Journal of Geosciences, Osaka City University
Vol. 42, Art. 7, p.103-114, March, 1999

Turbidite Sedimentation in the Late Paleozoic Talchir Gondwana Basin, Orissa, India

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Abstract

The Talchir Group of the Talchir Gondwana basin in Orissa was deposited predominantly in a lacustrine regime. Paleocurrents indicate lateral sediment dispersal from the southern margin of the northwest—southeast trending elongated lake basin. The middle part of the Talchir succession demonstrates turbidite sedimentation in lake-margin slope and base-of-slope environments, and five facies associations have been recognized: channel-fill sandstones organized into thinning- and fining-upward sequences; thinly interbedded sandstones and mudstones of an overbank and levee origin; massive to laminated, slope mudstone; depositional fan-lobe deposits revealing thickening- and coarsening-upward sequences; varve-like, lake basin floor mudstones.

Channels on the lake-margin slope were of small scale and were rapidly filled with frequent lateral shifting, probably due to a small catchment in which only local streams drained. The shallow depth of the channels caused active spillover sedimentation on the overbank and levee area. Fan lobes formed at the base-of-slope were short-lived as a consequence of shallow channel depths and rapid lateral switching of the channel position, resulting in only a minor progradation of essentially unchanneled lobes onto the lake basin floor.

Key words : Gondwana, Lacustrine turbidite, Sedimentary facies, Talchir Group, Talchir basin.

Introduction

The Talchir Group extends into all the regions of the Gondwana basins in India (Fig. 1) and forms the lowermost stratigraphic unit of the Gondwana sequence (cf. Veevers and Tewari, 1995). The term Talchir Group was first introduced by Blanford et al. (1856) from Talchir in Orissa to describe a group of rocks occurring at the base of the Gondwana sequence. They suggested the Talchir rocks to be glacial lake deposits. Since then, the Talchir basin (Figs. 1, 2) has been considered as the type area of the Talchir Group. It is commonly accepted that the Talchir Group was deposited in glacially sourced depressions (cf. Veevers and Tewari, 1995; Casshyap and Srivastava, 1988). In the Talchir basin, however, Pandya (1987) suggested that the earliest period of glaciation, as interpreted by the basal Boulder Bed (Blanford et al., 1856), switched over to a warmer phase towards the end of the Talchir period. Thus, the Gondwana sedimentation was possibly initiated in a post-glacial warm climatic condition. The Talchir Group of some of the other basins has also been allocated to deposition in a warm to semi-arid climatic condition (Rishi, 1971; Ahmad, 1975; Sen and Hatim, 1977).

The study of lithofacies and environments of deposition of the Talchir Group in the Talchir basin has revealed that the major part of the Talchir succession indicates lacustrine deposition in a rift-controlled lake (Pandya, 1990). Paleocurrent analysis indicates sediment dispersal from the southern basin margin towards the basin center, suggesting a transverse filling of the northwest–southeast trending, elongated lake basin (Das and Pandya, 1997). Occurrence of turbidite and slump features are suggestive of deposition in a moderately deep lake basin to lake margin environment (cf. Pandya, 1990). This paper describes and interprets facies of the lacustrine turbidite and associated deposits in the middle part of the Talchir Group, and provides a model of a lake-margin turbidite depositional system.

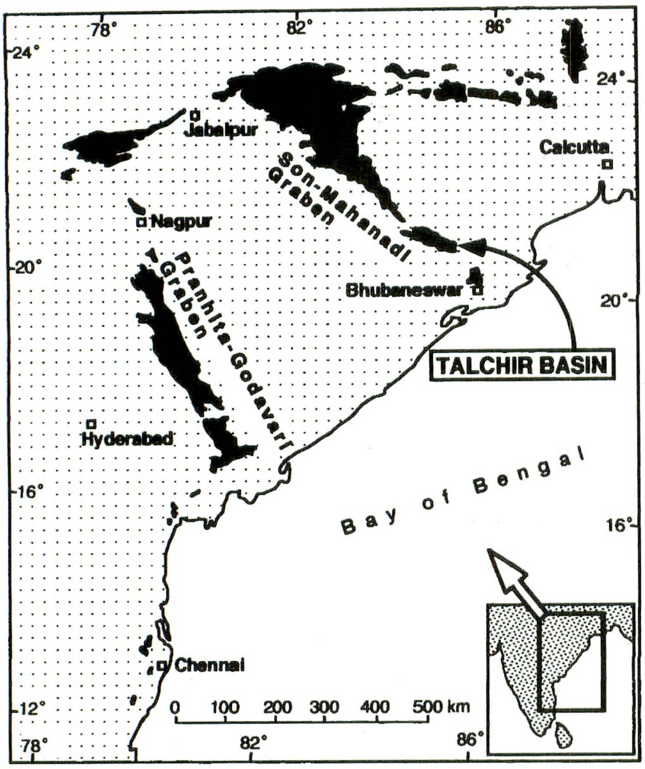

Fig. 1. Distribution of Gondwana basins in the eastern part of Peninsular India and location of the Talchir basin.

Geologic Setting

The Talchir basin is a northwest–southeast trending elongated basin covering an area of about 3,150 km^2. It lies near the southeastern end of the Son–Mahanadi graben between the Eastern Ghats mobile belt to the south and the Singhbhum craton to the north (Figs. 1, 2). The more than 1,000 m thick basin fill, ranging in age from Late Carboniferous to Triassic, is subdivided into the Talchir, Damuda and Kamthi Groups, in ascending order.

The area under study is located around Bedasar village (latitude 20° 52′ 30″ N, longitude 85° 4′ 0″ E) of Angul district, Orissa (Fig. 3). It lies near the south-eastern boundary of the Talchir basin. The Talchir Group of the present area is underlain by the Precambrian basement rocks of the Eastern Ghats Group to the south with a faulted contact. The locally unconformable nature of the contact is observable. The Talchir succession strikes in a direction N70° E and dips uniformly towards the north at low angles ranging from 5° to 10°, forming a homoclinal structure. The Talchir Group immediately overlying the Precambrian basement is represented by about 260 m of strata (Fig. 4), which are classified into three formations, informally named as Unit A, Unit B and

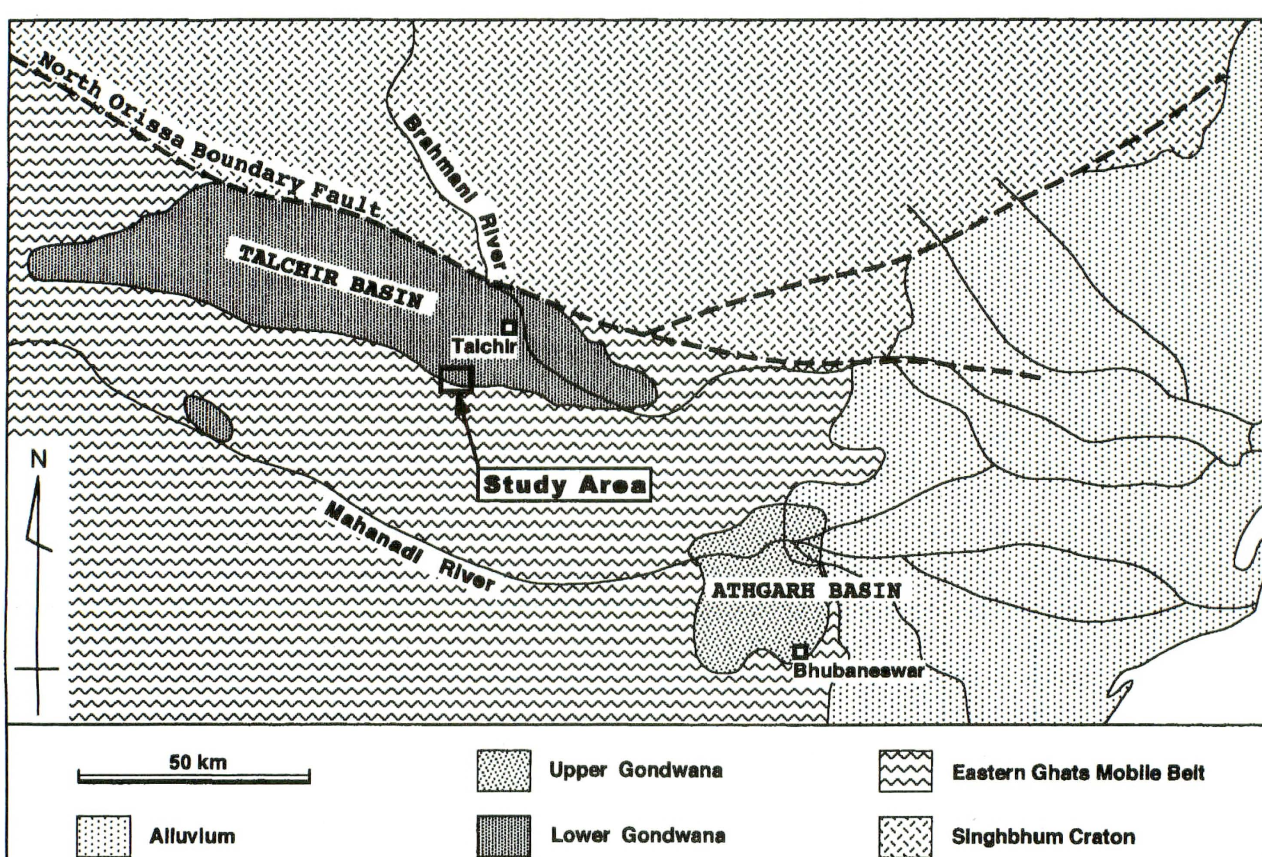

Fig. 2. Geologic sketch map around the Talchir basin showing the study area.

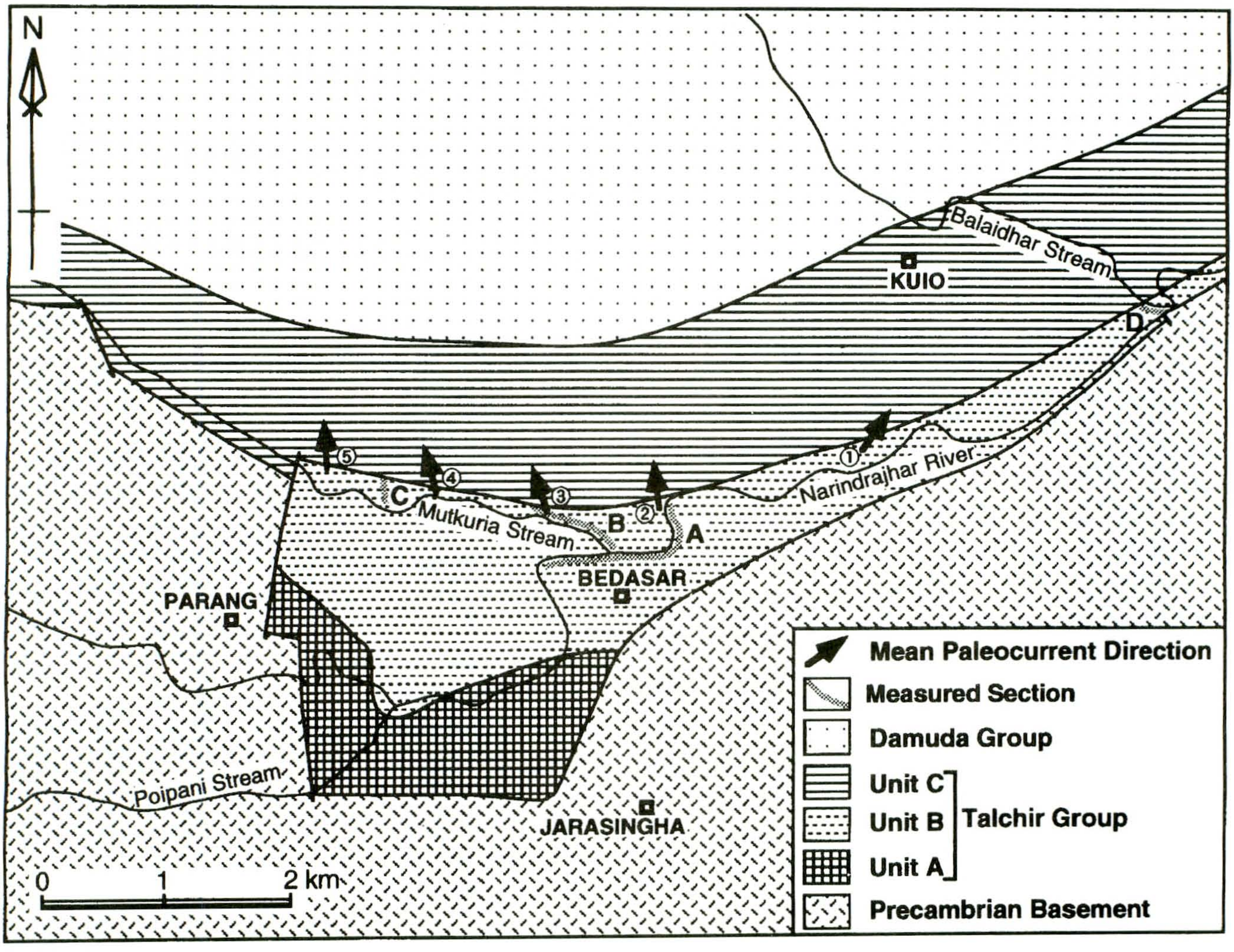

Fig. 3. Geologic map of the study area, modified from Pandya (1990) and Das and Pandya (1997). Locations of measured sections and mean paleocurrent directions are shown.

Unit C (Pandya, 1990). Unit A dominantly comprises conglomerate and sandstone that are deposited in an alluvial environment (Pandya, 1990), as well as a basal glacial tillite. On the other hand, Unit B and Unit C are dominated by finer sediments and are attributed to a lacustrine regime (Pandya, 1990).

This paper is concerned with the lacustrine deposits of Unit B, specifically with its upper part. The sections were measured along the Narindrajhar river and its tributaries, Mutkuria and Balaidhar streams (Fig. 3). The sections A, B and C can be correlated (Fig. 5), whereas the precise stratigraphic relationship between the section D and the others is uncertain.

Facies Associations

Five facies associations have been recognized in Unit B of the Talchir Group (Fig. 5). They are: Ⅰ. channel; Ⅱ. overbank and levee; Ⅲ. lake-margin slope; Ⅳ. depositional fan lobe; Ⅴ. lake basin floor.

Facies association Ⅰ: channel

Description

The deposits of this association form 5 to 8 m thick successions and dominantly comprise 0.4 to 2 m thick, commonly amalgamated beds of conglomeratic sandstone and coarse- to very coarse-grained sandstone (Fig. 6), with subordinate thinly interbedded sandstone and mudstone. Within this association, the sandstone and conglomeratic sandstone are organized into 2 to 5 m thick, thinning- and fining-upward sequences (Fig. 5), which occur either isolatedly or stack both vertically and laterally to form a multistoried and multilateral sandstone body.

The conglomeratic sandstones have a remarkable erosion surface at the base. Several decimeters deep scours are common, and beds are locally highly lenticular in shape. Lateral and vertical grading within beds occurs, and varies from

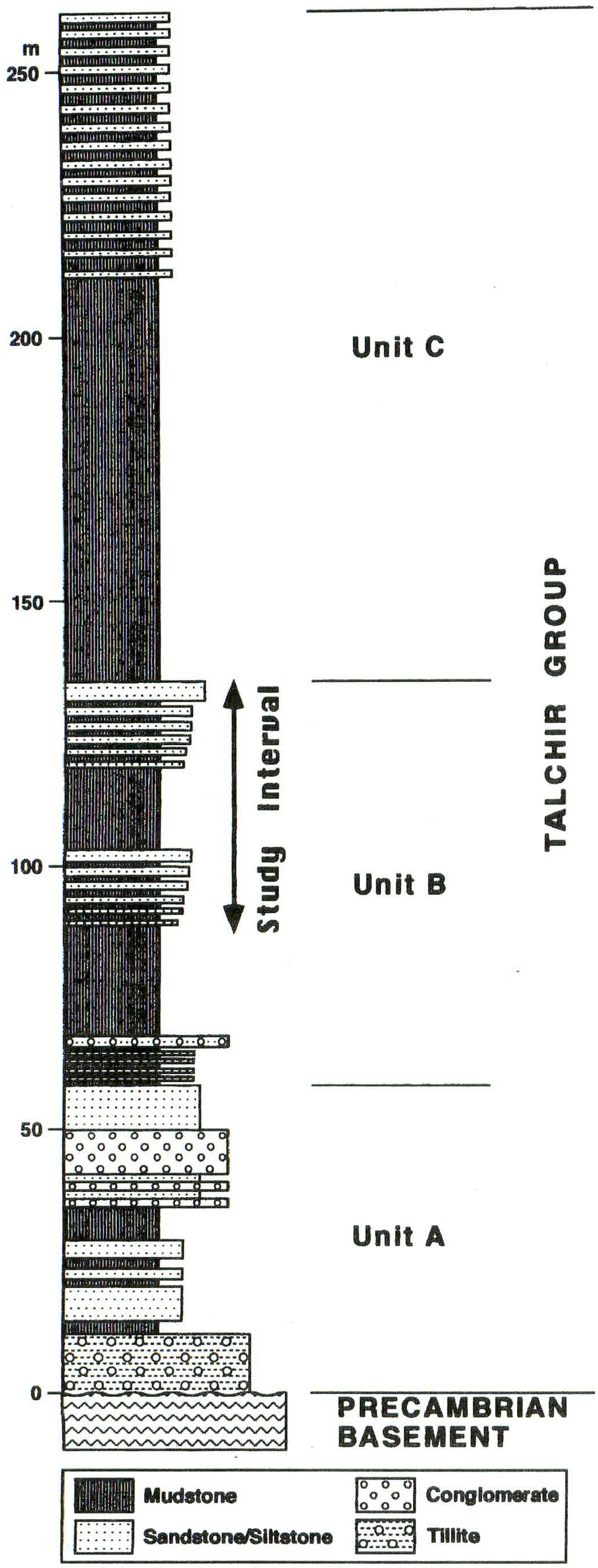

Fig. 4. Generalized stratigraphic section of the Talchir Group of the study area.

pebble conglomerate in the lower portion to medium- to coarse-grained, locally pebbly sandstone in the upper portion. Ripped-up mud clasts, up to 1 m in long dimension, are scattered in most of the beds. The beds are essentially unstratified, but some show crude subhorizontal stratification in the upper sandstone portion. Coarse- to very coarse-grained sandstones have an erosional basal surface and are commonly graded. Beds contain abundant ripped-up mud clasts, which are either scattered or are concentrated in discrete layers. Internally the major parts of the beds are unstratified. Flat stratification, however, occurs towards the tops of the beds. Several beds show ripple cross- lamination at the top. Thinly interbedded sandstone and mudstone occur towards the top of the thinning- and fining-upward sequences and tend to disappear due to deep erosion by the overlying sequence. Both sandstone and mudstone beds are up to 20 cm, most commonly less than 10 cm, thick. The sandstones have a sharp and flat base, are graded, and are internally parallel and/or ripple cross laminated.

Interpretation

The conglomeratic sandstones and coarse-grained sandstones of this association are interpreted as the deposits of gravelly and sandy high-density turbidity currents (Lowe, 1982). The conglomerate–sandstone couplet of conglomeratic sandstone beds suggests that flows were segregated into a basal traction carpet, in which clasts were dominantly supported by frictional dispersion due to clast collisions, and an upper, more fluidal, sandy turbulent flow in which grain support occurred probably by a combination of fluid turbulence and matrix-buoyant lift (Lowe, 1982; Nemec and Steel, 1984; Nemec, 1990; Sohn, 1997). The common occurrence of such bipartite beds implies sufficiently rapid emplacement of flows not to develop the lateral separation of gravel and sand fractions in a flow. Subhorizontal stratification in the upper parts of some beds suggests that flow fluctuations locally led to high-rate traction sedimentation in the final stage of deposition. The graded beds of coarse-grained sandstone are well comparable with Ta and Tab turbidites. Massive beds with restricted occurrence of stratification towards their tops represent fast settling from high-concentration suspension (Lowe, 1982). Thin sandstones interbedded with mudstone can be described as Tb, Tbc, or Tc turbidites and represent deposition from low-density turbidity currents (Lowe, 1982).

The thinning- and fining-upward sequences made up by the deposits of high-density turbidity currents are interpreted to have been formed by filling and abandonment of channels or by lateral shifting of active channels (Walker, 1978, 1985). Thinly interbedded sandstone and mudstone at the tops of some successions represent final infilling of an abandoned channel or deposition on the margin of a channel. Channels

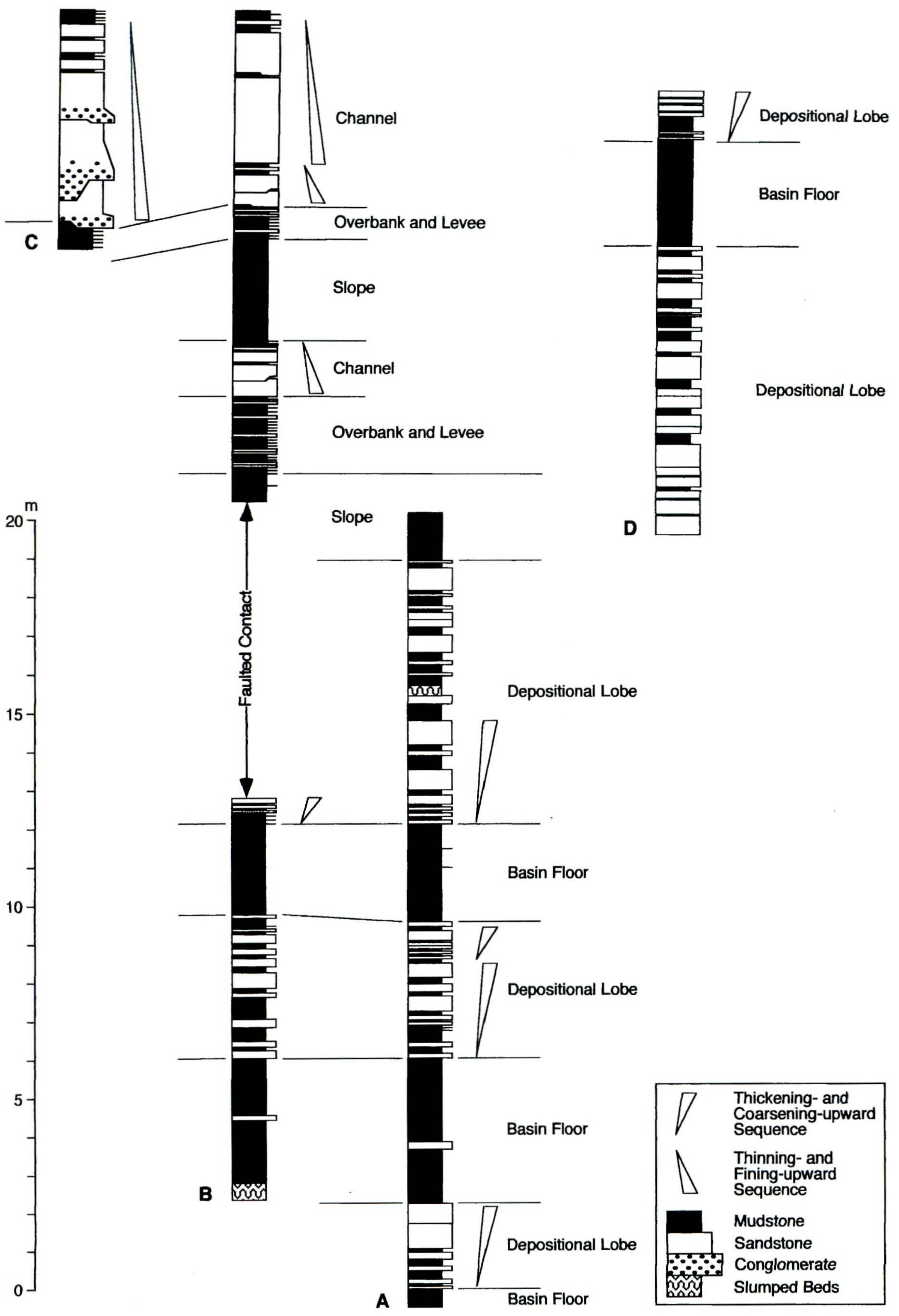

Fig. 5. Measured sections of the upper part of Unit B of the Talchir Group. Sections A, B and C can be correlated by tracing beds laterally.

Fig. 6. (A) Channel-fill sandstone resting on thinly interbedded sandstone and mudstone of an overbank and levee origin, section C. (B) Erosively based channel-fill sandstone, section C.

were shallow and were rapidly filled with frequent lateral shifting, resulting in the multistoried and multilateral sandstone body composed of relatively thin, thinning- and fining-upward sequences.

Facies association Ⅱ : overbank and levee

Description

The overbank and levee association occurs with channel sandstones (facies association Ⅰ) (Fig. 5). The deposits of this association form up to 2 m thick successions of thinly interbedded sandstone and mudstone (Fig. 7). Individual beds are generally less than 10 cm, most commonly less than 5 cm, thick. The sandstone:mudstone ratio is high, around 1:1. Bedding is irregular, and wavy and lenticular bedding is common. Beds are, in places, discontinuous with wedging and lensing out. Amalgamation of sandstone beds is also common. Sandstones show wide variability in grain size, that is fine- to very coarse-grained. Some beds contain ripped-up mud clasts. Most of the sandstone beds are graded, but their tops are generally in sharp contact with overlying mudstones. Internally sandstones show the Ta-c, Tbc, or Tc sequence. Ta

Fig. 7. Massive to finely laminated slope mudstone (S) overlain by overbank and levee deposits (O), on which small-scale channel sandstones (C) rest, section B. Note thin interbedding of sandstone and mudstone and high sandstone:mudstone ratio in the overbank and levee deposits.

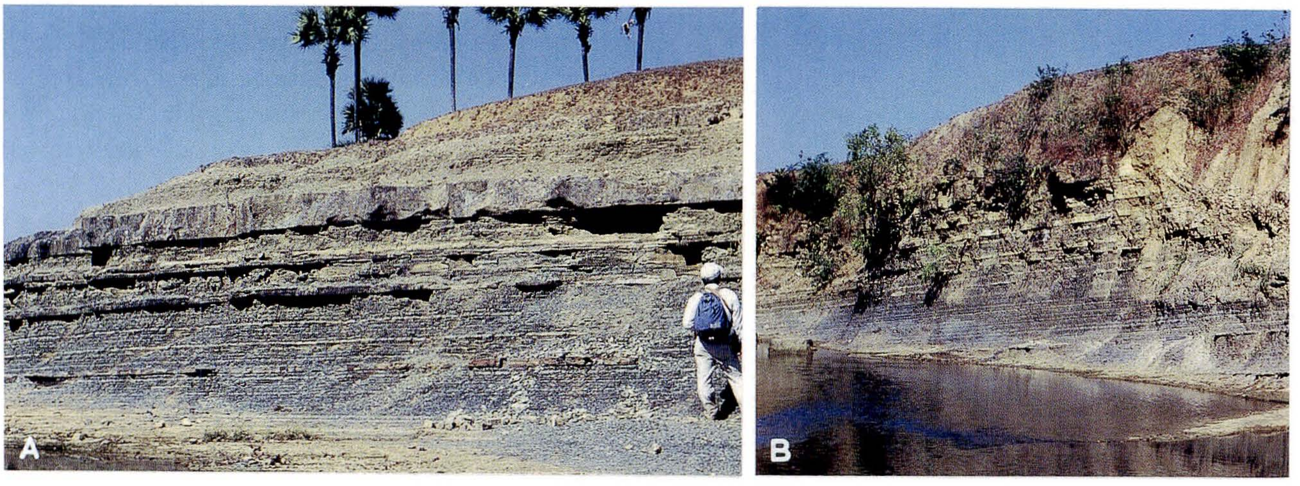

Fig. 8. (A) Lower part of a thickening- and coarsening-upward, depositional fan-lobe sequence, top of section A. (B) Lateral equivalent of the sequence shown in A, occurring to the east of section A.

and Tb beds are locally present.

Interpretation

Sandstones in this association are interpreted as classical turbidites, as suggested by the well-developed grading and internal structural sequences described using a Bouma model. The consistently thin sandstone beds resemble the distal representatives of turbidites (Walker, 1967). However, the succession of this association is rather comparable with the deposits interpreted in previous works on turbidite systems as natural levee or overbank deposits. These generally have thin bed thickness, a high sand:mud ratio, coarse grain size of sandstones, and irregular and discontinuous beds (Mutti, 1977; Mutti and Ricci Lucchi, 1978; Carter, 1979; Winn and Dott, 1979; Walker, 1985; Stow, 1985; Tanaka, 1989, 1993). All these features are characteristic in the deposits of this association. The occurrence of this association accompanying channel sandstones is consistent with an overbank and levee interpretation.

Facies association Ⅲ : lake-margin slope

Description

The slope association is represented by 2.5 to 4 m thick units of black to dark gray mudstone. They occur accompanying the channel (facies association Ⅰ) and overbank—levee (facies association Ⅱ) deposits (Fig. 5). The mudstone is massive to crudely finely laminated. Locally intercalated within mudstones are millimeters-thick layers of fine siltstone. These layers are commonly graded. Some show diffuse parallel-lamination.

Interpretation

Thick accumulation of mud implies predominance of suspension sedimentation in a low-energy environment subject to little influence of currents. Intercalations of thin, graded and laminated siltstone may be described as Td or Tde turbidite, and represent occasional invasion of currents and deposition of fine materials from slowly moving, dilute suspension clouds (cf. Stow et al., 1996). The deposits of this association are either comparable with deep basinal mud or with slope mud (Mutti and Ricci Lucchi, 1978). A slope origin of this association is strongly suggested by the juxtaposition of this association with the channel and overbank—levee deposits.

Facies association Ⅳ : depositional fan lobe

Description

The successions of this association are 2 to 7 m thick. They show strongly parallel bedding with consistent interbedding of sandstones and mudstones, which are generally arranged in up to 4 m thick, thickening- and coarsening-upward sequences (Figs. 5, 8). They either occur isolatedly or stacked vertically.

In the lower part of the thickening- and coarsening-upward sequences, sandstone is very fine- to medium-grained, and occurs in beds commonly less than 15 cm thick. The sandstone:mudstone ratio is low, approximately 1:2 to 1:3. The sandstone beds have a sharp and flat base with few scours, and are commonly graded. Some contain ripped-up mud clasts, which tend to be concentrated towards the top of the bed. Internally many of the sandstones are massive and are described as Ta beds. Locally present are Tab, Tac, Tb, or Tc beds. The upper part of the sequences comprises generally medium-grained sandstones with interbeds of mudstone. The sandstone beds are up to 1.2 m, most commonly 10 to 60 cm, thick. The sandstone:mudstone ratio is 2:1 to 1:1. The basal surfaces of the sandstone beds are sharp and smooth, but locally show shallow scours and bulbous current marks. Abundant mud clasts are common in the sandstones, either scattered throughout the bed or concentrated in the upper part of the bed. The thickest bed contains large mud clasts up to 1 m in long dimension. The sandstones are generally graded, especially in the upper part of the bed, but have a sharp contact with the overlying mudstone. Most of the beds are internally structureless (Ta beds); the Tab or Tb beds are locally observed.

Interpretation

The sandstone beds of this association are identical to classical turbidites like those of the association Ⅱ. Rhythmic interbedding of sandstones and mudstones, highly parallel bedding, and general absence of basal erosion features in the sandstone beds are indicative of deposition from the unconfined sheet flow of turbidity currents on the depositional surface. The predominance of Ta turbidites, even in the case of thin beds, suggests rapid deposition of a sand fraction, probably due to rapid reduction of a slope. The finer fractions would have moved further down slope as a dilute turbidity current. An alternative interpretation is that the maturity of turbidity currents was low enough to develop poor longitudinal grain size gradient within a flow (Kuenen and Menard, 1952; Middleton, 1970; Komar, 1972).

The thickening- and coarsening-upward sequences are interpreted in terms of outgrowth of a depositional lobe from a mouth of a channel onto the basin plain (Walker, 1978, 1984; Stow, 1985). The consistently thin (< 4 m) thickness of the sequences implies only a minor progradation of a lobe. This suggests that the channels feeding sediments were minor and shallow, and that channels were not stable but rapidly switched their position laterally (Walker 1985).

Facies association Ⅴ : lake basin floor

Description

This association is characterized by thick mudstones, which consist of regularly alternating dark- and light-gray layers (Fig. 9). These layers are 1 to 30 mm, most commonly less than 10 mm, thick, and form varve-like deposits. The dark layers consist of clay-size materials and are generally less than 5 mm thick, whereas the light layers are made up of clayey silt or silt and have variable thicknesses. The basal surfaces of the light layers are sharp and flat. The upper contact with the overlying dark layer is either sharp or gradational. Many of the light layers are internally graded and finely parallel-laminated, and they can be described as Td or Tde beds. Some show small-scale, ripple or climbing-ripple cross lamination which is covered by fine parallel lamination (Tcd beds). Such layers are slightly coarser grained and generally comprise coarse silt-grade materials.

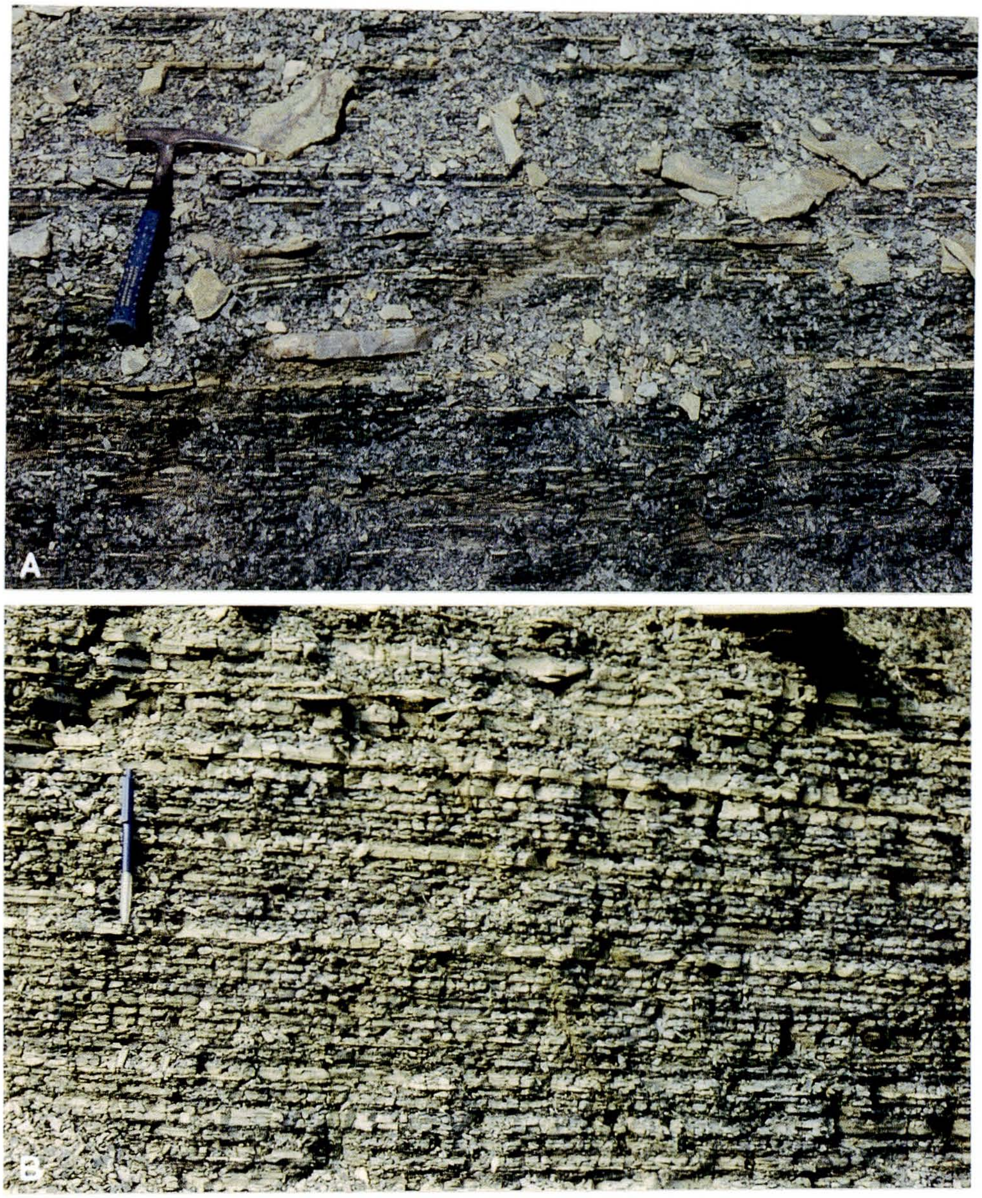

Fig. 9. Lake basin-floor deposits. (A) mudstones in the lower part of Unit B, to the south of section A. (B) Varve-like deposits underlying depositional fan-lobe sequence, section A.

Interpretation

Millimeter-thick, regularly alternating layers of fine and coarse sediment, similar to those of this association, are well known from modern and ancient lake deposits (Talbot and Allen, 1996). They may represent annual rhythms of sediment accumulation, that is, varves. The well-documented examples are the results of glacially influenced sedimentation (e.g. Ashley, 1975) or of thermoclinal sedimentation in stratified lakes (e.g. Sturm and Matter, 1978). It seems that the varve-like deposits of this association resulted from such annual sedimentation cycles. A thermocline origin is preferable in a warm climatic condition as suggested by Pandya (1990). On the other hand, the coarse layers of this association are somewhat thicker than those in typical varves; layers a little under 10 mm thick are common; some attain 30 mm in thickness. In addition, many coarse layers represent deposition from turbidity currents, as revealed by grading and internal stratification sequences comparable with the Bouma sequence. These facts suggest that the varve-like deposits of this association are probably of multiple origin, and that some of the coarse layers were deposited from turbidity currents which were not related to annual sedimentation cycles. Such an interpretation is consistent with the closely related occurrence of this association with the fan-lobe turbidites (Facies association Ⅳ). The thin, base-cut-out turbidites (Td ,Tde, and local Tcd beds) indicate deposition from low density, di-

Table 1. Summary of paleocurrent data of Unit B of the Talchir Group.

Sector Number	Facies association	Number of measurements	Mean paleocurrent direction
1	Fan lobe	20	30
2	Fan lobe	17	353
3	Overbank and levee	26	341
4	Overbank and levee	19	344
5	Overbank and levee	15	356

lute turbidity currents spread over the lake basin floor.

Paleocurrents

Paleocurrents of Unit B in the present area were already reported by Das and Pandya (1997), who analyzed the regional paleoflow and sediment-dispersal pattern of a part of the Talchir basin, including the present area. All the measurements in Unit B were obtained from asymmetric current ripples. The sector numbers 1 to 5 in Fig. 3 correspond to numbers 7 to 11 in Das and Pandya (1997), respectively. The measurements in the sectors 3, 4 and 5 were derived from the overbank and levee deposits (association Ⅱ) of this study and those in sectors 1 and 2 from the fan-lobe deposits (association Ⅳ). The analytical results are summarized in Table 1. These measurements indicate a broadly northward dispersal of detritus, with slight swing towards northeast and northwest (Fig. 3), suggesting lateral sediment supply during the Unit B period in the northwest–southeast trending, elongated Talchir basin.

Depositional Model: Conclusions and Discussion

Following the deposition of conglomeratic alluvial fan deposits in Unit A, the succession of Unit B was deposited in a lacustrine regime (Pandya 1990). Thick mudstones in the lower part of Unit B (Fig. 4) are contiguous to the varve-like, lake basin-floor deposits (association Ⅴ) in the study interval, and indicate deposition in a deep basinal environment. Transition from basin-margin alluvial fan to deep lacustrine basin should have caused the development of a steep lake-margin slope. The study interval of the upper part of Unit B demonstrates deposition in such lake-margin slope and base-of-slope environments. The closely related occurrence of the facies associations Ⅰ, Ⅱ and Ⅲ (Fig. 5) represents lake-margin slope (association Ⅲ) dissected by channels (association Ⅰ) which were accompanied by overbank and levee deposits (association Ⅱ). On the other hand, the combination of the facies associations Ⅳ and Ⅴ (Fig. 5) is attributable to the base-of-slope sedimentation. High-density turbidity currents flowed down-slope into the lake basin via channels dissecting the slope. Sediments delivered from the mouth of a channel were deposited at the base-of-slope, forming a sublacustrine fan lobe (association Ⅳ) which prograded onto the lake basin floor (association Ⅴ).

The succession of Unit B reveals, as a whole, a gradual change in the depositional environments within the lake; the basin-floor mudstones in the lower part are gradually replaced upward by fan-lobe sequences formed on the base-of-slope, which, in turn, grades upward into the deposits originating on the lake-margin slope dissected by channels with the levee (Fig. 5). This progression, in conjunction with the paleoflow pattern, implies basinward progradation of the steep lake-margin slope, indicating transverse filling of the elongated lake basin.

Channels on the lake-margin slope were small-scale and were rapidly filled with frequent lateral shifting, as revealed by relatively thin channel-fill sequences and the multistoried and multilateral channel-fills. The development of small feeder-channels was probably related to a small catchment of the hinterland, in which only local streams drained. Well-developed overbank and levee deposits closely associated with the channel fills are indicative of frequent spill-over of sediments from the channel. The shallow depth of the channels should have been primarily responsible for active spill-over sedimentation on the levee and overbank area. The upper portion of the channel flows was probably directly overspilled (cf. Chough and Hesse, 1980; Tanaka and Maejima, 1992). The resultant overbank and levee deposits thus show features indicative of deposition from high-energy turbidity currents, namely basal scours, coarse grain size in spite of thin bed thickness, and presence of ripped-up mud clasts. The entrained layer of the channel flows spread further outside the zone of active spill-over sedimentation onto the slope as a low-concentrated suspension cloud. Fall-out of fine materials from such a dilute cloud formed thin, graded and laminated silty intercalations within the slope mudstones. In many instances, however, the over-spilled suspension cloud would have continued to flow down slope into the deep basin, as suggested by general paucity of suspension fall layers in the slope mudstones compared with the abundance of levee and overbank sandstones. In this context, some of the silty layers in the lake basin-floor deposits may represent deposition from such a dilute flow.

Turbidity currents, which flowed down the channel, deposited their sand fractions at the base-of-slope due to reduction of slope and to releasing of a flow from a channel to unconfined depositional surface, forming a depositional fan lobe. After deposition of sand fractions on the lobe, the residual low-concentrated flow further spread out onto the lake basin floor and deposited the thin, base-cut-out turbidites. As a consequence of shallow channel depths and rapid lateral switching of the channel position, individual depositional lobes were short-lived and of small scale. Hence, only a minor progradation of lobes took place onto the lake basin floor, resulting in consistently thin lobe sequences. The depositional lobes were essentially unchanneled. This is different from many modern and ancient submarine fans and sublacustrine fans, which generally exhibit distinct channels on their inner to mid-fan portions (cf. Walker, 1978, 1984; Scholz et al., 1990). The complete absence of the channeled portions is also suggestive of the immature development of the fan lobes owing to deposition at the mouth of small-scale, short-lived channels.

Acknowledgments

We are indebted to B. Mishra (Government College), R. N. Hota (Ravenshaw College), S. K. Sahoo (Utkal University), D. S. Patnaik (Dharanidhar College) for their assistance in the field. J. Tanaka (Osaka Institute of Technology) is acknowledged for his suggestions on turbidite sedimentation. The manuscript benefited from reviews by journal reviewers, K. Hisatomi (Wakayama University) and A. Yao (Osaka City University). Partial funding for this research was provided to W. M. from OCU Oversea Science Mission Program.

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Manuscript received November 11, 1998.
Revised manuscript accepted February 16, 1999.