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DEPOSITIONAL PROCESSES IN A LATE MIOCENE POSTTECTONIC BASIN: TERRAVECCHIA FORMATION, SCILLATO BASIN, SICILY

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Abstract: Terravecchia Formation in the Scillato Basin is a good example of development of a post-tectonic basin. Practically continuous exposures across that basin give the rare possibility to observe the lateral distribution of lithofacies and gradual changes of sedimentary succession from an alluvial fan, fluvial plan to lacustrine and, eventually, to marine setting. The alluvial fan deposits are generally represented by polymictic, disorganised or crudely organised conglomerates representing mainly flow and debris flow deposits. The fluvial plain association is characterized generally by cross-bedded sandstones with streaks of conglomerates laid down within a channel bar system. Flood-plain deposits are subordinate. Sedimentary structures suggest deposition in a braided river. The fluvial plain association pass laterally to lacustrine/fluvial plain deposits represented by grey to pinkish mudstones with channelised sandstones. As an effect of subsidence the Scillato Basin was invaded by marine/brackish environment, and marly mudstones and siltstones with subordinate sandstones were deposited. That variability of sedimentary facies can be explained by vertical tectonic movements.

Abstrakt: Późnomioceńska formacja Terravecchia zachowana w basenie Scillato, stanowi dobry przykład rozwoju basenu posttektonicznego. Ciąg bardzo dobrych odsłonięć w poprzek basenu pozwolił na szczegółowe obserwacje rozkładu litofacji, struktur sedymentacyjnych oraz asocjacji facjalnych i ich wzajemnych związków. Wyróżnionych zostało kilka środowisk sedymentacyjnych, od stożka aluwialnego, przez rzekę roztokową po środowisko jeziorne i morskie. Osady stożka aluwialnego reprezentowane są przez czerwone i żółte, polimiktyczne zlepieńce, o strukturach zarówno bezładnych jak i uporządkowanych, powstałe w wyniku działania prądów i spływów rumoszowych. Osady rzeki roztokowej to głównie przekątnie warstwowane piaskowce związane z różnego rodzaju łachami piaszczystymi. Mułowcowe osady równi zalewowych zachowały się tylko sporadycznie. Osady rzeczne przechodzą lateralnie w mułowcowe osady jeziorne z licznymi osadami kanałowymi w ich dolnej części. Pod koniec rozwoju basenu, w rezultacie subsydencji tektonicznej, nastąpiła ingresja morska i powyżej osadów rzeczno-jeziornych rozpoczęła się sedymentacja osadów brakiczno-morskich z poziomami fauny.

Key words: sedimentological structures, river deposits, postectonic basin, Sicily

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INTRODUCTION

Upper Miocene (Upper Tortonian–Lower Messinian) deposits in the northern Sicily represent a post-tectonic molasse which developed on the already folded, overthrusted and partly eroded Numidian and Sicilidi tectonic units (Fig. 1). This molasse, known as the Terravecchia Formation (Flores, 1959; Schmidt di Friedberg, 1964-65), was sourced in part from an older orogen, mainly the Numidian Unit uplifted during the Late Tortonian. The Terravecchia Formation is represented by conglomerates, sandstones, marls and patch reefs, all showing diachroneity (Catalano, 1979; Catalano *et al.*, 1978). Generally, they form a sequence from alluvial clastic sediments to marine pelites with several cycles connected with changes in the rate of subsidence and/or amount of supplied materials. The distribution of facies implies that the sedimentation was generally controlled by synsedimentary tectonic movements and migration of basement subsidence towards the north. The development of the Terravecchia Formation terminated during the Messinian crisis and sedimentation of evaporites. The age of the Terravecchia Formation is attributed to the Upper Tortonian and Lower Messinian based on micro- and macro-fossils (Ruggieri *et al.*, 1969; Catalano & Sprovieri; 1971; Abate *et al.*, 1988). Scarcity of fossils within the terrigenous deposits creates difficulties in their correlation, but the available data

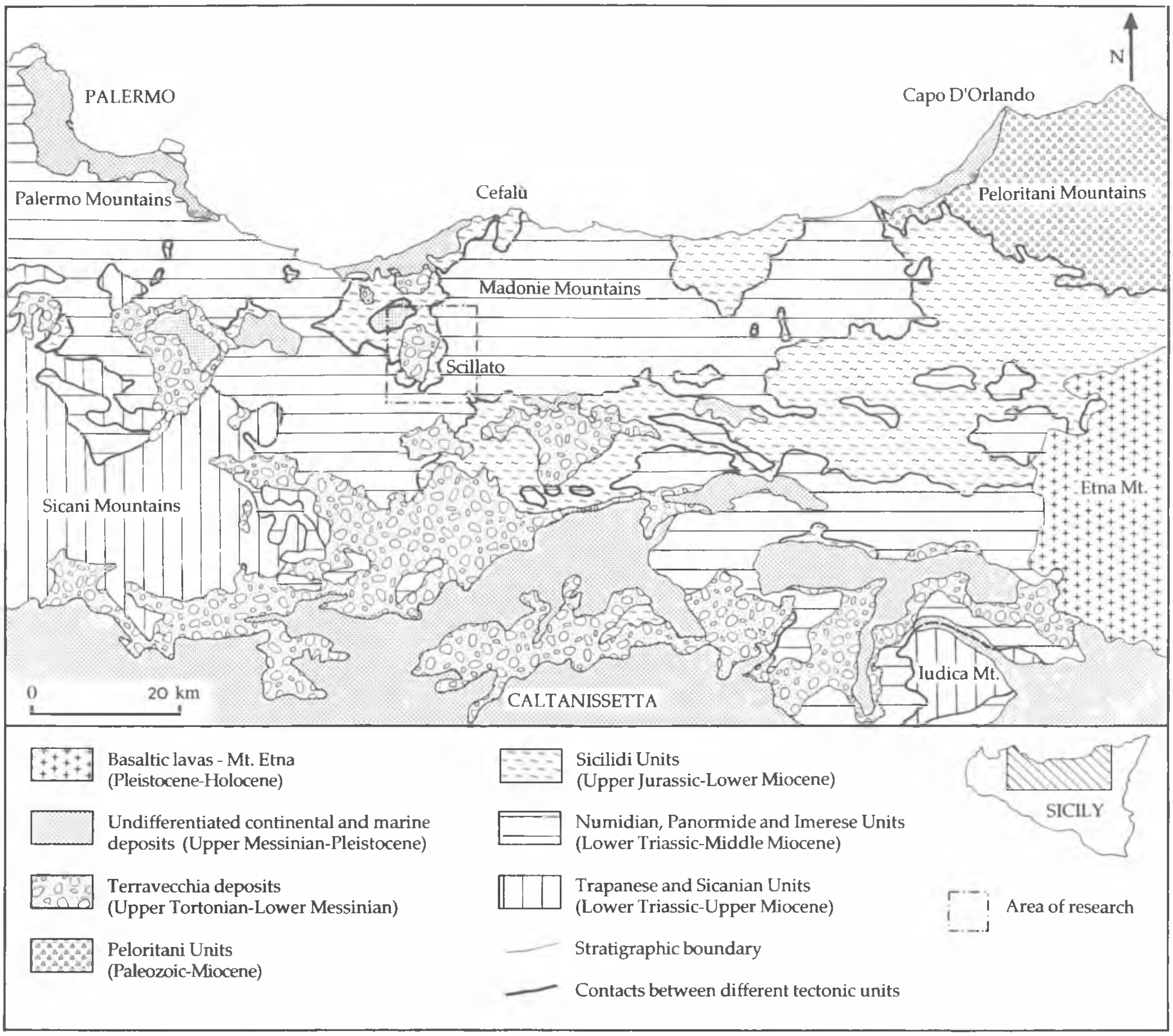


Fig. 1. Geological map of the northern Sicily (modifyed from Bigi *et al.*, 1992)

point to a distinct diachroneity of these deposits (Catalano, 1979).

Syn- and post-sedimentary tectonic movements resulted in confinement of the Terravecchia Fm. into several basins. One of these basins, the Scillato Basin, situated along the Imera River (Fig. 2), provides an unique opportunity to examine lateral and vertical transition from the continental to marine facies. Eastern, western and southern boundaries of the basin are erosive and northern boundary of it is partly terminated by fault.

The first sedimentological description of the sediments in the Scillato Basin was done by Abate *et al.* (1990), who distinguished there alluvial fan and fan delta deposits. The following studies were devoted to facies relationship and suggested also the occurrence of shoreline facies (Abate *et al.*, 1993, 1996). Jones (1994) identified there a succession of braided river deposits, shallow marine sands and deeper marine clays.

This study presents a detailed analysis of sedimentary structures, grain size, paleoflow indicators and facies relationship in natural exposures along the Imera river and its tributaries. Samples were processed for microfossils analysis. Individual facies were documented by photos. The facies associations were studied by constructing vertical columnar sections. Relying on these studies the sedimentary conditions are presented and a model of paleotectonic evolution of the Scillato Basin is proposed.

GEOLOGICAL SETTING

The Scillato Basin is a small piggy-back basin ca. 3.5 km broad and 6.0 km long, entirely separated from other areas occupied by the Terravecchia Fm. (Fig. 2). The comparison of its facies with those of neighbouring areas suggests that the separation of the Scillato Basin started already during sedimentation of the Terravecchia Fm. The age of the sediments in the Scillato Basin is defined as the Upper Tor-

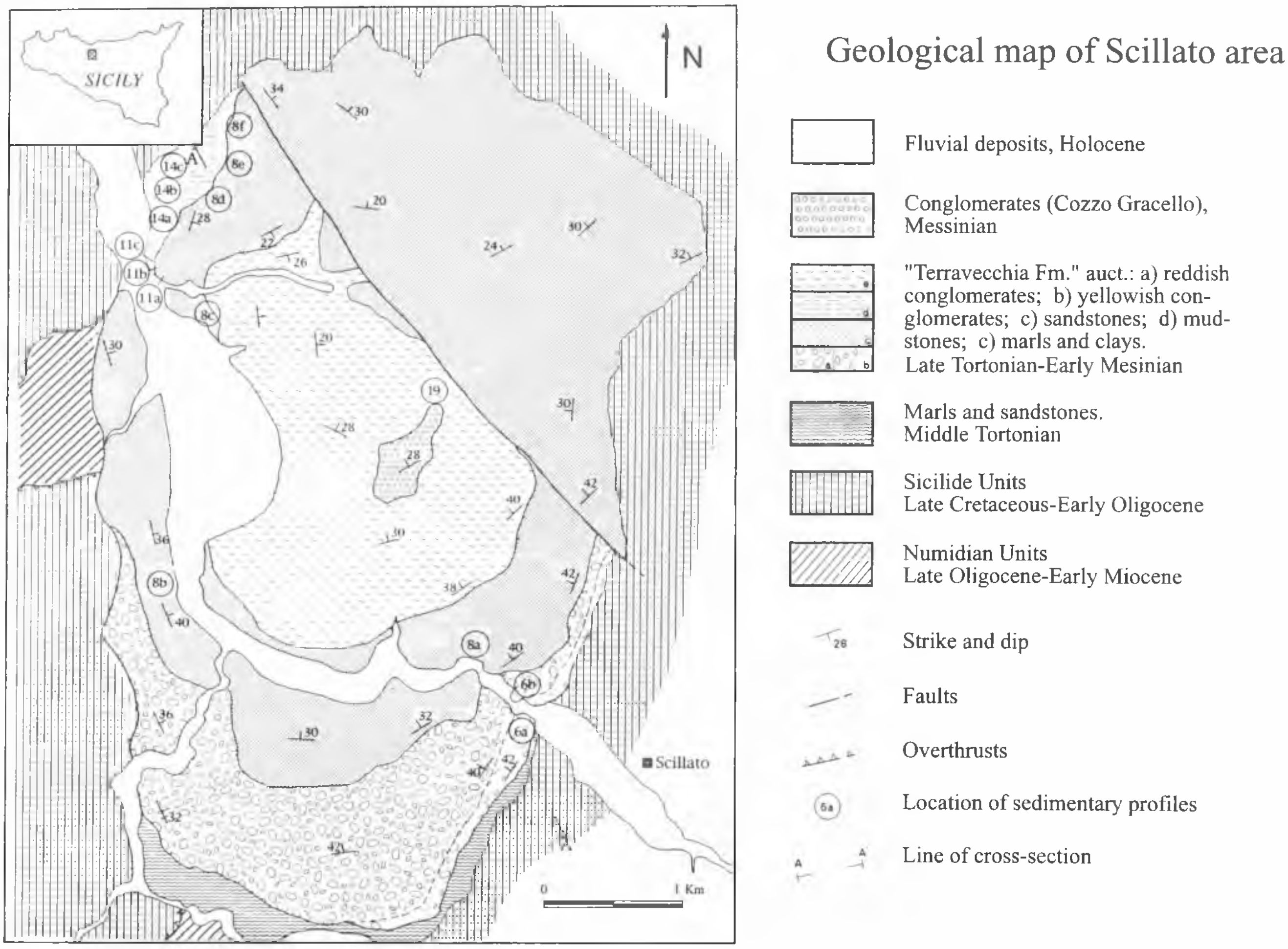


Fig. 2. Geological map of the Scillato Basin. Numbers in circle refer to numbers of figures with litho-stratigraphic sections

tonian–Lower Messinian, on the basis of the Middle Tortonian foraminifera which occur in marls underlying the basin and the Early Messinian marine fauna found in the upper part of the Terravecchia Fm. (Crimi, 1984,1987)

Terravechia Fm. in the Scillato Basin fills a broad, gently inclined brachysyncline. Its northern part is directly underlain by the Sicilidy and Numidian tectonic units. The southern part of the basin rests on eroded marine marls, marly sandstones, conglomerates and sandstones of a Middle Tortonian age, which represent a remnant of an older sedimentary cycle (Fig. 3 & 4). The Late Tortonian–Early Messinian sedimentary cycle which represents the main infill of the basin, is represented in the lower part by diversified conglomerates, sandstones and marls (Fig. 4). Generally, they record a vertical transition from continental to marine environments. The whole sequence is more than 1200 m thick.

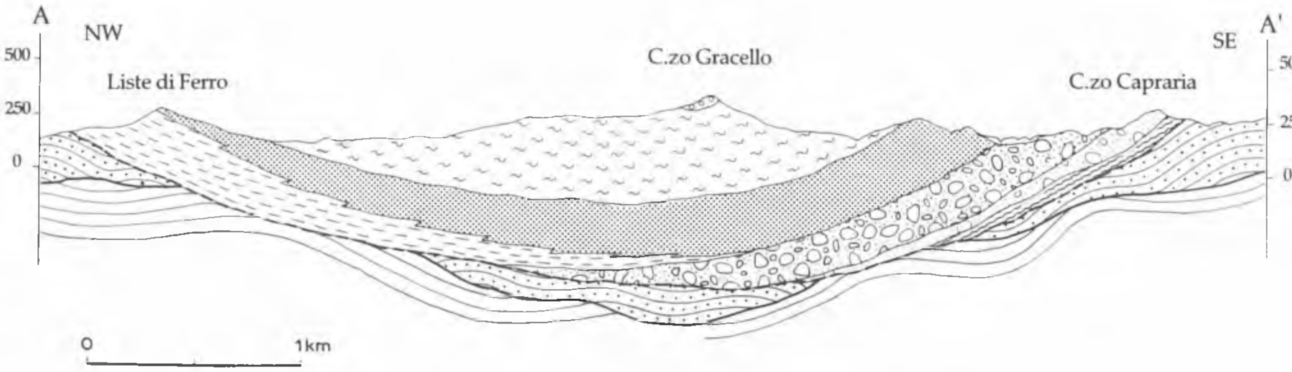


Fig. 3. Cross section of the Scillato Basin. Explanation of symbols – as in Fig. 2

Fig. 4. Lower part of the Facies association 1 – red conglomerates lying directly on the Middle Tortonian. Massive, partly imbricated (1 – facies 1), sheet-like (facies 5), matrix supported (facies 2) and channel fill (facies 6) conglomerates are visible. Intercalation of very coarse sandstones, locally laminated. Left bank of Imera river

LITHOFACIES

Lithofacies were mainly defined on the basis of grain size, bedding, sedimentary structures and shape of units. They are partly based on work by Ramos *et al.* (1986). Within the Terravecchia Formation 19 facies were distinguished.

Facies 1. Massive, crudely organised, imbricated, clast-supported conglomerates (Facies Aa & Ab of Ramos & Sopena, 1983) (Figs 5A & 5E). They are thick-bedded (up to a few m thick) with sharp, erosive bases. Clast are sub-rounded-rounded, from few cm to tens of cm in size, usually crudely imbricated. Sporadically, conglomeratic layer, pass upwards into laminated coarse grained sandstone (Fig. 5F). These conglomerates may be regarded as the products of fluidal sediments flows (Nemec & Steele, 1984).

Facies 2. Massive, matrix supported conglomerates (Fig. 5D) up to several m thick. This facies displays disorganised fabric. Clasts-size reaches up to tens of cm. Some clasts are arranged vertically. Locally, crude bedding is visible. Near the bottom, there are zones with inverse grading (Fig. 5B), while the uppermost part may show normal gradation with conglomerates passing quickly to laminated, very coarse sandstones. Such conglomerates were deposited by diversified debris flows (comp. Nemec & Steele, 1984).

Facies 3. Graded conglomerates (Fig. 5C). This facies occurs infrequently. Gradation, often inverted in the lower part of the layer, is the main component of the facies which displays a relatively high sandy matrix content. The clasts are usually a few cm in size, sporadically they are larger. Thickness of layers attain up to several m. Base of layers is sharp, erosive. Such sediments may represent deposits laid down by high density turbidity currents (Lowe, 1976, 1982).

Facies 4. Planar cross-stratificateded conglomerates (Fig. 11). This facies is generally rare. It displays tabular, gently concave cross-stratification. Clasts are rounded, a few centimetres in size. The conglomerates sometimes pass laterally into cross- stratified very coarse sandstones. The latter might originate from avalanching of sediments transported by traction current; they are interpreted as foreset beds of a small, local, Gilbert-type delta (see Picard & High, 1973).

Facies 5. Sheet-like conglomerates. (Fig. 6C). They display clast-supported or matrix-supported textures and are often graded. Their thickness may reach more than 1 m. The discussed conglomerates occur as separate layers. They may be regarded as deposited by catastrophic flows (see Collinson, 1996).

Facies 6. Channel-fill conglomerates (Figs 4 & 10). This facies is represented by elongated lens-like bodies,

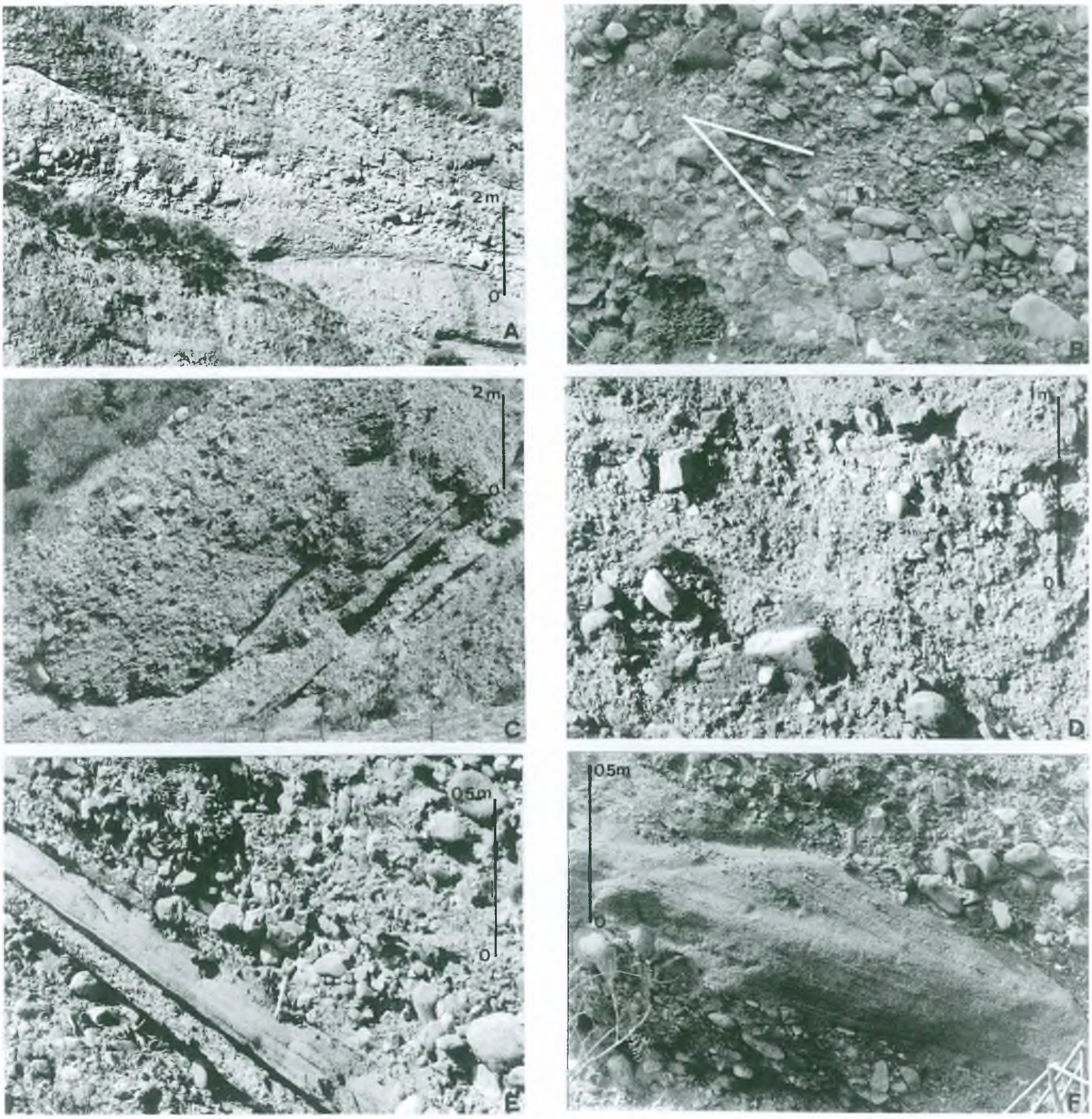


Fig. 5. Main facies and structures associated with conglomeratic alluvial fan deposits (Facies association 1): **A.** Detail of Fig. 4, massive, crudely organised conglomerates (facies 1) visible in the upper part of picture and channel fill conglomerates (facies 6), sheet like conglomerates, partly channelised. Lower part of the Facies association I. **B.** Clast-supported conglomerates, small channel. Above that channel, coarsening-upward (shear zone), imbricated conglomerate. Facies 2 – middle part of the Facies Association I. Left bank of Imera river. **C.** Graded conglomerates with inverse grading in the lower part and normal grading in the upper part. High density turbidity currents deposits (facies 3). Right bank of Imera river. **D.** Massive crudely organised, matrix-supported fine-grained conglomerates (Detail of Fig. 4). Visible vertical clast. Debris flow deposit (facies 2). **E.** Partly matrix-supported conglomerate (mudflow deposit), interbedded by finer material (facies 1). Left bank of Imera river. **F.** Intercalation of cross-bedded, coarse-grained sandstones within conglomerates. Gravels in the conglomerate are inclined generally in the same direction as cross-bedding (facies 1). Left bank of Imera river

with erosive, concave basis and sharp flat upper surfaces. Their thickness is up to 2.0 m, their width reaches up to 20 m. The conglomerates generally show the presence of grading, there are also cross-bedded or massive conglomerates (Fig. 14) showing a multi-storey pattern. This facies is a product of variable, mainly tractional flows.

Facies 7. Conglomerate lags (Figs 7C, 7G & 8F). They are thin-bedded, commonly only a few clasts or even one clast thick. Lateral extension is from few decimetres up to dozens of metres. Usually, they occur at the base of a sandy

Fig. 6. Top part of conglomerate facies association: Sheet-like (C) conglomerates (facies 7) with mudstone (M) intercalation (facies 17). Left tributary of the Imera River

layer. Locally, however they rest on an upper surface of a sandy layer. The conglomerate lags generally record winnowing by strong currents.

Facies 8. Sandstones with planar cross-bedding (Figs 7A & 7B) represent the most abundant facies. Cross-bedding is tabular, concave, less frequently sigmoidal (comp. Facies TB of Ramos *et al.*, 1986). Different types of cross-bedding are commonly interbedded. Lower surfaces of layers are usually flat. Grain size of the sandstones ranges from coarse to fine. Thickness of sandstones varies from few cm to dozens of cm. They are regarded as products of migrating dunes. In this facies, a separate (Subfacies 8a) subfacies may be distinguished. It is represented by medium-bedded sandstones with an assemblage of a variety of current structures, starting as horizontal lamination, passing upwards into cross-stratified lenses, and topped by ripple cross-lamination (Fig. 10B), the latter are finer-grained and micaceous. The subfacies 8a was deposited by decelerating currents; the uppermost part of it displays a slightly different current direction.

Facies 9. Sandstones with trough-bedding (Figs 7D & 7H) are of minor significance (Facies T and t of Ramos *et al.*, 1986). They form lenticular bodies with concave erosional base. The throughs are up to several tens of cm deep and up to a few m wide. They represent local channelfill deposits.

Facies 10. Sandstones with herring-bone cross-bedding (Fig. 7F). This facies is characterised by bimodally dipping foresets. Usually, these structures are interpreted as formed in a tidal zone (e.g. Leckie & Singh, 1991). However in this facies there is a lack of others structures and sediments connected with a marine environment, therefore herring-bone cross-bedding was form by a drastic, local changes of river flow directions.

Facies 11. Sandstones with parallel lamination (Figs 7E & 8C). Their thickness range from a few cm to few m. The sandstones are usually medium-grained. In some cases, at the top of layers appear small symmetrical ripples. Locally, traces of burrows occur. This facies is interpreted as a product of upper flow regime (upper-regime flat bedding) (e.g., Stear, 1985; Ramos *et al.*, 1986).

Facies 12. Sandstones with gradation (Fig. 7D) are of minor significance. This lithofacies consists of coarse- to fine-grained, graded sandstones. Commonly, they start as gravels. Their thickness ranges from few tens of cm up to two m. The base of layers is erosive. This facies generally represents deposits laid down by high-density currents. Sporadically, graded layers form medium-bedded, lenticular bodies which may be products of episodic, decelerating flows.

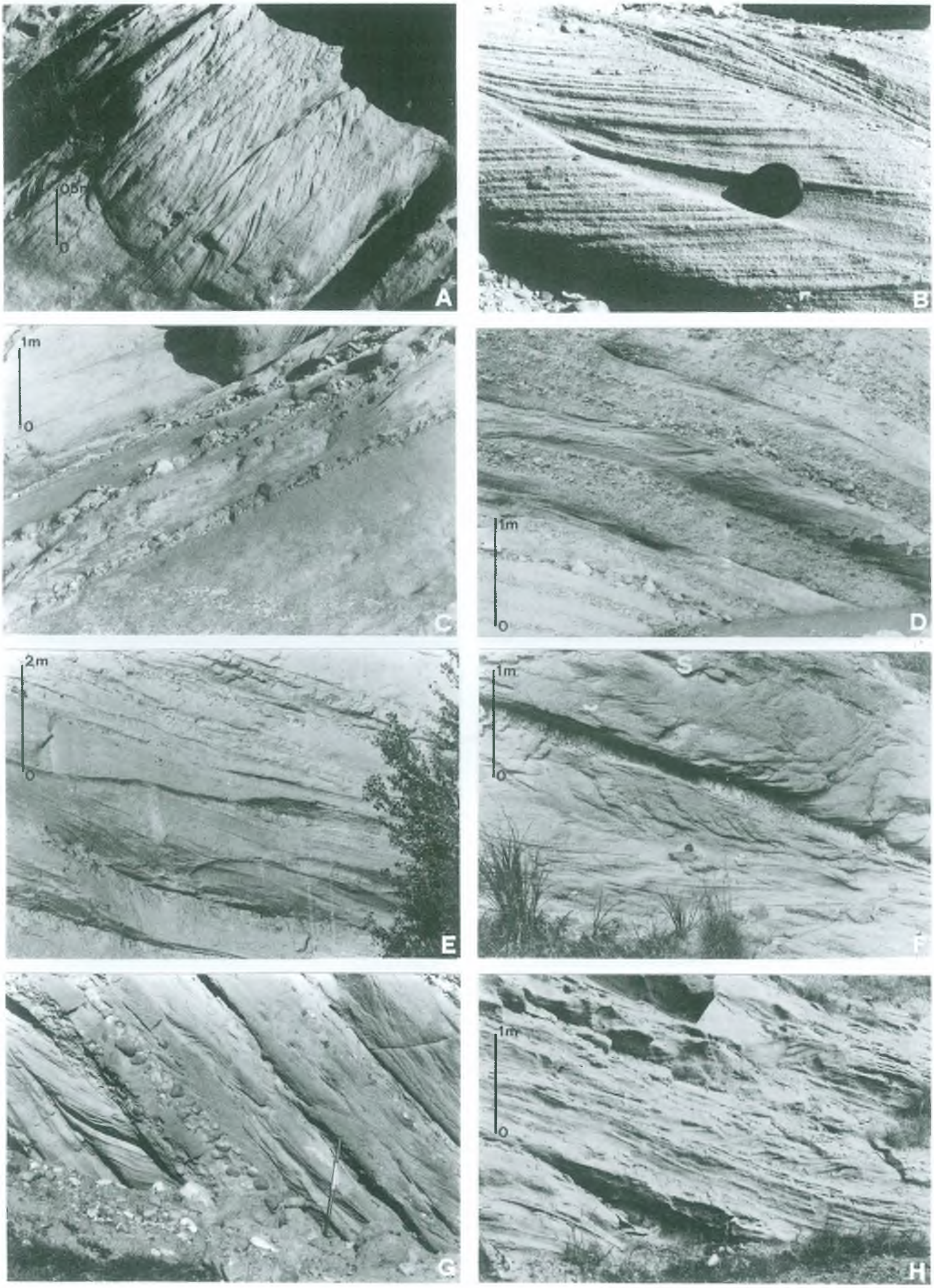
Facies 13. Massive, structureless, tabular or lenticular sandstones (Fig. 7E, at the top). This facies is represented by medium- to thick-bedded, medium- and fine-grained sandstones. It might originate as a result of rapid deposition by density currents connected with flood.

Facies 14. Sandstones with large ripples (Figs 8F & 8G). These dune bed-forms are generally straight, symmetrical or asymmetrical, with an amplitude of up to 10 cm and wave length from 30 to 50 cm. They are generally attributed to strong wave action in shallow water. The asymmetrical ones may be "formed by current-generated waves that are deflected towards the banks of the channel" (Picard & High, 1973) or be an effect of gentle traction current (Selley, 1988). Some sandstones bodies display flattened crests explained as an effect of water depth decrease.

Facies 15. Sandstones with bioturbation (Figs 8C, 8D & 8H). This facies is characterised by the presence of burrows, produced mainly by worms, on upper surface of some sandstones. They are generally irregular, although star-like structures are also visible. Appearance of traces-fossils was connected with a tranquil period.

Facies 16. Chanell fill sandstones (Figs. 9 & 10). This facies is represented by lenticular bodies with concave erosional base and flat upper surface, it occurs within facies 17. The channels are up to 3 m deep and tens of m wide. Sometimes, they are stacked and show lateral migration.

Fig. 7. Main facies and structures associated with braided river deposits (facies association II). Imera river: **A.** Facies 8. Planar cross-bedded sandstones of repeating sheet-flooding. Point bar deposits. **B.** Facies 8. Planar, slightly concave cross-bedded sandstones. Point bar deposits. Flow was obliquely away from viewer. **C.** Tabular cross-bedded sandstones with graded conglomerate lags (facies 7). Middle-fan. Channel and bar deposits. **D.** Tabular and trough cross-bedded sandstones (facies 9) with sheets of graded conglomerates (facies 5). Middle-fan. Channel deposits. **E.** Laminated medium grained sandstones (facies 11), partly channelised. In upper most part homogenous layer of sandstone (facies 13), below it a slump structure (s). Proximal part of fan. **F.** Layers with a variation of cross-lamination: low angle, ripple and planar, and in the upper part herring-bone cross-bedded sandstones (facies 10) are visible. Middle fan. Channel deposits. **G.** Cross-bedded sandstones with conglomerate lags (facies 7). **H.** Trough-cross bedded sandstones with washouts and small channels (facies 9). The lower part is built of parallel sandstone and mudstone layers (facies 9), locally with traces of burrowing. Distal fan. Channel-bar deposits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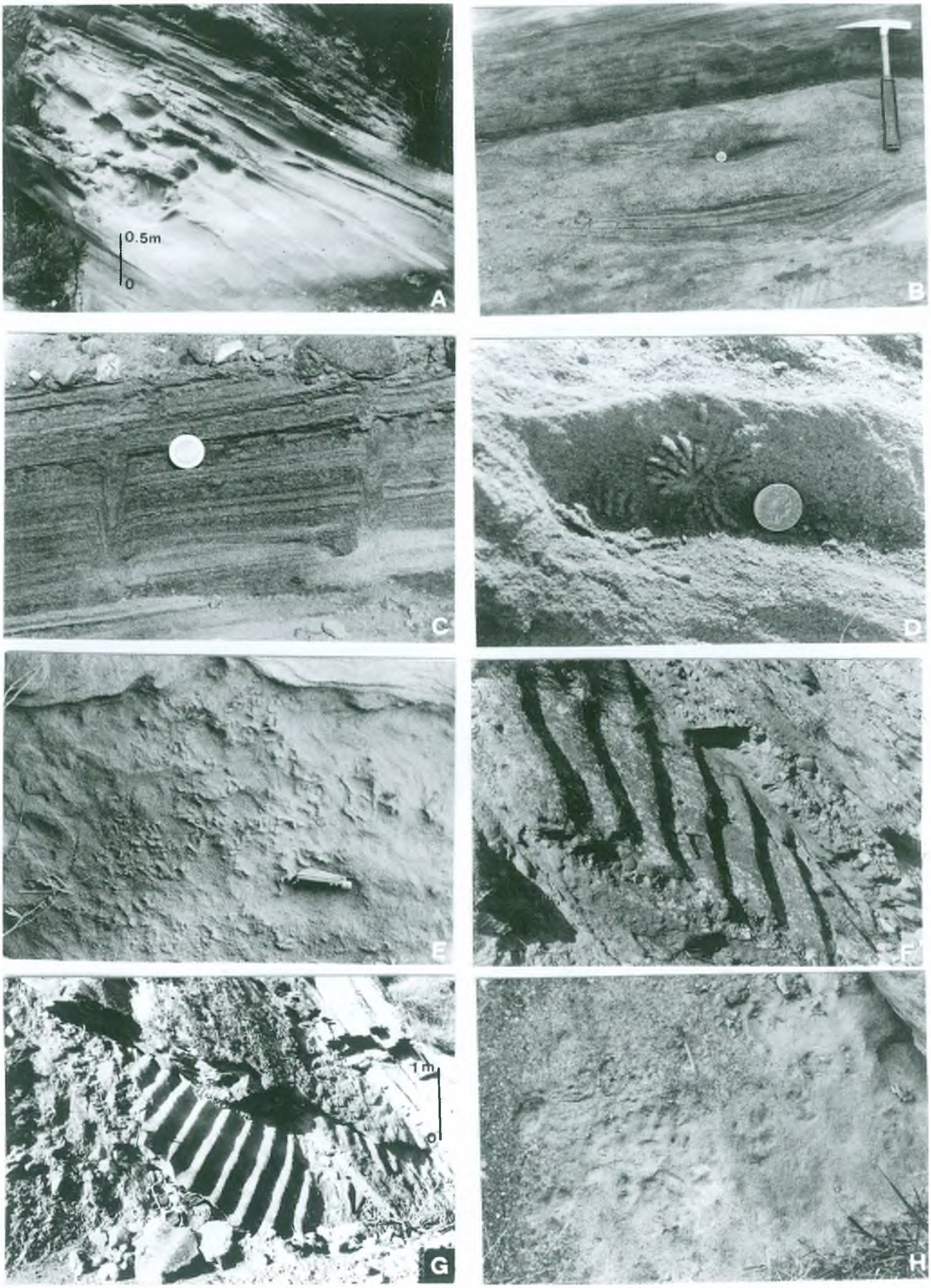
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The sandstones display a variety of sedimentary structures: lamination, trough cross-stratification and gradation. They represent channel-fill deposits. Medium- and thin-bedded, medium- to fine grained, cross-laminated sandstones (Facies 8) are sometimes connected with this facies. Generally, they form the uppermost part of channel deposits and may represent crevasse splay deposits (cf. Doktor & Gradziński, 1985).

Facies 17. Massive mudstones and sandy mudstone. Three subfacies (17a, 17b and 17c) may be distinguished. The subfacies 17a is composed of grey, ungraded, massive or poorly laminated mudstones and sandy mudstones, up to several m thick (Fig. 10). Locally, the mudstones are calcareous. This subfacies form complexes tens of m thick and are interpreted as low-energy environment deposits. The subfacies 17b is represented by individual layers (Fig. 6) forming intercalations in sandy or conglomeratic facies; they are products of rapid deposition by flood (cf. Collinson, 1996). The subfacies 17c consists also of grey massive mudstones and sandy mudstones with intercalations of silts, however its deposits are generally calcareous and contain sparse sandstone layers and levels with marine fauna (Fig. 12). This subfacies represents a low-energy marine/brackish environment. The above three subfacies are grouped together, being generally formed by subaqueous suspension sedimentation.

Facies 18. Massive mudstones with dispersed clasts. They are massive, sometimes contorted sandstone layers, very thick-bedded, containing dispersed extra- and intrabasinal clasts. Massive mudstones with large sandstone clasts may be interpreted as subaqueous deposits, from dense muddy currents, while contorted sandstones – as slump deposits, both being possibly connected with earthquakes.

Facies 19. Banded mudstones (Fig. 10 & Fig. 11). This facies is characterised by apperance in very thick massive or crude banded mudstones of vertical changes of colour, usually from pink-reddish or brownish, in the lower part of bed, to blackish in the uppermost part. Locally the sequence starts from grey mudstone This distribution of colour might be controlled by decreasing of the Fe^{3+}/Fe^{2+} ratio (cf. McBride, 1974) and by changes of organic carbon content (cf. Potter *et al.*, 1980). The mudstones, similar to Facies 17, represent deposits low-energy environment deposits.

FACIES ASSOCIATIONS

The following sedimentary facies associations in the main depositional cycle have been recognised within the Scillato Basin:

1 – red and yellow conglomerates,

2 – yellow, cross-bedded sandstones,

3 – mudstones and siltstones with lenses of sandstones and conglomerates,

4 – grey calcareous mudstones and siltstones with marine fauna,

These facies associations are partly interfingered, generally representing a succession from continental to marine environment.

Facies association 1: Red and yellow conglomerates (Fig.13)

The conglomeratic complex (Fig. 4), up to 150 m thick (Riparato Mt. profile) consists of thick-bedded (up to 5 m), disorganised or crudely organised clast- and matrix-supported, often amalgamated conglomerates (Facies 1–6 & 18). The conglomerate layers are bounded by sharp flat soles (Fig. 5C) and by erosional channels, up to 2 m deep. The channel-fills display cross-bedding. Clasts from few a cm up to 1 m in size, are generally well-rounded, often imbricated (Figs 5D). The conglomerates are polymictic. Pebble-size and still smaller clasts are represented by: sandstones from the Numidian Flysch, glauconitic sandstones, pelagic calcilutites, variable limestones (e. g. platform and reefs ones) derived from the Panormide Unit, shales from the "Argille Varicolori", and opaque quartz. Boulders are represented mainly by igneous (granites, porphyries) and metamorphic rocks. Within the conglomeratic complex, there are streaks of finer material, and some conglomerates terminate with parallel- or cross-laminated, coarse-grained sandstones.

The conglomeratic complex displays an overall upward-fining sequence. Towards its top the number of sandstone intercalations increases and thick layers of mudstones (Facies 18) appear. Current and/or wave ripples are often connected with the sandstone intercalations. Some mudstone layers display slump structures or contain dispersed sandstone clasts (Facies 18). The upper part of the sequence displays quick lateral facies changes. Locally, channels a few m deep and more than 10 m wide, cut the mudstones (Fig 13b).

There is a characteristic change in colour of the con-

Fig. 8. Main facies and structures associated with braided river deposits (facies association II). Imera river: **A.** Medium- and fine-grained sandstones with local ball and pillow structures due to water escape. In the upper part, horizontal parallel lamination (facies 11) formed by low velocity currents. Point bar deposits. Middle fan. **B.** A point bar sequence: low angle cross laminae at the base, trough cross-laminae, current-ripple laminae at the top, covered by a film of siltstone. Middle fan. **C.** "Escape structure", probably of organic origin in horizontal laminated sandstones. **D.** Star-like trace fossils. Upper surface of a sandstone bed (facies 15). Coin is 2 cm. in diameter. Proximal fan. **E.** Small irregular burrow traces (facies 15). **F.** Facies 14. Slightly sinusoid large ripples on top of conglomerate layer (Lag ripples), with partly flatted crests as an effect of changing of water depth. Hammer is 35 cm long. **G.** Facies 14. Straight crested large ripples, and starved ripples above. Middle fan. **H.** Animal spoors on the top of a sandstone. Middle fan

Fig. 9. Facies association III. Lower part, with channellised sandstones, represents flood plain deposits. The upper part is built of lacustrine mudstones (facies 17). Right bank of Imera river

Fig. 10. Facies association III. Isolated channel sand bodies (facies 16) in lower half of picture, thin sandstones connected partially with the channel-fill may represent crevasse splay deposits. Banded mudstone (facies 19) above that complex pass upwards to massive, grey mudstones (facies 17a). Fluvial sandstones in the uppermost part of the slope. Right bank of Imera river

Fig. 11. Lacustrine banded mudstones (facies 19) of vertical changes of colour from pink reddish to blackish in the uppermost part, with sporadic sheet sandstones. Grey marls (facies 18) in the uppermost part of the slope. Right bank of Imera river

Fig. 12. Facies association IV: **A.** Horizon with marine fauna, in the lowermost part of the picture (F), covered by thick series (G) of grey mudstones (facies 17b) passing upwards into grey and pale pink colour mudstones. **B.** Detail of horizon with marine molluscs

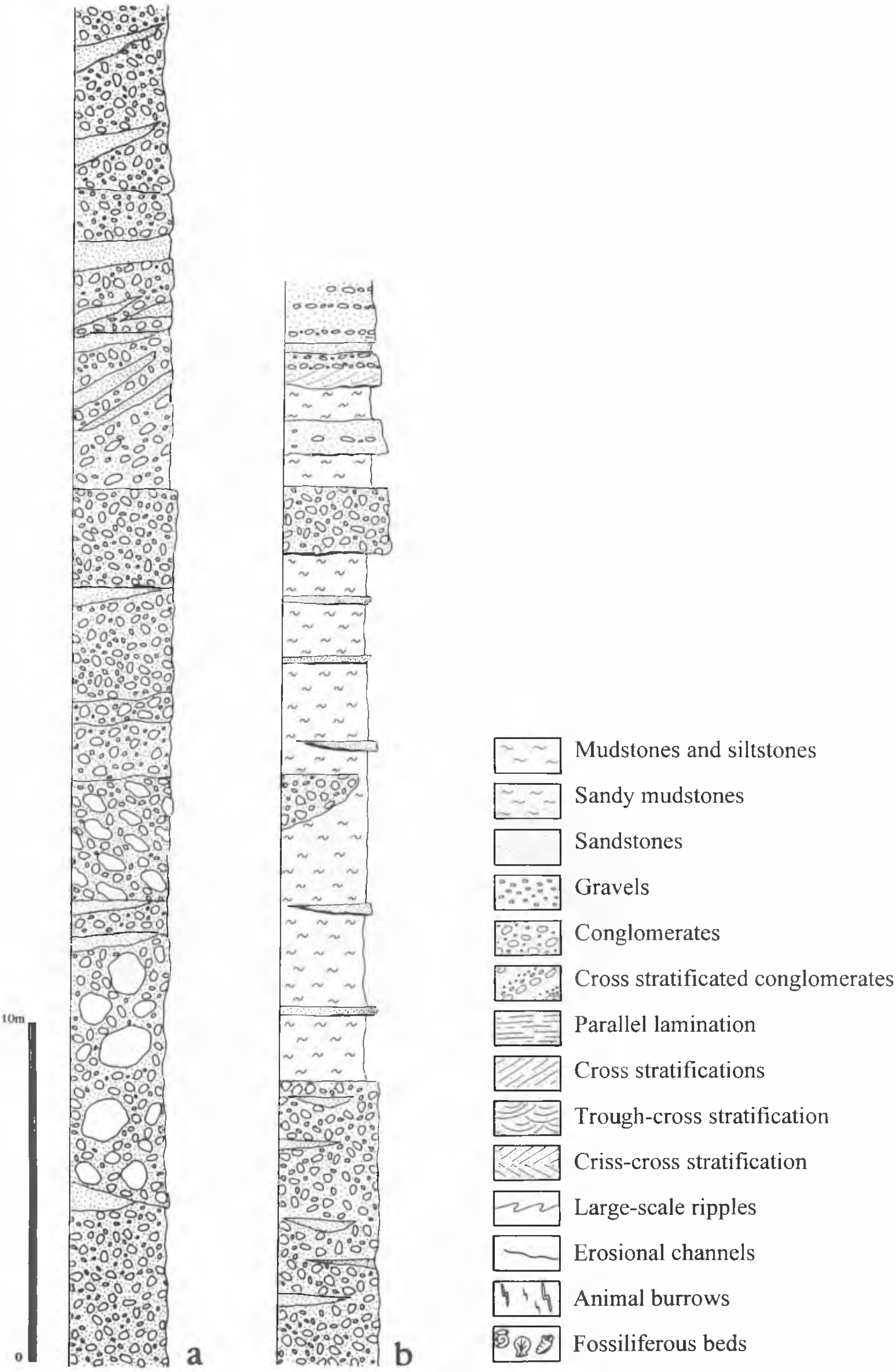


Fig. 13. Detailed lithostratigraphic section of alluvial fan deposits (Facies association I); **a)** lower part where Facies 1 and 2 prevail. In the higher part of profile a lateral accreted conglomerate with sandstone drapes is visible; **b)** uppermost part with ephemeral lake (flood plain) and channel deposits

glomeratic complex, from red in the lower part to yellow towards the top.

The observed current structures (cross-bedding and imbrication) suggest that the clastic material was transported generally from the north and north-east. A southern source was observed only sporadically, mainly within the upper part of the conglomerates.

The whole sequence wedges out rapidly towards the north. Due to later erosion, the southern extension of the conglomerate is unknown, however, in exposures situated 7 km towards the south there are no more conglomerates present and the Terravecchia Fm. begins with mudstones.

Interpretation

The observed sedimentary structures and lenticular shape of the conglomeratic body indicate that it represents subaerial alluvial fan deposits with an upward decrease deposition energy. The observed structures suggest that the fan was formed close to its source area (comp. Sanchez-Moya *et al.*, 1996), the latter situated towards north-east. The fining-upward conglomerate layers with imbricated clasts, and conglomerates with streaks of finer material and with floating larger clasts may represent braided stream flow deposits; those with unoriented or poorly imbricated clasts were probably deposited by debris-flows (cf. Nemec & Steel, 1984; Nemec & Postma, 1993).

Some well-sorted, clast-supported conglomeratic layers may represent sieve deposits (cf. Hooke, 1967). The differences in clasts roundness in conglomerates imply that the material was derived from sources situated at different distances; the composition of clasts is, probably, only partially representative of the source areas due to selective weathering and decomposition during transport. The upper part of the sequence with intercalations of massive mudstones shows interfingering of alluvial fan and lake or flood plain environments, and it can represent ephemeral interchannel lake deposits with channels and debris-flow clastic deposits. The observed distorted structures in mudstones, and the occurrence of pebbly mudstones are evidences of subaquueous slumping. The change of colour of conglomerates from red to yellow may be a result of climate change from semi-arid to more humid. Lack of river deposits on downcurrent prolongation of the described fan suggests that it could represent a terminal fan (cf. Kelly & Olsen, 1993; Parkash *et al.*, 1983).

Facies association 2: Complex of yellow sandstones (Figs 14 & 15)

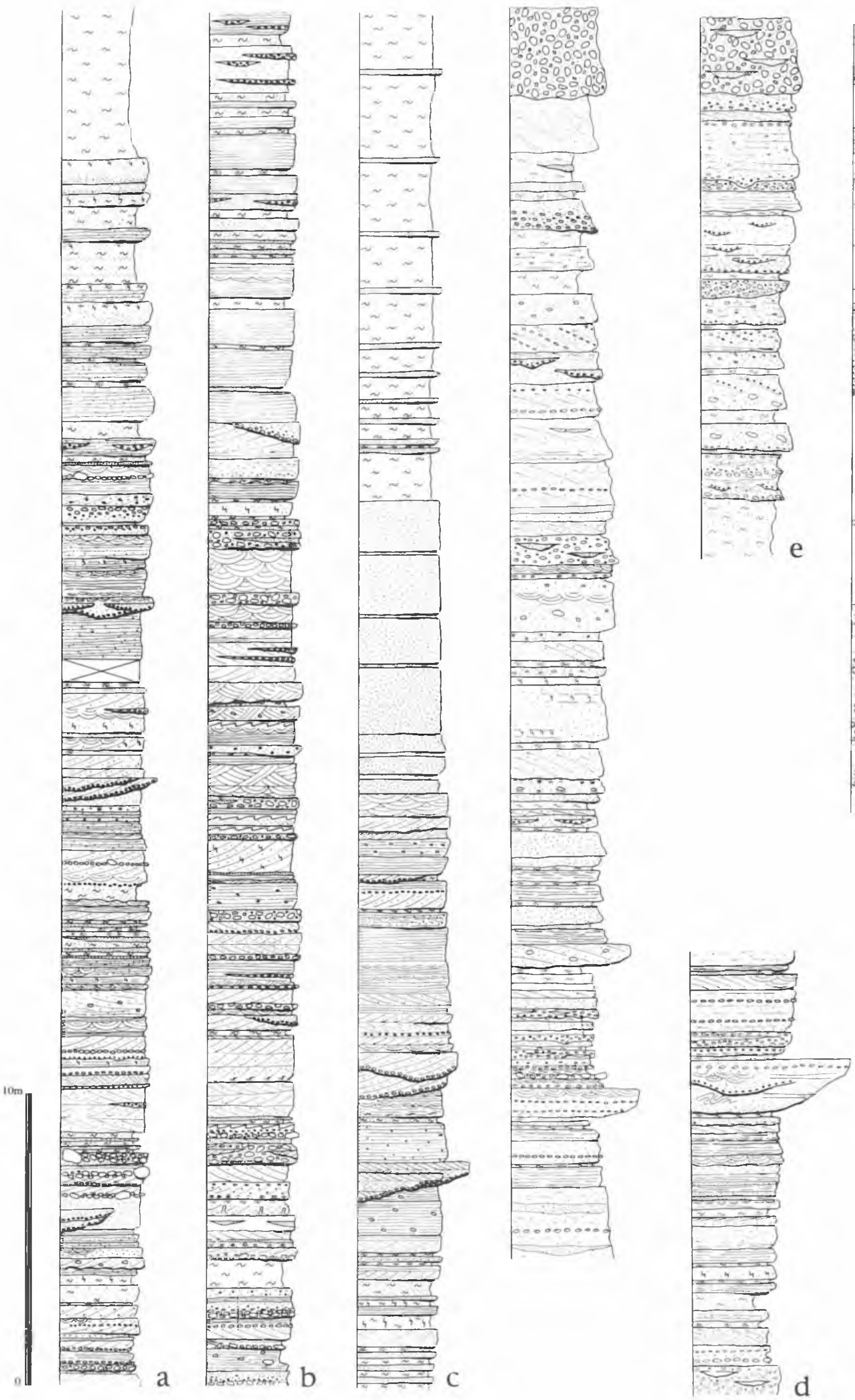
This facies association, more than 200 m thick, encompasses a broad range of sand-dominated sediments (Facies 7–17). They are represented mainly by yellowish, well sorted sandstones with unidirectional (Fig. 7A) and sporadic bidirectional cross-bedding (Fig. 7B). Intercalations of non-marine pelitic deposits are rare and thin, usually a few cm thick. The sandstones vary in grain size from very coarse to fine. Intercalations of thin- and medium-bedded conglomerates (Facies 4 & 7) play a subordinate role (Figs 7C & 7D), and they are generally confined to the western part of the basin. Layers boundaries tend to be sharp. Channels are rare, their depth do not exceeding a few tens of cm (Fig. 7E). Intercalations of non-marine pelitic deposits are rare and generally thin, usually few cm thick (Fig. 7F). In the distal, northern part, a majority of sandstone beds display alternation of medium-scale planar cross-bedding, trough cross-stratification and parallel lamination with small local wash-outs (Fig. 7H). Locally, laminae are gently folded or overturned, probably as a result of vertical movement of water (Selley, 1988). Occasionally, some beds show the presence of slump balls and pillows and/or irregularly distorted structures (Fig. 8A). Some sandstone beds displays characteristic sequence of sedimentary structures: pebbly basal lag is succeeded by medium-scale, low-angle cross-stratification with some horizontal lamination and medium-scale cross-bedding, the latter which is terminated by small-scale ripple bedding (Fig. 8B). The upper part of a bed is sometimes strongly bioturbated (Figs. 8C, 8D & 8E). In a few cases, on the top of beds, there are large-scale ripples with amplitude up to 10 cm and wave-length from 30 to 50 cm (Figs 8F & 8G). In one case, structures similar to animal tracks are visible on the upper surface of layer (Fig. 8H).

In the middle part of the profile, massive (14c) to diffusely parallel-laminated grey muddy sandstones, locally with scattered pebbles are present. They sometime occur as infill of broad and shallow channels. The upper part of mudstones occasionally display small-scale symmetrical or current ripplemarks. Towards the top of the sequence, the number of parallel-bedded sandstones increases. Intercalations of conglomerate are often graded, planar tabular bedding may also be observed, especially in the northern, marginal part of the complex in question (Fig. 15). Inclined laminae occasionally show gradation.

The majority of cross-lamination shows that dominant current was flowing generally northwards at the beginning of the sequence, becoming more variable upwards the sequence. In some conglomeratic layers, inclination of laminae was directed towards the south, especially in the northern part of the basin.

Interpretation

The described lithofacies association is believed to represent channel deposits of a sandy braided river (alluvial-plain deposits) passing into a lacustrine-delta system. The association displays a variety of sand and gravel bedforms reflecting changes of flow velocity, variable clastic imput and water depth. The through cross-stratified sandstones are interpreted as the product of migrating dunes under lower-flow-regime conditions (cf. Miall, 1977). Smaller tabular sets may be produced by strait-crested dunes (cf. Collinson, 1996). The sedimentary cycles characterised by coarse lag deposits may be attributed to channel and/or channel-bar deposits. The alternations of parallel-laminated, rippled and cross-stratified sandstones with subordinate conglomerates layers is a result of repeated sheet-flooding (cf. MacCarthy, 1990). The vertical sequence observed in some more internal parts of the basin, starting with planar cross-stratification to ripple-cross lamination, and accompanied by upward-fining of quartz grains, is interpreted as the product of a waning flood flow and decreasing water depth. This sequence shows a strong similarity to the point-bar sequence (cf. Picard & High, 1973). Scarcity of deeper than a few tens of cm erosional channels hints that accumulation prevailed over erosion. Thin, pelitic beds of short lateral persistence are interpreted as interchannel flood deposits and/or ephemeral lakes deposits. Small scale, symmetric oscillation ripples are attributed to that environment, whereas dunes were connected with shallower part of channels or with channel-bar system. Overturned and strongly disturbed foresets (partly structurless) may be connected with partial liquefaction of the deposits.



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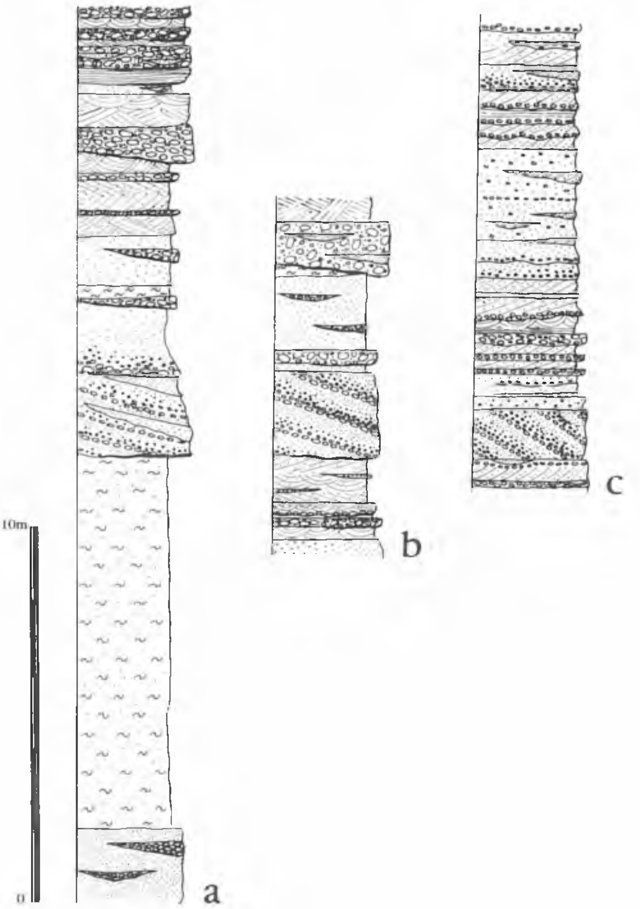


Fig. 15. Detailed lithostratigraphic sections of facies associations II, on the margin of braided river fan. Explanation of symbols as in Fig. 13

In this braided-river fan, several parts can be distinguished: a – a proximal/mid part characterised by local occurrence of conglomeratic layers (Fig. 14a), b – a middle part with prevailing coarse sand sedimentation (Fig. 14b), c – a distal part with intercalations of mudstones and greater amount of parallel-bedded sandstones sometimes with bioturbated levels (Fig. 14c). Increase of conglomerate layers, and general change of the current direction, in the north-western part of the basin (Figs 14d, e & f) indicate an existence of another, local source of clastic material.

Besides short term fluctuations in sedimentary conditions, there existed a long term change in environments expressed by the increase of muddy sandstones towards the top of the sequence and by general change of sedimentary structures from prevailing cross-bedding to parallel-lamination and gradation, as well as by an increase of the number of homogenous sandstone bodies (Figs 14a, b & c). All this suggests a general decrease in supply of clastic material, a decrease in environment energy and drowning of the alluvial plain with sporadic rapid deposition by density currents.

The increase of lateral variation of the current direction towards the distal and higher parts of the sequence imply change into more sinuous river system. Variation of current directions diminishes along with increasing number of fine-grained, muddy sandstones. Appearance in the highest part the sequence of fine-grained sandstones (Fig. 14c) is interpreted as a transition to marine environment. The sequence containing laminated, bioturbated sandstones near the facies 13 could be deposited as a subaqueous delta plain (cf. Changsong *et al.*, 1991). A part of sandy and conglomeratic deposits that interfingers with mudstone facies association (see below) can be attributed to wave-reworked, beach and nearshore deposits of lacustrine system (cf. Dunne & Hempton, 1984). The occurrence, along the margin of the lake, of cross-stratified conglomerates with laminae dipping towards the south (Fig. 15), can be attributed to subaqueous bars or to small, local Gilbert-type delta (cf. Picard & High, 1973).

Facies association 3: Mudstones and siltstones with lenses of sandstones and conglomerates (Fig. 16)

This facies association is characterised by up to several m thick layers of massive, structureless, grey mudstones (Facies 17a) or by sporadically calcareous sandy mudstones, with lenses of sandstones and conglomerates in the lower part of the profile (Figs 9 & 10). The mudstone beds often show vertical change in colour (Fig. 11); from grey in the lower part of bed, to pinkish or brownish and blackish in the uppermost part of bed (Facies 19). Locally, synsedimentary faults cutting mudstone beds are developed.

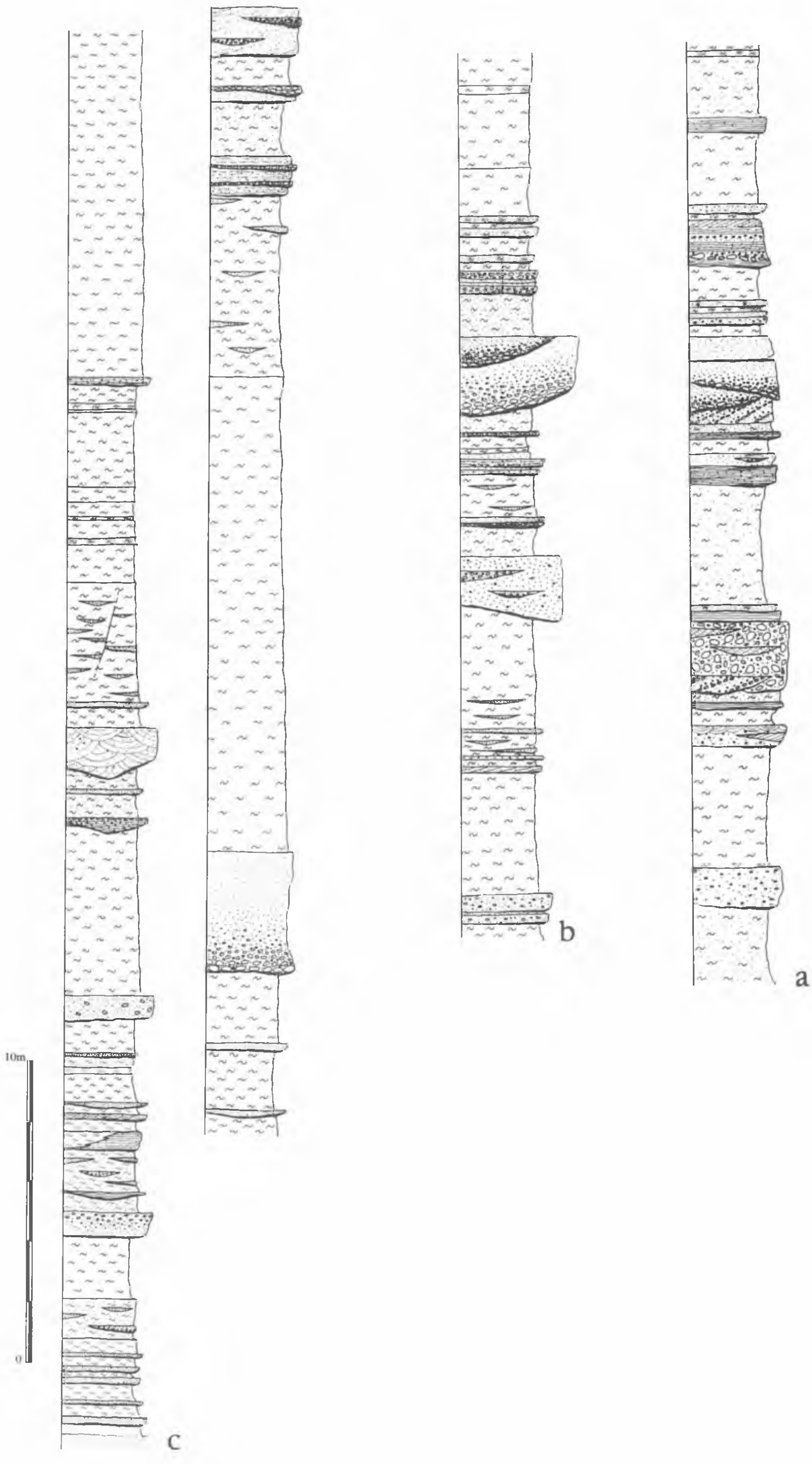
This association reaches the maximum thickness of up to 100 m in the northern part of the basin. In that part, the most striking feature is the occurrence of lenticular, erosively-based bodies of graded, parallel and/or low angle cross-bedded sandstones up to several m thick (Facies 6 & 16) which are often amalgamated and occasionally multistorey (Fig. 10). The upper surface of the clastic beds is flat, sometimes with closely packed lags on the top. The directions of the channels are usually W–E, while cross lamination is inclined towards NW. Thin- and medium-bedded sandstones are often connected with these channels. They are usually cross-laminated and cross-bedded.

Towards the northern margin of the basin, grain size of the sandstones increases, and transport from the north prevails. In the southern marginal part, where this facies interfingers with conglomerates, layers of sandy mudstones locally contain scattered clasts of sandstones (up to 20 cm), and intercalations of thin-bedded sandstones are sometimes strongly contorted. In that part of the basin channels filled by coarse-grained clastics are wider than in central part.

Interpretation

The fine-grained facies in the lower part of the sequence

Fig. 14. Detailed lithostratigraphic sections of braided river deposits (facies association II): (**a**) proximal/mid part; (**b**) mid part; (**c**) more distal part with transition to marine environment; **d, e, f**) sections representing another, northern, more coarse-grained fan. Explanation of symbols as in Fig. 13



10m
0
c
b
a

represents a floodplain environment; the coarse-grained lenses represent ephemeral channel deposits (cf. Puidefabregas & Van Vliet, 1978; Friend, 1983). The higher part of sequence represents a lake environment. Channel deposits are considered to have been initiated during occasional catastrophic floods and storms. Occurrence of pebbly lags on tops of some channel fills was a result of removing finer material by waning currents. Intercalations of thin- and medium-bedded sandstones, sometimes visibly connected with channel deposits, may represent crevasse splay deposits(cf. Doktor & Gradziński, 1985; O'Brien & Wells, 1986) and/or levee deposits (cf. Hughes & Lewin, 1982). Elongated thin- and medium-bedded sandstone bodies situated farther off channels may represent isolated crevasse splays (cf. Farrell, 1987). Appearance of pale purple mudstones in the higher part of sequence may indicate ephemeral nature of the lake (cf. MacCarthy, 1990). The observed fluctuation in the colour of siltstones and mudstones may reflect changes in iron and carbon contents (cf. Potter *et al.*, 1980), their significance for recognition of climatic changes from more arid to more humid is disputable (cf. Reeves, 1968).

Facies association 4: Grey calcareous mudstones and siltstones with marine fauna (Fig.17)

These sediments form a sequence about 400 metres thick of calcareous, generally grey mudstones, sandy mudstones and siltstones (Facies 18b) with subordinate intercalations of fine- to coarse-grained sandstones (Facies 11 & 8). The mudstones form layers from tens of cm up to several m thick (Fig. 12A), extending laterally for hundreds of m. The sandstones are from a few cm to tens of cm thick, rarely they are more than 1 m thick. Some sandstone bodies are lenticular. The dominant sedimentary structure in the sandstones is parallel lamination, whereas cross-bedding is subordinate. The lower surface of sandstone beds is sharp, the upper one sometimes shows gradation upwards into mudstones.

The mudstones contain foraminifera *Elphidium macellum*, *E. flexuosum*, *Ammonia inflata miocenica*, *Orbulina universa*, and Ostracodes (Crimi, 1987).

In the lower and the upper parts of the sequence, there occur at least two horizons with marine molluscs. In the lower horizon, the mollusc shells are dispersed within thick sandy mudstone layers whereas in the higher horizon, the shells are concentrated on top of sandy bed in form of a hardground (Fig. 17B). In that horizon, they are represented by (*Omphaloclathrum miocenicum* (Michelotti), *Glycymeris glycymeris* (Linne), *Arca syracusensis* (Mayer), *Ostrea gigensis* Schlotheim, *Hinnites brussoni* de Serres, *Ringicardium hians* (Brocchi) (Crimi, 1984). In the upper part of the sequence (Fig. 17A), the mudstone layers locally display vertical changes in colour from pinkish to greyish (Facies 19).

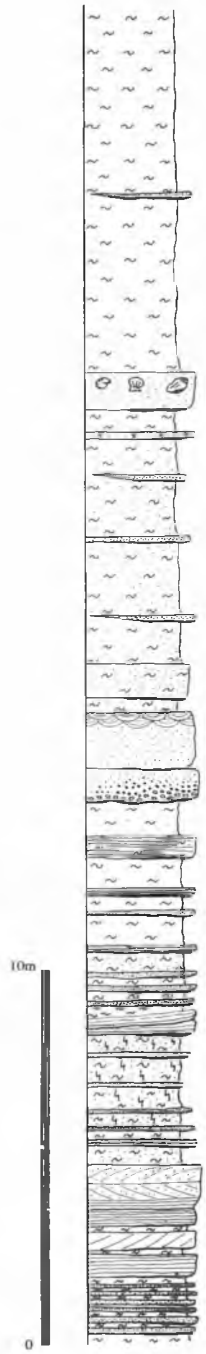


Fig. 17. Detailed lithostratigraphic section of marine/brackish facies association IV with marine fauna horizon (facies 17b). Explanation of symbols as in Fig. 13

Interpretation

The mudstone complex represents low energy deposits laid down within a brackish/marine environment with sporadic influx of normal marine water, as is evidenced by the

Fig. 16. Detailed lithostratigraphic sections of floodplain and lacustrine deposits : **a)** lower part of the section representing floodplain deposits, with layers of sandstones and conglomerates, passing upwards into lake deposits; **b)** northern, more distal area with channel clastic bodies (lower part of the succession); **c)** northern margin of the flood plain. Explanation of symbols as in Fig. 13

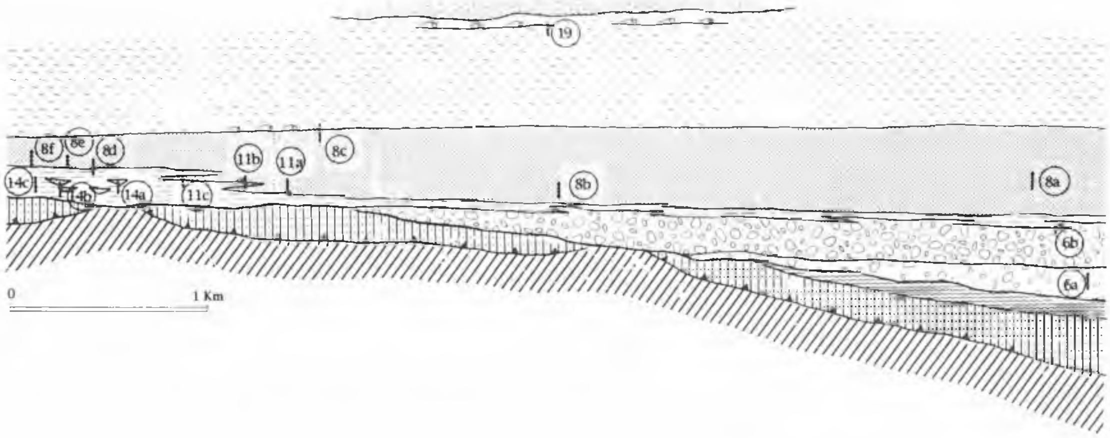


Fig. 18. Lithostratigraphic section across the Scillato Basin showing the distribution of the facies associations. Numbers refer to lithostratigraphic sections. Explanation of symbols as in Fig. 2

shallow marine fauna. The mudstones are interpreted as deposits of subaqueous suspensions or low density muddy flows (comp. Johnson & Baldwin, 1996). The horizontally stratified sandstones can be attributed to the deposits of wave or even storm driven bedload traction and in lesser degree to density currents (Johnson & Baldwin, 1996). Layers abundant in fossils were connected with periods of low-rate accumulation and, probably, with influx of normal marine water. Appearance of variegated mudstones in the higher part of profile, and disappearance of marine fauna, are effects of return of brackish/lacustrine environment.

RELATIONSHIPS BETWEEN FACIES ASSOCIATIONS

The relationship between the lithofacies is shown on Fig. 18. In the lower part of the sequence, represented by fluvial and lacustrine sediments, it is possible to distinguish proximal, medial and distal sequences. The proximal sequence, situated in the south, starts with the conglomeratic complex which in its higher part containes intercalations of mudstone lithofacies (Fig. 13b). The succeeding part of the sequence is dominated by the sandstones lithofacies (Figs 14a & 14b) of braided river fan type. The more distal part is almost devoid of conglomeratic complex at the base, and starts with a sandstone complex with intercalations of marls. The alluvial fan drained directly into silty floodplain lakes (Fig. 16). Probably a part of the sequence which includes laminated bioturbated sandstones represents subaqueous delta plain facies. In the lacustrine lithofacies situated further northwards, a dominant role is played by marly facies with lenses of conglomerates and sandstones (Fig. 16). Along the northern margin of the basin there was an influence of another smaller fan. The relation between fluvial and lacustrine lithofacies is well observable along the Imera river. Both lithofacies are interfingering, and it is possible to distinguish four progradation and regradation stages (Fig. 19) terminated by ingression of the fluvial facies over the whole area (Fig. 9). It should be stressed that the facies architecture observed in the Scillato Basin is typical for fan-braided-lacustrine deposits (e.g. Changsong *et al.*, 1991). The alluvial/lacustrine lithofacies are upward passing rapidly to brackish-marine facies (upper part of profile c in Fig. 14) represented by massive mudstones with subordinate sandstone intercalations (Fig. 16).

The sequence of the Terravecchia Formation, although generally continuos, displays three surfaces of low-angle unconformites: the 1st – at the end of development of conglomeratic alluvial fan; the 2nd – at a latter stage of braided system; and the 3rd – during the marine period. These unconformites are considered to be a result of synsedimentary tectonism.

HISTORY OF THE BASIN

During the development of the Scillato Basin, three main stages may be distinguished (Fig. 20).

Stage I (Fig. 20 I)

During this stage, the Madonie Mts which flanked the Scillato Basin to the north and north-east, were rapidly uplifted, probably along a system of faults. As a result, coarse and very coarse material was supplied from the north and north-east and deposited as a local sub-aerial alluvial fans. The Scillato fan was a part of such fan system which developed in the northern/central part of the Sicily. Lack of more distal clastic sediments suggests that it could have represented a marginal fan. Occurrence of the marly intercalations within the highest part of the conglomeratic complex is interpreted as influxes of ephemeral lake or floodplain environments which developed to the north of the alluvial fan. At the end of this stage, a new source area appeared to the south of the Scillato Basin.

Stage II (Fig. 20 II)

At the beginning of this stage, a major change in sedimentation reflecting change in subsidence took place. The

Fig. 19. Transition between braided river and floodplain/lacustrine deposits. Progradation of clastic fan on lacustrine mudstones is visible in middle part of the picture. Difference in dips of layers between lower and upper part of the fan may be a result of synsedimentary tectonic movements. Flat area with ravines, in the right part of the picture is built up of marine/brackish mudstones (facies association 4). In the background, mountains built of the Mesozoic rocks of the Monte di Cervi Unit. Right bank of Imera river

rate of subsidence increased in the northern part of the basin, while its southern part started to rise. The northern source area ceased to deliver the clastics, and a new source appeared towards the south and south east: a majority of clastic material was delivered from that direction. This was accompanied by the decrease in grain size and the frequency of conglomeratic deposits. Basing on composition of the conglomerates, it can be supposed that their material was reworked from older alluvial fan conglomerates. An elevation probably partially separated the Scillato Basin from the more southern basins. In its front, a braided river passing into flood-plain lake system developed. Increasing variability of current directions towards the top of the profile suggests that the alluvial system changed with time to more sinuous one. The braided river complex is composed of mature sediments derived probably from a distant source. Sporadic occurrence of gravel layers may be explained by rapid floods. The braided river sandy complex terminated in a lake dominated by silty deposits with isolated channel sand-bodies. The northern margin of the basin was probably affected by synsedimentary faulting.

The alluvial system passed with time into a lake with periodic regressions.

The migration of the sandy complex towards the lake may be attributed to decreased subsidence in the basin,

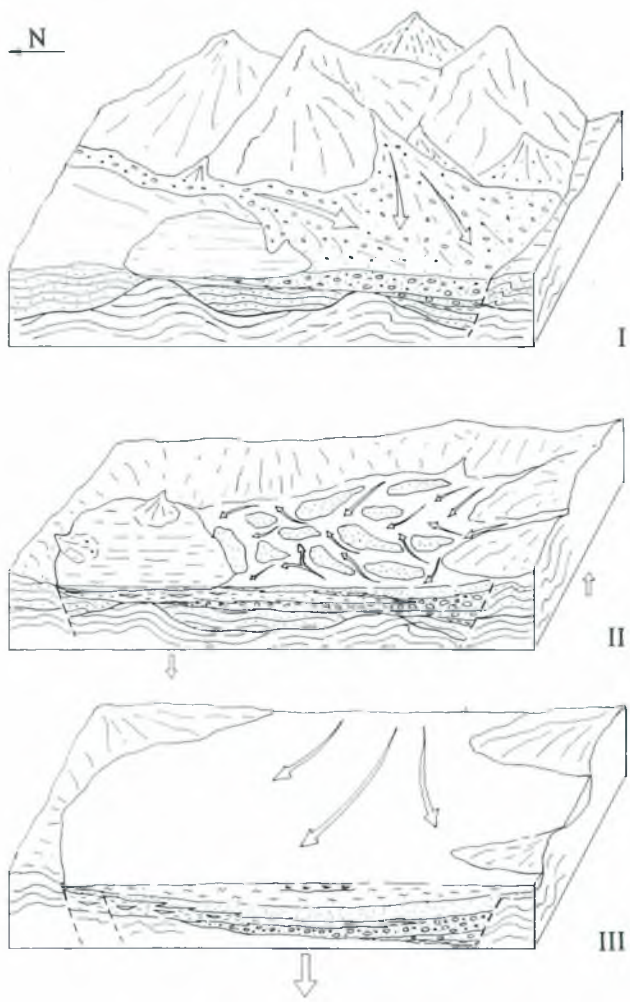


Fig. 20. Paleogeographic reconstruction of consecutive stages of the Scillato Basin development: a) Stage I: conglomeratic alluvial fan; b) Stage II: braided river and lacustrine; c) Stage III: marine/brackish

whereas fluctuations in supply of sandy material could be an effect of oscillation of water level and/or of change in influxes of clastic material. Eventually, the lake sedimentation was replaced by a sandy river complex which embraced the whole Scillato Basin.

Stage III (Fig. 20 III)

At the beginning of this stage, the supply of sandy material by a river considerably diminished. This was caused by a general subsidence of southern Sicily accompanied by denudation in source area. A marine incursion was a response to this subsidence, the Scillato Basin was invaded by the sea, and a marine/brackish environment with ostracodes became established. The sedimentation induced by different density currents prevailed. The presence of marine foraminifers and mollusc fauna indicate influxes of normal marine water. The occurrence, in the upper part of the sequence, of pinkish to blackish silty deposits, similar to those of stage II, suggests that marine/brackish environment changed in time into brackish/lacustrine one.

The history of the Scillato Basin was abruptly terminated by an influx of fluvial conglomerates, deposited mainly by gravity flows which started the next sedimentary cycle.

CONCLUSIONS

The development of the Scillato Basin is a good example of the development of a small intramontane basin in a tectonically unstable area. The nearly continuous subsidence in the Scillato Basin implies that the basin was located in a fault-controlled extensional setting. It was surrounded by tectonically active borders which were also active as clastic source areas. Areal shifting of these areas played an important role in controlling the sedimentation pattern.

The sedimentary history of the Scillato Basin includes three stages showing a generally fining-upward trend. The first stage was represented by alluvial fan deposits supplied from the north-east uplifted area. During the second stage, braided rivers extended from the south towards the lake located in the north. The sedimentation pattern was controlled by asymmetrical subsidence of the basin, faster in the north and slower in the south. The third stage with marine incursion was a response to a general subsidence. Occurrence of a horizon of hardground with marine fossils evidences temporal brake of that subsidence. In the Scillato Basin, a nearly continuos profile of a deposits from fluvial fan through braided river/lacustrine to marine/brackish environments may be observed. This cycle was terminated by a new influx of diastrophic, coarse-grained deposits passing upwards to the evaporates.

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Streszczenie

PROCESY OSADOWE W PÓŹNOMIOCEŃSKIM BASENIE POSTTEKTONICZNYM: FORMACJA TERRAVECCHIA, BASEN SCILLATO, SYCYLIA

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Osady górnego Miocenu (Terravecchia Fm., górny torton–dolny mesynian) w północnej Sycylii reprezentują post-tektoniczną molasę, która została osadzona na sfałdowanym i częściowo zerodowanym podłożu (Fig. 1). Jest ona reprezentowana przez starsze osady kontynentalne (zlepieńce i piaskowce i mułowce) oraz młodsze osady morskie. Granice litofacji mają przebieg diachroniczny. Syn- i post-orogeniczne ruchy tektoniczne podzieliły utwory formacji Terravecchia na szereg izolowanych basenów. W jednym z takich basenów, na północny zachód od miejscowości Scillato (Fig. 2), istnieje możliwość ciągłego prześledzenia poziomych i pionowych przejść facjalnych (Fig. 3) od osadów facji stożka aluwialnego przez osady rzeki roztokowej do osadów jeziornych i morskich. W utworach tych wyróżniono 19 litofacji: zlepieńców masywnych, o zwartym szkielecie ziarnowym (Fig. 5A & 5B), zlepieńców masywnych o rozproszonym szkielecie ziarnowym (Fig. 5B & 5D), zlepieńców o uziarnieniu frakcjonalnym (Fig. 5C), zlepieńców o warstwowaniu przekątnym, zlepieńców warstwowanych (sheet-like, Fig. 6 & 9D), zlepieńców rynnowych (Fig. 13 & 14), bruku korytowego (Fig. 9C, 9G & 10F), piaskowców z tabularnym warstwowaniem przekątnym (Fig, 7A & 7B), piaskowców z rynnowym warstwowaniem przekątnym (Fig. 6 & 7H), piaskowców warstwowanych poziomo (Fig. 7E & 8C), piaskowców o uziarnieniu frakcjonalnym (Fig. 7D), piaskowców masywnych, bezstrukturowych (Fig. 7E, w prawej górnej części), piaskowców i zlepieńców z wielkimi ripplemarkami (Fig. 8F & 8G), piaskowców z bioturbacjami (Fig. 8C, 8D & 8 H), piaskowców kanałowych (Fig. 9 & 10), masywnych mułowców i mułowców piaszczystych (Fig. 9, część górna, Fig. 12A & 6), mułowców z klastami i blokami oraz mułowców wstęgowanych, szarych i różowych (Fig. 11).

Facje te grupują się w cztery asocjacje facjalne: czerwonych i żółtych zlepieńców (Fig. 4 & 13) reprezentującą osady stożka aluwialnego; żółtych, przekątnie warstwowanych piaskowców stanowiących głównie osady piaszczystej rzeki roztokowej (Fig. 14 & 15); mułowców z soczewkami piaskowców i zlepieńców reprezentujących osady jeziorne oraz równi zalewowych (Fig. 16 & 19); mułowców z poziomami fauny morskiej (Fig. 17). Lateralny roz-

kład tych assocjacji facjalnych wskazuje na ich częściową diachroniczność (Fig. 18 & 19).

Rozwój basenu Scillato sugeruje, że utworzył się on w warunkach tensyjnych w obrębie rowu o założeniach uskokowych i otoczony był wyniesieniami aktywnymi tektonicznie, które dostarczały znacznych ilości materiału klastycznego.

Rozwój basenu Scillato można podzielić na trzy etapy (Fig. 20). W czasie pierwszego etapu (Fig. 20 I) rozpoczęła się szybka sedymentacja osadów gruboklastycznych tworzących stożek aluwialny, a pochodzących z pasma górskiego Madonie usytuowanego w kierunku NE od basenu Scillato. W drugim etapie nastąpiła wyraźna zmiana zrówno obszarów alimentacyjnych jak i grubości dostarczanego materiału (Fig. 20 II), który akumulował w warunkach rzeki roztokowej i jeziorzysk. W trzecim etapie, w wyniku postępującej subsydencji, nastąpiła ingresja morska (Fig. 20 III). Pod koniec tego etapu morze ustąpiło, rozpoczęła się ponowna sedymentacja osadów rzecznych należących już do następnego cyklu sedymentacyjnego.