. Petrology, v. 45, p. 105–112.

DISCUSSION

SIZE ANALYSIS OF SILT AND CLAY BY HYDROPHOTOMETER

C. R. TILLY
Postgraduate student of Earth Science Department,
University of Waikato, Hamilton, New Zealand

INTRODUCTION

In the *Journal of Sedimentary Petrology* (1971, v. 41, p. 489–496), an article was published on size analysis of silt and clay by hydrophotometer, by C. F. Jordan, Jr., Glen F. Fryer and Elze H. Hemmen.

Since the publication of this excellent article, the hydrophotometric method for the size analysis of silt and clay has probably been adopted by university students other than those of the University of Waikato (New Zealand).

However, in the article there are some errors in calculation detected by the writer in the course of his study of pumiceous sediments.

This article points out these errors and adds comments on the mathematics involved.

DISCUSSION

Some of the settling times and all of the "mid-diameters" given on page 490 are in error in that they do not stem from a consistent and accurate use of the standard scale for sedimentary particle sizes which is based on the geometric series built on powers of two.

On page 490, the following times, presumed to be for particles of quartz-type density, are given as: 46 sec; 1 min, 22 sec; 3 min, 3 sec; 5 min, 25 sec; 12 min, 12 sec; 21 min, 42 sec; 48 min, 50 sec.

For New Zealand conditions, and for water at 20°C, the correct times as calculated from the given formulae are, respectively: 45.9 sec; 1 min, 31.75 sec; 3 min, 3.5 sec; 6 min, 7 sec; 12 min, 13.9 sec; 24 min, 27.8 sec; 48 min, 55.8 sec.

The erroneous times are incorporated in the data sheet on page 492.

Only the errors for the settling times for particles of size 5.5 phi, 6.5 phi and 7.5 phi are serious.

These half-phi values are, of course, geometric means and should be determined by the use of the appropriate formula.

Likewise all the "mid-diameters" are geometric means and must be determined accordingly.

Concerning the formulae on page 489 for the determination of settling times, all the quantities concerned are constants for each set of conditions except the particle diameters.

Now these diameters form a geometric progression (symbol = G.P.). The squares of the terms of a G.P. is another G.P. and the latter G.P. multiplied consistently by constants remains a G.P. Hence the derived settling times also form a geometric progression.