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Fining-Upward Cycles in the Biyad–Wasi Sandstones (Lower–Middle Cretaceous) in Central Saudi Arabia

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The stratigraphic variation in grain size distributions, in the Biyad–Wasi sequences studied have probably been produced in response to two main factors. The smaller-scale, field-recognized cycles are ascribed to fluctuations in the depositing agent(s), that is, the fining-upward cycles denote stream (fluvial) deposits, while the few coarsening upwards sequences may indicate portions of a temporary lacustrine (lake) sequence developed in the interflude region of the alluvial plain and are probably not connected with any deltaic environment but may be caused by sediment winnowing and reworking. This latter postulation is supported by the small proportions of fine silt and clay indicated by the median (Md) column. The larger-scale cycles defined by the grain-size analyses probably represent longer-term fluctuations in the grade of sediment being supplied to the depositional basin, possibly in response to tectonic or diastrophic movements in the source-area.

The term "cycle" is applied to a pattern of sedimentation that recurs in an orderly manner throughout a succession, and may also denote the period of time during which such sediments developed (Duff *et al.*, 1967). Cyclic sequences vary in thickness from a metre or more up to tens or even hundreds of metres.

However, fining-upward cycles are characteristic of sedimentary facies formed by a decrease in current velocity, and consequently an upward decrease in modal grain size. Generally, the cycles of this type encountered in the present study are analogous to these described by Allen (1964a and 1965b), De Raaf *et al.* (1965) and Visher (1965b).

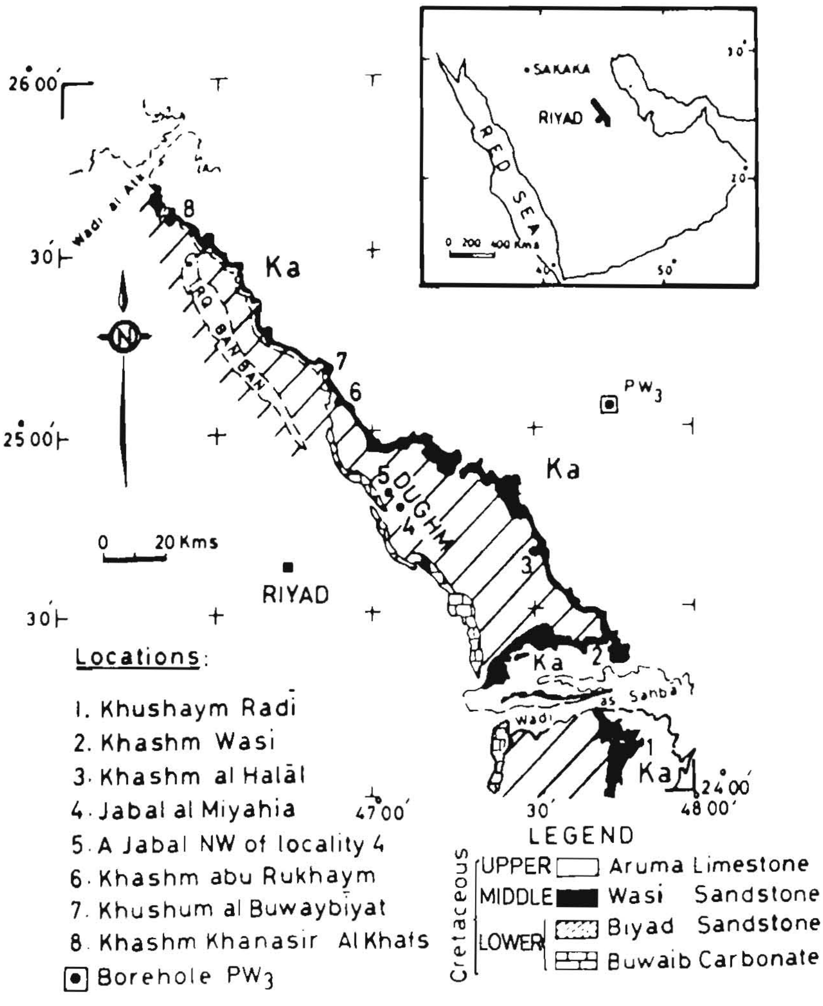

Fig. 1. Geologic map of the studied area, showing sample locations.

Within the studied Biyad–Wasi succession (Fig. 1) the thickest cycle observed, at an outcrop, is about 26 m (at locality 3). Eacy cycle is composite in character, having a well-developed and distinct lower coarse member and an upper fine member (Fig. 2). The lower member is represented mainly by the coarse-grained sandstone (Moshrif 1976, Facies-F), with distinct medium-scale cross stratification (Conybeare and Crook 1968) as the dominant sedimentary structure. At the base of this member, an erosional surface is occasionally exposed, marking the lower boundary of each cycle. On the other hand, when exposed and observed the base

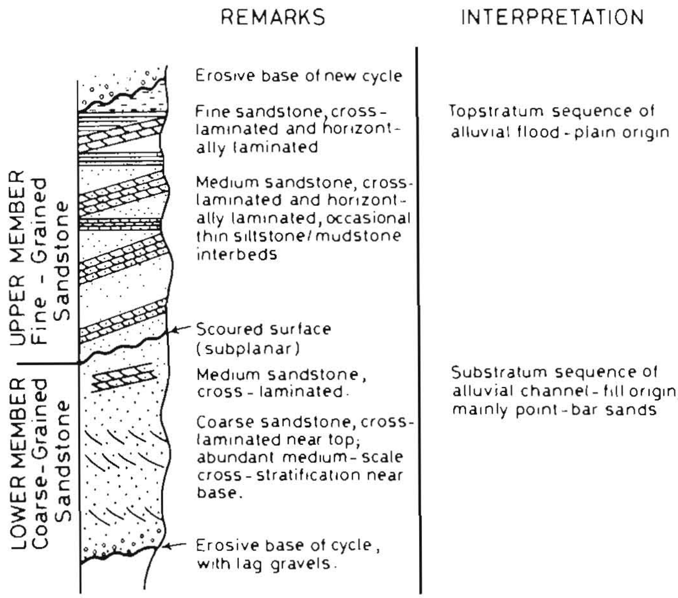

Fig. 2. Typical Biyad–Wasi cycles, repeated throughout the stratigraphic succession.

is often marked by a gravelly and pebbly layer, a few centimetres thick, with an eroded bottom surface. This comprises a lag deposit, which always is overlain by the coarse-grained, cross-bedded sandstone (Moshrif 1976, Facies-F). Moreover, sedimentary structures vary between medium- or large-scale cross strata (2 m scale) in the lower part to small-scale cross bedding (i.e. cross-lamination, centimetre scale) in the upper part of this member (Fig. 2).

The upper, fine member of each cycle is represented by the fine-grained sandstone (Moshrif 1976, Facies-G), with cross-lamination and horizontal lamination as the prevalent sedimentary structures. The uppermost part of this member is often poorly exposed but, when seen, it is composed of laminated silty mudstone (Fig. 1, locality 3). The junction between the lower coarse member and the upper fine member is usually represented by an eroded and scoured surface that is mantled by a thin layer of mixed quartz pebbles and mud clasts. Mud clasts or pebbles are also scattered within the lower member.

Although shales are generally lacking from the Biyad outcrops, they are recorded from the Borehole PW_3, (Fig. 4), where they appear to recur at the top of the cycles. The relative scarcity of shales at outcrop may be due to erosion, leaching, and concealment of this material. Another and very probable explanation for the more frequent presence of shales in the borehole PW_3 (which lies to the east of the studied outcrop sections; see Fig. 1) and its less appearance or absence in the outcrop is that finer sediments, i.e. shales, are normally more accumulated in the down-current direction (as shown by the borehole), occurring less often in the up-current regions (as reflected by the outcrop sections).

The fining upwards cycles of the Wasi Formation closely resemble those of the Biyad except that in the former a few sequences are extremely ferruginous. Furthermore, similar sedimentary structures (i.e. medium scale cross bedding in the lower coarse members and cross lamination or horizontal lamination in the upper fine members) have been observed in both successions.

Figures 3 and 4 are representative successions of the Biyad and Wasi Sandstones in the outcrop and subsurface, respectively (see Fig. 1).

Discussion and Interpretation of the Biyad–Wasi Fining-Upwards Cycles

The combination of upward rhythmic repetition of Biyad facies, the overall decrease in modal grain size and progressive variation in sedimentary structures all substantiate the presence of these fining upwards cycles. Fining upwards cycles or sequences have been interpreted as the products of sedimentation in laterally moving channels in fluvial, tidal, and estuarine environments. Thus, to investigate the formation of the lower, coarse-grained member it is essential to refer to the general models of fluvial channel sedimentation described and postulated by many geologists [e.g. Allen (1963b, 1964a, and 1965b), Beerbower (1964), Visher (1965a, b), Moody-Stuart (1966), Potter and Blakeley (1967)], and the more recent quantitative model of Allen (1970).

However, Potter and Blakeley (1967, p. 245) have indicated that high-velocity currents in laterally migrating streams generally curve the concave banks of a meander and form a new bank with the coarse sediments (i.e. lag deposits) being deposited on the channel floor and the finer material being carried downstream. This lag deposit is analogous to those observed above the eroded and scoured basal surfaces of the Biyad fining upwards cycles (see Moshrif, 1976, p. 179). Subsequently, convex banks are developed on the opposite side of the meander loops and filled with channel material, usually in the form of point-bar deposits, mainly coarse-grained, large-scale cross-bedded sands. Since stream migration is continuous, this point-bar deposit continues to grow and forms a thick cross-bedded sequence overlying the basal lag deposit. Allen (1963a, b) has indicated that large and small scale cross-bedding are formed in this way as a result of ripple migration, whilst scoured surfaces are due to aggradation on plane beds (Allen, 1964b) that occur in lateral accretion deposits (i.e. point-bar deposits).

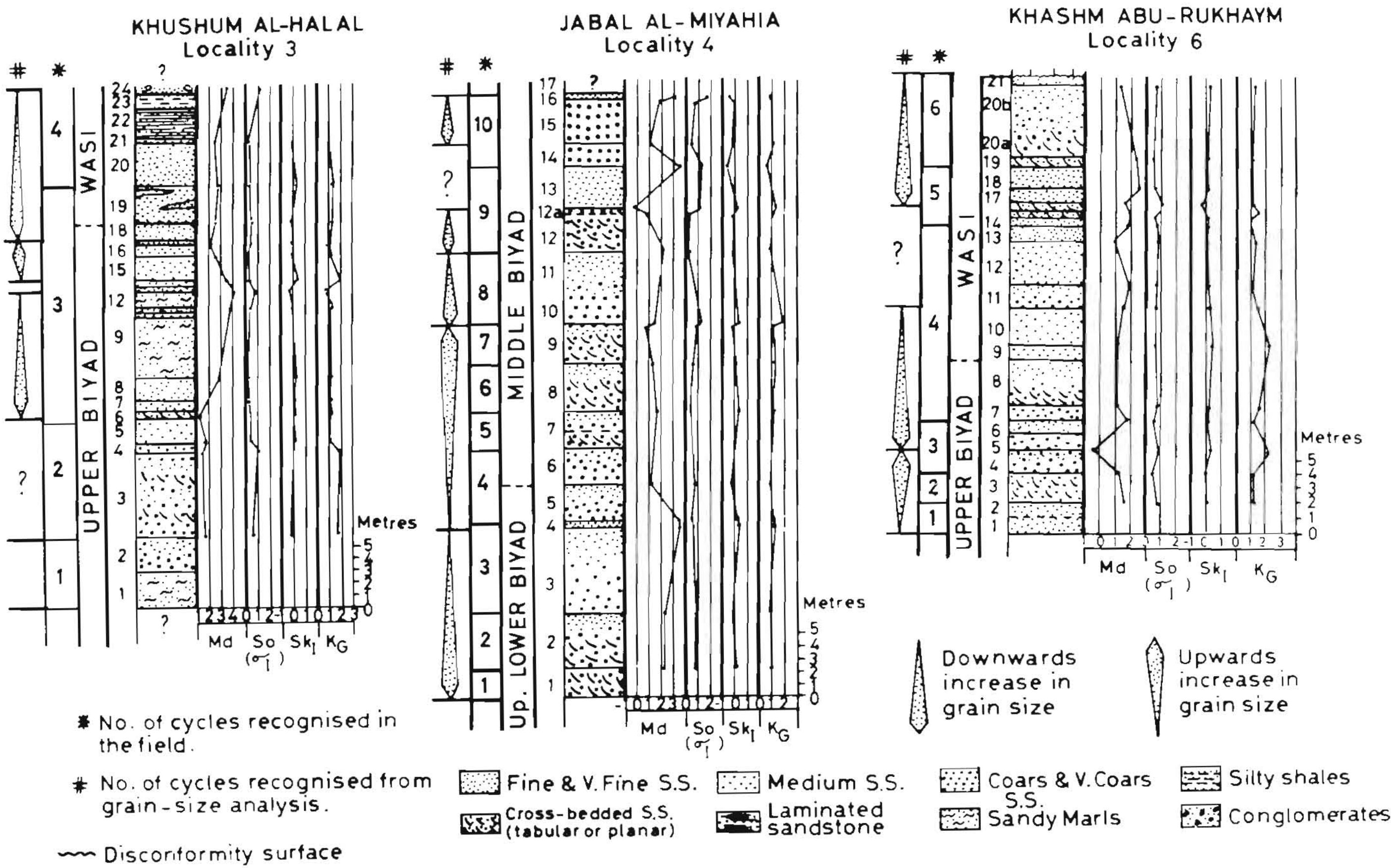

Fig. 3. Vertical variation in grain-size parameters in the Biyad–Wasi lithofacies.

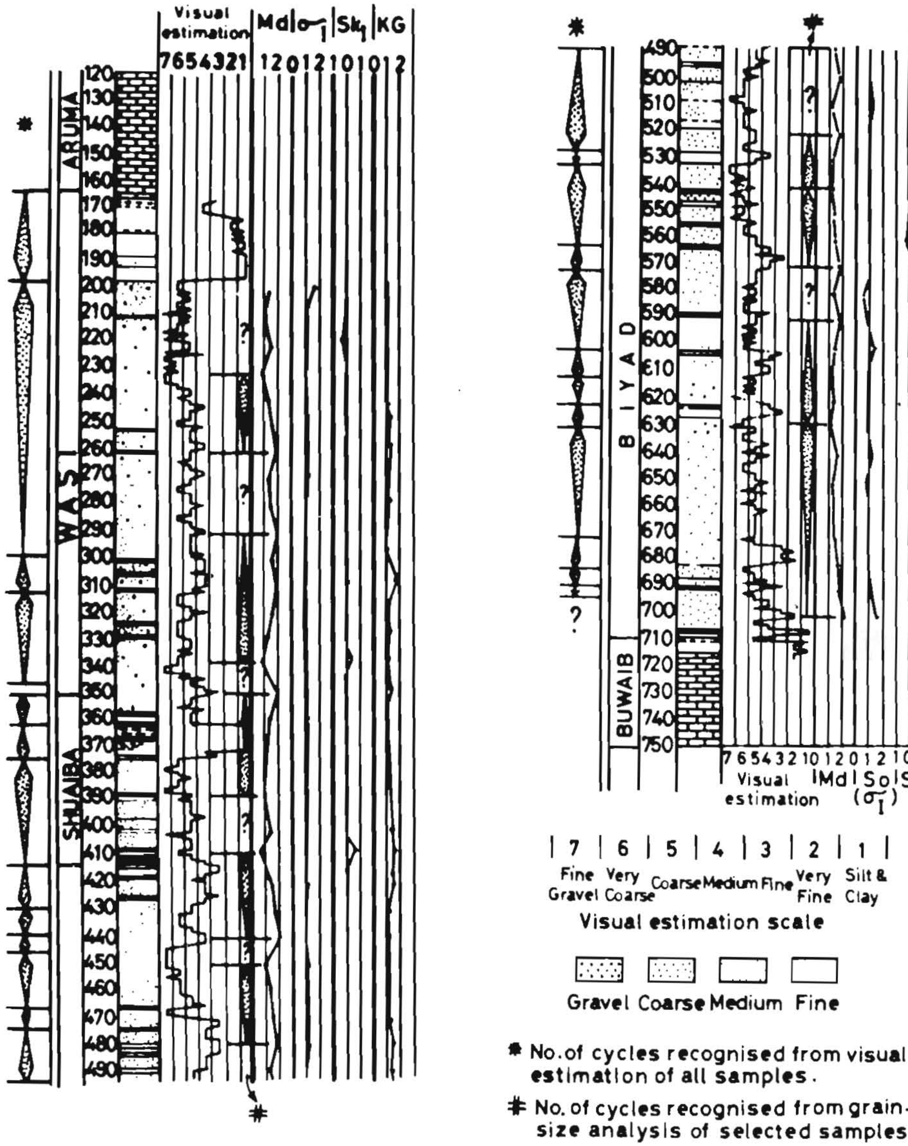

Fig. 4. Vertical variation in grain-size parameters in the Biyad–Wasi lithofacies, Borehole PW_3.

Harms and Fahnestock (1965) have indicated that stream velocity decreases upwards from the stream floor, and subsequently gentler and quieter currents have slowly formed small-scale cross strata (cross lamination) in the upper part of the point-bar deposit. Moreover, Frazier and Osanik (1961), Lane (1963), Harms and Fahnestock (1965), and Allen (1965b) have investigated modern point-bar deposits and have recorded the presence of prevalent and well-formed large-scale cross bedding. Thus, it seems very likely that the Biyad coarse-grained lower sequence, with its major large (or medium) scale cross-stratification in the lower part and cross-lamination in the upper part, represents a point-bar deposit.

In most of the fining-upwards successions described in the literature, the basal coarse members are uniformly ascribed to within-channel processes, but the upper fine members from different sedimentary environments, although lithologically comparable in character, appear to have originated in different ways. For example, Land and Hoyt (1966), Klein (1970), and Evans (1970) have described fine members formed in tidal and estuarine fining-upwards sequences and have related these to sedimentation within the intertidal zone. On the other hand, Allen (1964a, p. 166) has attributed the fine member of the fluvial fining-upwards succession to sedimentation in an alluvial floodplain as top-stratum, or over-bank sediments.

The fining-upward cycles of the Biyad–Wasi Sandstones are here interpreted as deposits formed within fluvial rather than tidal channels because of the absence of marine fossils, shells and skeletal debris, and the presence of wood fragments and plant debris (Moshrif 1976), the abundance of shale pebbles or clasts, the moderate amount of biogenic disturbance and, above all, the unimodal cross-bedding azimuths (Moshrif 1976, Fig. 5; Allen 1965a, b; Potter 1967; Johnson and Friedman 1969; Reading 1970). Furthermore, in estuarine and tidal channel sequences, Klein (1970, p. 978) and Evans (1970, p. 506) have shown that the upper fine members are characterised by extreme bioturbation, while in fluvial channels biogenic disturbance is minimal, as in the Biyad–Wasi cycles.

Stratigraphic Variation in Grain-Size Distributions

Sorting and skewness reveal only slight changes in either parameter vertically throughout the sections concerned. However, vertical variations in median grain-size are more marked and suggest the existence of fining upwards cycles at many stratigraphic levels, together with a few coarsening upwards sequences (see Fig. 3 and 4). Thus, several of the fining upwards cycles recognized in the field have also been determined from the grain-size data. On the other hand, many cycles recognized in the field do not coincide with those determined from the median grain-size variations (see Fig. 3 and 4). This apparent disparity probably results from the fact that cycles determined in the field have been recognized basically from a combination of many features, such as vertical changes not only in grain size but also in sedimentary structures, and the overall aspect of each cycle with respect to the vertically adjacent sequences. However, the cycles defined from the grain-size values are based on a series of samples, and are therefore dependent on factors such as the particular horizon from which each sample was obtained, and the possible errors in sieving techniques, but are most probably due to major and long-term variations in the grain-size of the original transported material.

The median grain-size of all samples supplied from the borehole PW_3 has been determined by visual estimation and comparison with a laboratory sand size-scale (i.e. from fine gravel to silt and clay fractions, and these size fractions are represented by descending numerical values as shown in Fig. 4). However, only a limited number of samples were selected for the full grain-size analysis, and again the cycles revealed by the median parameter plots do not fully coincide with the cycles obtained from the visual estimation. The frequent coarsening upwards cycles observed in both determinations may be due to the loss of finer material during the coring processes, and it appears that it is very difficult and probably misleading to use either the visual estimates of grain size or the median numerical values alone in recognising or determining the number of cycles involved in the present sequences, and perhaps in any other sequences. Nevertheless, Table 1 indicates the total number of cycles in the Biyad–Wasi Sandstones that are recognised in the field, from the median parameters and from visual estimation, and this shows no relationship between the number of cycles recognised in the field and those distinguished by other means, except that there is always a smaller number of the latter type.

Table 1. Number of cycles recognised in Biyad–Wasi Sandstones.

Localities	No. of cycles recognised in the field	No. of cycles recognised from size analysis
Khashm Wasi, Locality 2	4	2
Jabal Al-Halal, Locality 3	4	3
Jabal Al-Miyahia, Locality 4	9	5
A. J. NW of Jabal Al-Miyahia, Locality 5	10	3
Khashm Abu-Rukhaym, Locality 6	6	3
Kh. Al-Buwaybiyat, Locality 7	3	4
Kh. Khanasir, Locality 8	8	4
Total of Cycles	44	24
Borehole, PW_3	Visual estimation 25	9

Table 2. A comparison between the overall averages of textural parameters of Biyad–Wasi Sandstones sampled at outcrops and those sampled in the Borehole, PW_3.

All samples studied from	Mean of median (Md)	Mean of mean (MZ)	Mean of ST deviation sorting (σ_I)	Mean of skewness (SK_I)	Mean of kurtosis (KG)
			Outcrop Measured Sections		
Wasi + Upper Biyad	1.6ϕ	1.7ϕ	0.7 Moderately well sorted	0.1 Fine-skewed	1.4 Leptokurtic
Middle Biyad	1.7ϕ	1.7ϕ	0.7 Moderately well sorted	−0.03 Near symmetrical	1.1 Leptokurtic
Lower Biyad	2.5ϕ	2.5ϕ	0.7 Moderately well sorted	0.1 Fine-skewed	1.0 Mesokurtic
			Borehole, PW_3		
Wasi + Upper Biyad	1.3ϕ	1.3ϕ	1.1 Poorly sorted	−0.03 Near symmetrical	1.2 Leptokurtic
Middle Biyad	1.4ϕ	1.3ϕ	1.0 Moderately well sorted	−0.2 Coarse-skewed	1.2 Leptokurtic
Lower Biyad	1.4ϕ	1.5ϕ	1.1 Poorly sorted	0.2 Fine-skewed	1.3 Leptokurtic

Conclusion

It is concluded that the vertical variation in grain size distributions in the sequences examined have probably been produced in response to two main factors. The smaller-scale, field-recognized cycles are attributed to fluctuations in the depositing agent(s), that is, the fining-upwards cycles denote stream (fluvial) deposits while the few coarsening-upwards sequences may be disconnected with any deltaic environment but form part of a temporary lake sequence in the interflude region of the alluvial plain or may be caused by sediment winnowing and reworking. This latter postulate is supported by the small proportions of fine silt and clay indicated by the median column, and also indicated by the results summarised in Moshrif (1976, Tables 4.1–4.3, Appendix 4.1). The larger-scale cycles defined by the grain-size analyses probably represent longer-term fluctuations in the grade of sediment being supplied to the depositional basin, possibly in response to tectonic or diastrophic movements in the source-area. Table 2 provides the overall averages of the textural parameters of the Biyad–Wasi Sandstones, and it is apparent that as the median or mean value increases, the sands become better sorted and the sandstones tend to become slightly more fine-skewed.

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تناقص دورى رأسى فى حجم الحبيبات فى رمل البياض ـ الوسيع (الطباشيرى الاوسط السفلى) فى وسط المملكة العربية السعودية

محمد عبد الغنى مشرف

قسم الجيولوجيا ـ كلية العلوم ـ جامعة الملك سعود

يمكن أن يعزى تكون التغير الطبقى فى توزيع حجوم الحبيبات فى تتابع البياض ـ الوسيع بأنه استجابة لعاملين رئيسيين . فالدورات الصغيرة المدى الواضحة فى الحقل يمكن أن تعزى الى التغيرات الطفيفة فى عوامل الترسيب فالتناقص الدورى الرأسى فى حجم الحبيبات مثلا يدل على رواسب نهرية بينما تدل التتابعات الرأسية القليلة ذات التزايد الحجمى الحبيبى على أنها أجزاء من رواسب بحيرات مؤقتة تكونت فى مناطق الفيض خلال سهول الفيضان ويبدو أنها لا ترتبط برواسب بيئات الدلتا ، ولكن ربما تكون نتجت بواسطة الازاحة واعادة الترسيب . ويؤيد الافتراض الاخير وجود الكميات القليلة من الغرين الناعم والصلصال كما يتضح من معامل الوسط .

وتمثل الدورات الكبيرة الواضحة من التحلل الحجمى للحبيبات ـ التذبذب الطويل المدى فى الرواسب الواصلة لحوض الترسيب . وهذا قد يكون نتيجة للحركات التكوينية أو الكوارث التى تعرضت لها منطقة مصدر هذه الرواسب .