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Foliations developed during slump deformation of Miocene marine sediments, Cyprus

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Abstract—Foliations within a Miocene slumped bioclastic sandstone unit of the Pakhna Formation, southern Cyprus, were investigated in order to assess the importance of slump strain, liquifaction and compaction in their generation. There are two approximately orthogonal sets of folds, F_1 and F_2. F_1 folds are upright to inclined slump folds formed during slope-failure translation of the sediment. The cores of upright F_1 folds have a steeply dipping macroscopic fabric defined by the axial surfaces of small tight folds in compositional layering. F_2 folds occur on steeply-dipping limbs of F_1 folds. F_2 folds are small and asymmetric with flat-lying axial surfaces, and are interpreted as compaction generated. A pervasive flat-lying microscopic fabric defined by grain and pore long axis orientation is found in both fold sets, and is probably a liquifaction fabric enhanced by compaction. A pervasive steeply-dipping microfabric parallel to the axial planes of slump folds is not present in any of the slumps investigated.

INTRODUCTION

DOWNSLOPE translation of unlithified sediment during gravity failure can generate fold and fault geometries that are analogous to tectonic deformation features found in both high- and low-grade metamorphic areas (Jones 1937, Hellwig 1970, Woodcock 1976, Farrell 1984, Tobisch 1984). Some fabrics present in slumped units have been interpreted as generated during pre-lithification gravity failure (slumping) (Williams *et al.* 1969, Yagashita 1971, Woodcock 1976, Bohlke & Bennett 1980, Tobisch 1984, Visser *et al.* 1984).

Slump folds with associated cleavages have been described in the literature (e.g. Corbett 1973, Woodcock 1976, Tobisch 1984). However, the axial surfaces of these folds are commonly sub-parallel to underlying undisturbed bedding. During soft sediment deformation, processes other than slump straining may produce fabrics parallel to the axial surfaces of recumbent slump folds. Downslope failure in poorly consolidated sediment may result in rapid pore-fluid expulsion and liquidization (thixotropy, sensitivity, liquifaction, fluidization and visco-plastic flow; see Allen 1982, Owen 1985), and by this process flat-lying fabrics can be generated (Owen 1987). Sediment consolidation involving soft grain straining, the reorientation of inequant grains, and the modification of pore-space geometries also produces a sub-horizontal fabric (Maltman 1981, Grainger 1985). As slope failure frequently involves only the superficial layers of sediment, folding and faulting can occur before the sediment is significantly consolidated (Boulter 1983). Therefore, fabrics that are parallel to the axial planes of recumbent slump folds may have been modified or wholly generated by the development of bedding-parallel compaction fabrics (Maltman 1981, Tobisch 1984).

The purpose of this paper is to describe and interpret foliations from slope-failure deposits in Miocene marine sediments from southern Cyprus, with emphasis on fabrics developed in upright folds where any burial-related compaction fabric is at a high angle to fold axial planes. Mechanisms of fabric development and modification are reviewed, and the importance of slump strain, liquidization and compaction in generating foliations is discussed.

GEOLOGICAL SETTING AND SLUMP SEQUENCE ORGANIZATION

The examples of soft sediment deformation described in this paper are from southern Cyprus, where sub-horizontally-dipping Koronia Limestone deposits of the Pakhna Formation crop out at Amathus in the Khalassa Basin (Eaton 1987), see Fig. 1. These rocks have not been tectonized or metamorphosed, and diagenesis has been restricted to minor recrystallization of micrite and growth of carbonate into pore spaces.

At Amathus, a 7 m thick sequence of Koronia Limestone is exposed, and contains lenticular slumped units making up 30% of the section (Figs. 2 and 6a). Two slump horizons were studied, Slump A and Slump B

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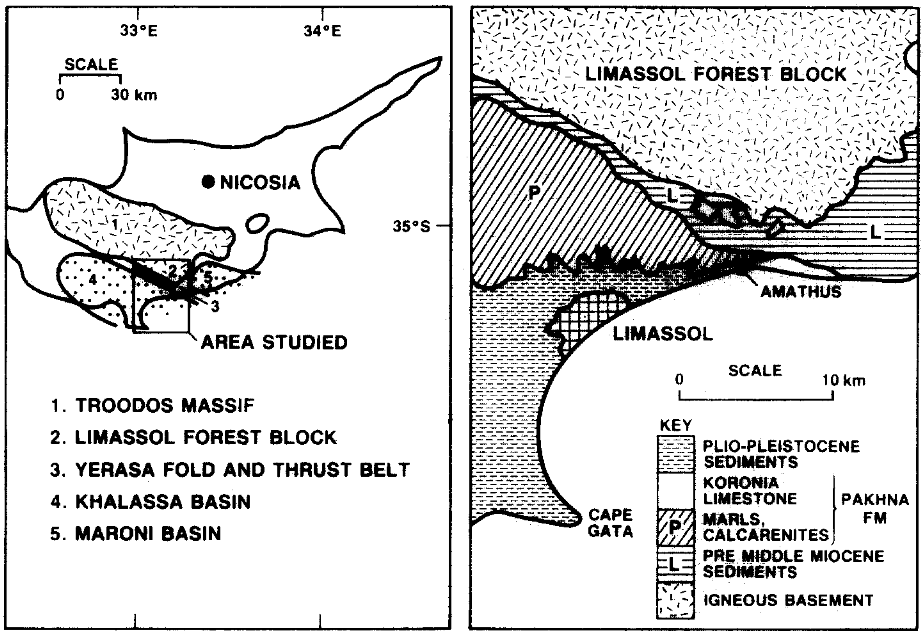

Fig. 1. Geological map of southern Cyprus showing the position of Amathus in the Khalassa Basin.

(Fig. 2). Strain histories in the different slump units vary from simple extensional or contractional strain to a complex development of strain overprinting, with sheath folds and recumbent isoclinal folds, developed (Farrell & Eaton 1987). These slumps are up to 1 m thick and are separated from each other either by undisturbed sediment (punctuated slope failure) or by slump detachments (no temporal break between the emplacement of successive slumps inferrable). The tops of some slump units are minor irregular erosive surfaces overlain by coarse bioclastic sandstones (Fig. 6a). This suggests that slope failure commonly involved only the upper 1 or 2 m of sediment, and that slumps were 'open cast' (*sensu* Corbett 1973).

Soft sediment deformation features are best observed in thinly interbedded (10 mm scale) marlstones and bioclastic sandstones. The thicker bioclastic sandstones do not exhibit soft sediment strain features, but the intrusion (injection) of these sandstones in the cores of anticlinal slump folds, and the observation of ptygmatically-folded sandstone dykes, implies that they were incorporated into the failed sediment packets (see Fig. 12).

MESOSCOPIC FEATURES

Faults and shear zones

The basal detachments of slumps vary from sharply defined faults parallel or oblique to the underlying beds, to shear zones in marls and inferred shear-zone detachments in massively bedded bioclastic sandstones. Many faults link into the basal detachment, forming contractional and extensional imbricate fan geometries (Boyer & Elliott 1982, Gibbs 1984). However, some faults are apparently non-linking, and can be traced into fault tips where displacement dies to zero (Elliott 1976). Normal

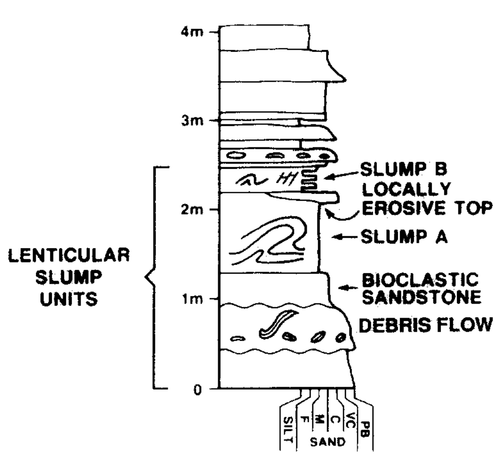

Fig. 2. Logged section of the exposure at Amathus showing slumped units separated by undisturbed bioclastic sandstones and marlstones.

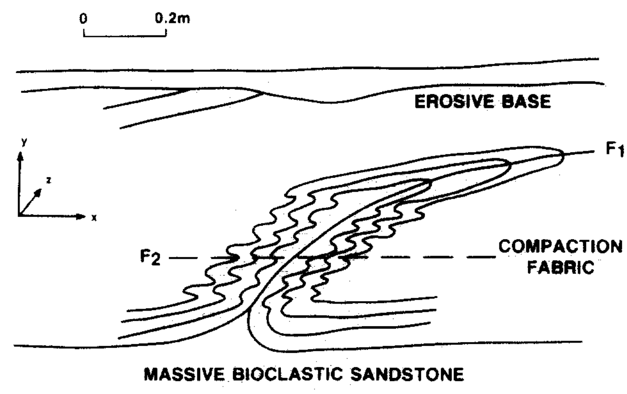

Fig. 3. Line drawing of F_1 slump fold in Fig. 6(a). Note curved axial plane and development of F_2 compaction folds with flat-lying axial surfaces. Note reference frame x, y, z referred to in text, with the z-axis perpendicular to the plane of the figure.

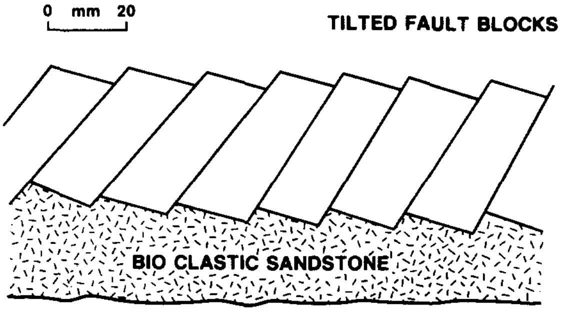

Fig. 4. Line drawing of closely spaced planar normal faults. Faults are not listric, and detach into the underlying massive bioclastic sandstone.

faults in Slump B (Fig. 2) may be listric, but are commonly closely spaced planar faults (Fig. 6b). Where planar normal faults are present, a gently-dipping basal detachment is not clearly defined, and fault definition is lost in the underlying structureless bioclastic sandstones (Fig. 4). Many of the normal and reverse sense displacements within the sediment take the form of shear zones of variable width (Figs. 6b & c). Bedding laminations can be traced through many of these zones with no apparent loss of continuity. In other shear zones, bedding laminations have been destroyed by pervasive flow of the unlithified sediment. Within shear zones, bedding laminations may be displaced across planar discontinuities. Offset distances are long compared to grain dimensions, and either die into fault tips, or are part of a linked fault system that joins with the basal detachment (Fig. 5). Shear zones with normal and reverse sense displacements are also associated with asymmetrical folds in Slump B (Fig. 7a). Reverse faults cut fold short limbs, whereas long limbs are cut by extensional faults (Fig. 8). An intersection lineation is observed where micro-normal and micro-reverse faults cut bedding surfaces (Fig. 6a).

Fold styles and mesoscopic strain

For the purposes of the following descriptions and discussion it is assumed that bedding and depositional surfaces (bedding planes) are indicated by compositional layering. Where bedding is tightly folded the dip of the enveloping surface (a surface which is tangential to the hinges of the minor folds) is given.

Meso-scale (0.5–2 m wavelength) folds in Slumps A and B vary in style from upright symmetrical folds and conjugate folds to inclined asymmetrical folds, recumbent isoclinal folds and sheath folds. The geometry of exposure does not allow the degree of cylindricity to be estimated over large distances, but within the limitations of the exposure folds are observed to vary from cylindrical to markedly non-cylindrical. Axial surfaces vary from planar to markedly non-planar.

In the cores of upright to inclined, symmetrical folds in Slump A, where bedding is approximately co-planar with the overlying undeformed sediment, bioclastic beds are deformed into tight chevron folds (Fig. 7b). These small wavelength (10–20 mm) angular folds define a sub-vertical crenulation foliation and have axial surfaces approximately parallel to the axial surfaces of the larger folds on which they are developed. On steeply inclined limbs of F_1 slump folds the bioclastic sandstones are deformed by small asymmetrical angular F_2 folds (Figs. 7b and 9). However, in contrast to the chevron folds in the cores of the larger upright and inclined folds, the axial surfaces of these small folds define a flat-lying

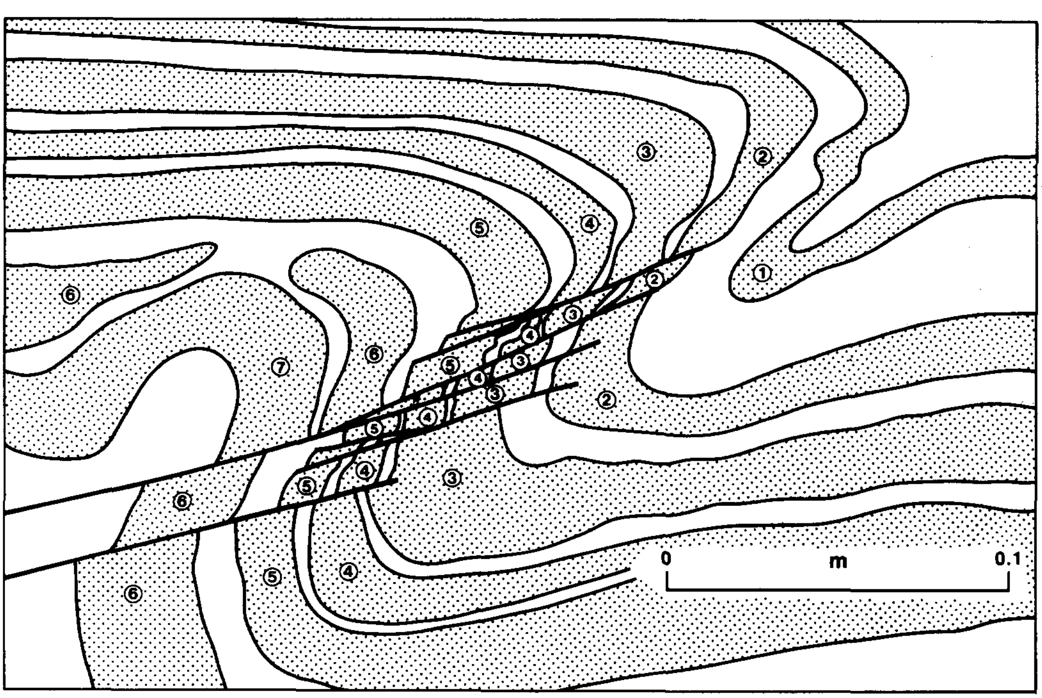

Fig. 5. Line drawing of shear zone cutting conjugate fold of Fig. 6(c). Bedding offsets decrease to the right. Bed widths vary on either side of the faults, indicating deformation during fault propagation.

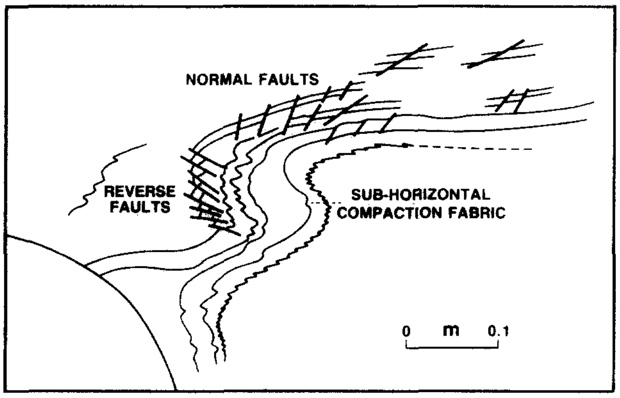

Fig. 8. Line drawing of Fig. 7(a).

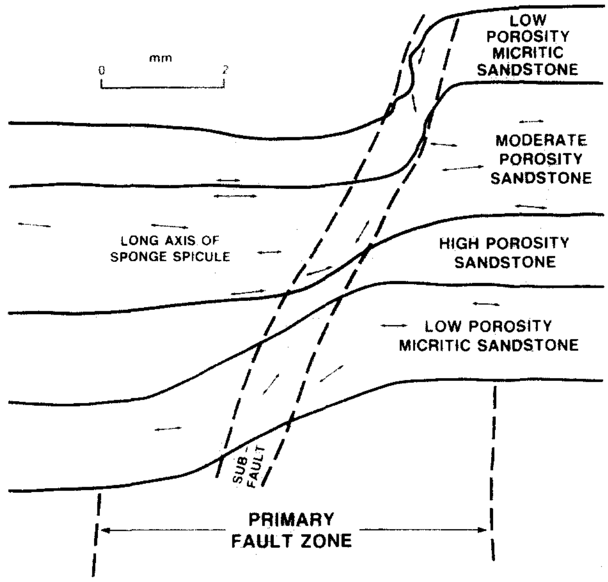

Fig. 10. Line drawing of normal fault zone in interbedded marlstone and siltstone from Slump B. A narrow sub-fault, with reduced porosity and prominent reorientation of grain long-axes, is developed within the wider primary fault zone. Layer thicknesses are most attenuated where undeformed porosities are highest.

foliation. Where upright and inclined folds have plunging axial traces, minor folds in the fold core have the same azimuth of axial-trace plunge as the larger fold, whereas recumbent minor folds on the fold limbs have sub-horizontally plunging axial traces. F_2 folds have the same sense of displacement on both sides of the F_1 fold axial surfaces (Fig. 3) and are therefore not parasitic folds. The development of two approximately orthogonal fabrics in Slump A indicates two phases of strain. No overprinting relationship of minor folds with flat-lying and steeply-dipping axial surfaces has been observed. Where bedding or the bedding enveloping surface is co-planar with underlying undisturbed bedding there is no macroscopic evidence of the flat-lying fabric.

FABRIC–BEDDING RELATIONSHIPS

A sample was taken from sub-horizontal undeformed bedding to investigate compaction fabrics. Within sandstone beds (up to 20 mm thick), laminae (1–3 mm) range from a moderately well-sorted sponge-spicule and peloidal fine sandstone with moderate to high visible porosities, to a poorly sorted sponge-spicule-rich micritic sandstone with no peloidal texture and low visible porosities. The most abundant grains are complete and fragmental sponge spicules that vary in shape from long (up to 1 mm) thin rods to complex three-dimensional shapes. Peloids are partially micritized calcareous algal fragments although some may be faecal pellets. Diagenesis is restricted to minor micrite recrystallization and growth of small carbonate crystals into pore spaces. In thin-section, undisturbed bedding shows a sub-horizontal foliation parallel to bedding (compositional layering), defined by the long axes of micrite pellets, pore spaces and sponge spicules. The absence of ripple cross-lamination or other bedforms indicates that the depositional microfabrics were flat lying and parallel to compositional layering. Micro-fabrics inclined to compositional layering can therefore be assumed to indicate modification of an original depositional fabric.

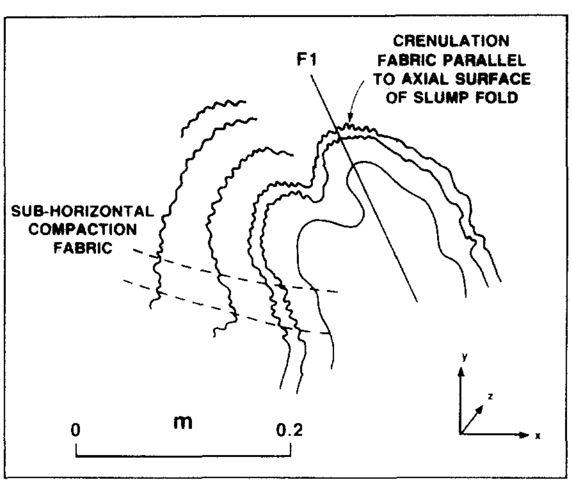

Fig. 9. Line drawing of Fig. 7(b). Note the reference frame x, y, z, referred to in the text, with z normal to the plane of the figure.

Because of the grain-size and grain-composition heterogeneity between thin sections it has not been possible in this initial study to quantify grain orientations comparatively. However, fabrics defined by a preferred dimensional orientation of inequant grains and pore spaces are evident in all of the thin sections studied.

In Slump B where bedding is cut by normal fault zones the upper and lower bedding surfaces have different geometries. Upper bedding surfaces have a step (fault scarp) up to 2 mm high whereas lower surfaces have smoother outlines (Fig. 10). Within the 5–10 mm wide fault zone orthogonal bed thickness is lower than outside the zone, visible porosity is reduced and grains define a rough foliation inclined to the flat-lying foliation outside the fault zone. Strain is heterogeneously distributed in the fault zone. Within the fault zone a 1–2 mm wide inclined sub-fault is commonly developed. This sub-fault is characterized by much reduced visible porosities, and by more pronounced rotation of the long axes of grains towards the vertical. Where this sub-fault cuts the upper

Fig. 6. (a) F_1 slump fold from Slump A. See also Fig. 3. A prominent intersection lineation is developed on F_1 fold limbs by small F_2 compaction folds with sub-horizontal axial surfaces. The upper part of the slump has been cut by a minor erosion surface. (b) Closely spaced planar normal faults from Slump B. Note that small displacements are taken up on fault zones of measurable width. (c) Upright conjugate slump fold from Slump B. A basal detachment that is horizontal and bed-parallel in the left of the picture cuts obliquely up-section and deforms the right limb of the fold. Steeply-dipping bedding in the left limb of the fold is deformed by small compaction crenulations. See also Fig. 5.

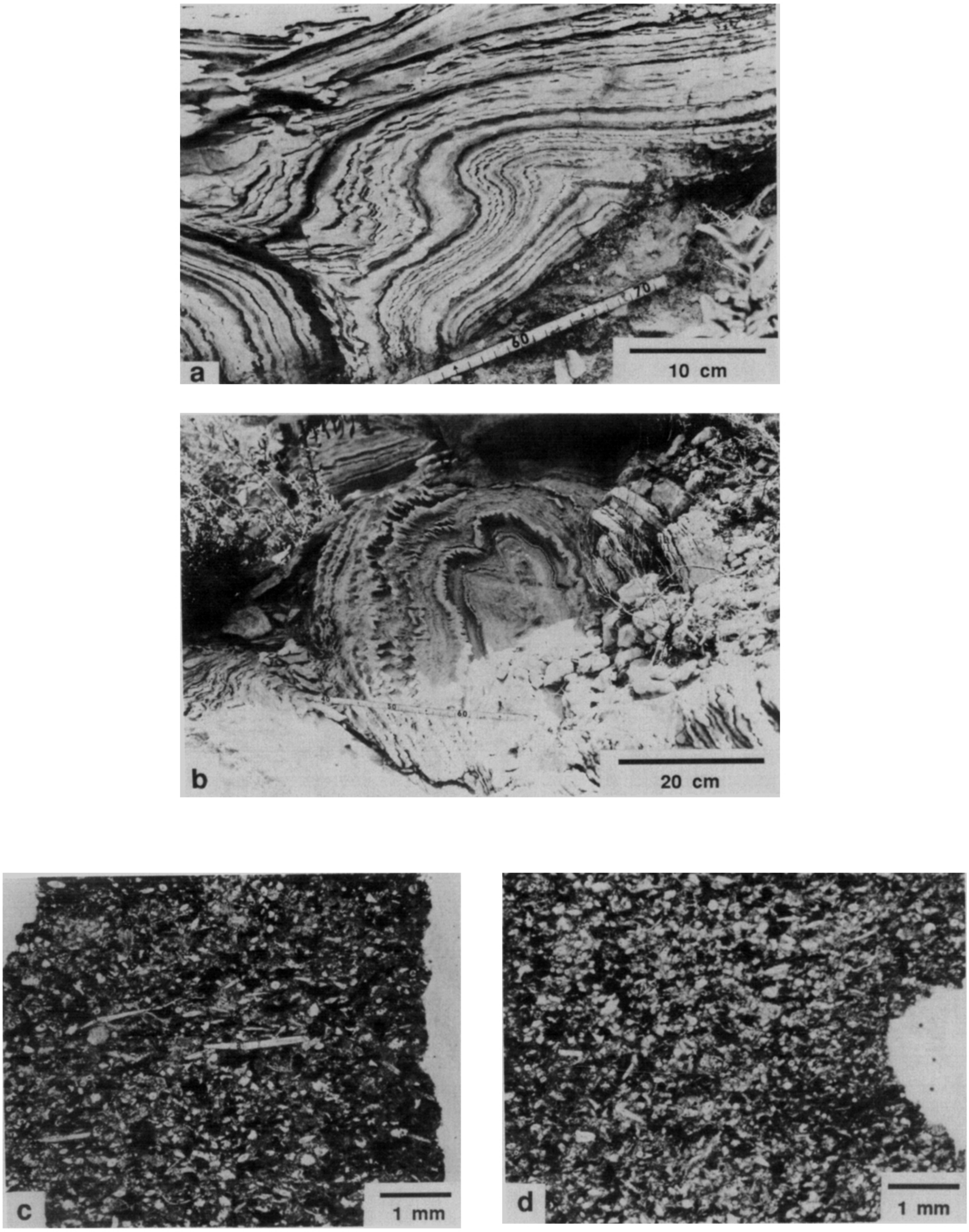

Fig. 7. (a) Asymmetric anticline from Slump B, with normal faults developed on the long limb, and reverse faults on the short limb (see also Fig. 8). (b) A gently-plunging symmetrical fold from Slump A. Small folds in the core were sampled to investigate the possible development of a steeply-dipping fabric parallel to the slump fold-axial surface (see also Fig. 9). (c) Photomicrograph to show fabric development in the y–z plane of the fold illustrated in Figs. 7b and 9. A flat-lying fabric is defined by orientation of inequant grains, and is co-planar with F_2 axial planes and with undisturbed bedding. A fabric parallel with the steeply-dipping F_1 fold axial surface is not visible. (d) Photo-micrograph from F_2 fold nose to show fabric development in the y–z plane (taken from the limb of the F_1 fold illustrated in Figs. 3 and 6a). The flat-lying foliation is co-planar with the axial surface of F_2 folds and with undisturbed bedding, but is at a high angle to the folded bedding surface.

and lower bedding surfaces it is commonly coincident with the development of steps in the bedding surface.

Two folds in Slump A were sampled to investigate the development of strain fabrics. It was not possible to sample unslumped sediment equivalent in composition to the contractionally slump-strained sediment. Therefore it has not been possible to evaluate fabrics in this lithology produced by compaction only.

Fold 1 (Figs. 7b and 9) is symmetrical, parallel in style, with an inclined axial surface and a fold axial-trace plunging 15°. A sample was taken from the fold core, where the bed-enveloping surface is sub-parallel to overlying undisturbed beds, to investigate the steeply dipping crenulation fabric defined by the axial surfaces of major and minor slump folds. Thin sections were taken, from the core region of one of the minor folds, parallel and perpendicular to the fold hinge and axial plane of the larger fold. A flat-lying fabric approximately co-planar with compositional layering is visible in both the x–y and y–z planes of the fold (Fig. 7c; see Fig. 9 for orientation of the reference axes x, y and z). A steeply-dipping fabric, parallel to the axial surface of these minor folds, was not present.

Fold 2 is tight to isoclinal with a markedly curved axial surface and a sub-horizontally-plunging axial trace (Figs. 3 and 6a). Samples were taken from steeply-dipping bedding to investigate the sub-horizontal crenulation fabric. A flat lying fabric, co-planar with the axial surface of the minor F_2 folds is observable in the x–y and y–z planes of the fold (Fig. 7d; see Fig. 3 for reference frame). This fabric is at a high angle to the steeply-dipping compositional layering.

Thus, irrespective of the attitude of the compositional layering, all samples in Slump A show a flat-lying fabric approximately co-planar with F_2 axial surfaces and underlying undisturbed bedding.

DISCUSSION

Slope failure and slump strain

Two types of foliations are present in the slumps at Amathus. (a) In Slump B localized steeply-dipping fabrics defined by preferred dimensional orientation of inequant grains are developed in normal and reverse shear zones. (b) In Slump A there is a pervasive flat-lying fabric, commonly at high angles to slump folded compositional layering and defined by a preferred dimensional orientation of inequant grains. In order to assess the contribution of slump strain to fabric modification it is necessary to consider the style of deformation in a failed sediment package and the effects of components of pure and simple shear in generating and modifying fabrics.

Downslope failure can be modelled in terms of three sequential phases of development: (1) an initiation phase involving the propagation of a basal detachment; (2) a translation phase when the detached unit moves downslope; and (3) a termination phase when cohesion with the substrate is regained (Farrell 1984). The failed unit can be extensionally and/or contractionally strained during any or all of these phases of slump development (Farrell 1984) often leading to final strain states that indicate complex histories of progressive deformation and strain overprinting (Woodcock 1976, Farrell 1984, Tobisch 1984, Farrell & Eaton 1987).

Upright symmetrical folds and inclined asymmetrical folds are frequently developed in slumps that have only been translated short distances implying that many slump folds initiate with upright to inclined axial surfaces during pure-shear longitudinal shortening of the slump (Farrell & Eaton 1987). This initial pure shear produces folds by buckling so that the upright folds are predominantly parallel in style (Woodcock 1976, Farrell 1984). The presence of buckles implies that a bedding parallel mechanical anisostropy was developed in the sediment soon after deposition (Woodcock 1976).

In larger slumps, which are inferred to be far travelled, folds tend to be tight to isoclinal and recumbent with curvilinear hinges. There is a tendency for folds to become similar in style as the axial surface tends towards parallelism with underlying undisturbed bedding (Naylor 1981, Farrell & Eaton 1987) (Fig. 11). By analogy with tectonically deformed rocks, sheath folds and isoclinal similar recumbent folds are frequently the product of simple-shear deformation (Escher & Waterson 1974). This indicates that during slump translation strain is predominantly by simple shear (Farrell & Eaton 1987). Simple-shear deformation rotates planar elements, such as fold-axial surfaces, towards parallelism with the lower and upper surfaces of the slump, and rotates linear elements, such as fold hinges, towards the downslope direction (Farrell & Eaton 1987) (Fig. 11).

Thus, the development of buckle folds, shear zones and deformation involving the rotation and tightening of folds indicates that final strain states involve components of both pure and simple shear strain (Woodcock 1976, Farrell 1984, Visser *et al.* 1984, Farrell & Eaton 1987). Fabrics can develop in unlithified sediment during both pure and simple shear straining (Williams *et al.* 1969, Visser *et al.* 1984). Localized fabric development associated with shear zones varies depending on the clay content of the sediment incorporated into the shear zone. In mud-rich sediment shear-zone development involves both the rotation of grains towards parallelism with the shear-zone margins, and pore-space destruction to produce layers of low-permeability consolidated mudstone (Bohlke & Bennett 1980, Maltman in press). In sand-grade sediments movement will be by cataclastic flow, which is a dilationary process (Mandl *et al.* 1977, Brodzikowski 1981), and which may leave the shear zone with higher porosity than surrounding sediment. The frequently observed localization of clastic dykes along shear zones (Brodzikowski 1981, Farrell 1984) may be a response to their higher porosities after a phase of cataclastic shearing. Normal-sense shear zones investigated in this study involve grain rotation and porosity destruction, resulting in changes in bedding thickness within the fault zone. The absence of dilatant

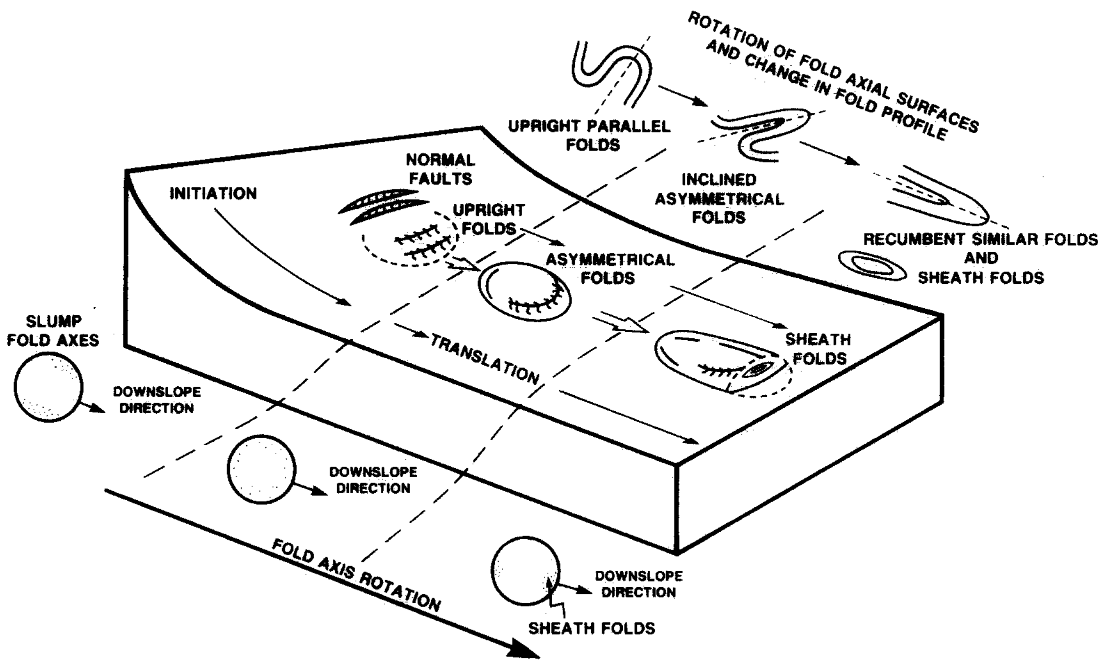

Fig. 11. Developmental scheme showing slump fold profile, axial plane and fold axis orientations during initiation and translation of a slump. Folds evolve from upright and parallel, with axes sub-parallel to the strike of the palaeoslope, to recumbent similar folds and sheath folds with axes rotated towards the down-palaeoslope direction.

textures may be related to the presence of micrite, because clay grade material suppresses the development of dilatancy (Mandl *et al.* 1977, p. 126).

The development of pervasive axial-surface fabrics generated by slump folding has been suggested by a number of authors (Williams *et al.* 1969, Yagashita 1971, Corbett 1973, Woodcock 1976, Tobisch 1984). In this study possible slump-strain fabrics were investigated by looking for steeply dipping fabrics where the effects of liquidization and compaction in contributing towards the generation of the fabric could be excluded. However, a steeply-dipping fabric parallel to the axial surface of the upright to inclined slump folds in Slump A has not been observed. The absence of this steeply-dipping fabric may indicate either that its development was suppressed or that it has been overprinted by some other fabric forming process that generated the flat lying fabric. Fabric forming processes that may have acted on slumps, subsequent to slumping, are principally liquidization and compaction.

Liquidization

Pore-fluid pressure controls the shear strength of sediment. Gravitational failure occurs when the presence of excess pore fluid has reduced the shear strength so that it is exceeded by the downslope shear-stress component of the weight of the sediment (Saxov & Nieuwenhuis 1982). Pore-fluid mobilization further weakens failed sediment packages and aids in the sediment disaggregation and mixing with the ambient fluid that converts sub-aqueous slumps into debris flows and turbidity currents. Liquidization (thixotropy, sensitivity, liquefaction, fluidization and visco-plastic flow) is an important group of processes during slumping because liquidized sediment is capable of deforming in response to stresses that would be too small to induce deformation of the sediment in its unliquidized state (Williams *et al.* 1969, Tobisch 1984, Owen 1987). Slumping often produces complex deformation structures because a number of liquidization processes may act during sediment deformation. The relative importance of each liquidization process varies depending on the grain size, fluid content and fluid mobility of a deforming sediment package.

During liquefaction grains temporarily loose contact with each other, potentially destroying depositional fabrics and generating liquefaction fabrics with the long axes of grains lying sub-horizontally (Owen 1985). Grain separation is small during liquefaction so that bedding laminations are often preserved. In contrast, fluidization involves wider separation of grains and may involve grain transport (elutriation) and the formation of clastic injection structures (Lowe 1976). Fluidization commonly involves the destruction of bedding laminations and the formation of sub-horizontal liquefaction type fabrics as grains settle from suspension. Whereas liquefaction commonly affects whole beds, fluidization tends to affect discrete dewatering dykes and channels so that fluidization fabrics may not be developed throughout the bed.

Evidence that Slump A may have been liquidized comes from the presence of clastic dykes filled with bioclastic sandstone that root into the slump detachments. The presence of the clastic dykes indicates that parts of the slump were fluidized and that high pore-fluid pressures were associated with the slumping event. Fold development may therefore have taken place when the slump was liquefied. Liquefaction of Slump A may have initiated the sub-horizontal fabric defined by inequant grains (Figs. 7c & d) and suppressed the development of, or overprinted, any steeply-dipping fabric that may have developed during slumping.

Compaction

The effects of a pure shear compaction strain on a slump will be (a) to shorten steeply-dipping bedding and clastic dykes by folding; (b) to modify recumbent fold geometries from parallel to similar in style (Naylor 1981, Farrell & Eaton 1987); (c) to enhance sub-horizontal depositional, liquefaction and slump-strain fabrics, as compaction strain involves the rotation of the long axes of grains into parallelism with sub-horizontal bedding, and the destruction of pore spaces leading to a denser packing arrangement (Maltman 1987); (d) to accentuate the curvature of fold-axial surfaces; and (e) to rotate fold-axial surfaces towards the horizontal.

Evidence that significant compaction took place after slumping in Slump A comes from the ptygmatic folding of clastic dykes associated with slumps. Populations of ptygmatically-folded clastic dykes can be used to estimate the amount of sediment compaction (Hiscott 1979). The presence of ptygmatically-folded dykes in the Cyprus slumps indicates that the sediment was unconsolidated during slumping, and that a compactional strain of approximately 30–40% has occurred post-slumping. Refolding of steeply-dipping bedding within the slump to produce a flat-lying fabric defined by F_2 fold axial surfaces was probably produced by compaction strain.

Whereas liquefaction may have taken place over minutes or hours during the emplacement of the slump, the compaction-related folding may have been gradual in response to increasing overburden. As the compositional layering was rotated during buckle folding, grains must have been rotated relative to the compositional layering in order to remain sub-horizontal and sub-parallel to the fold axial surfaces. The co-planar alignment of a flat-lying liquefaction grain fabric with the F_2 axial surfaces of these small chevron folds was enhanced during compaction by grain rotation and pore-space destruction.

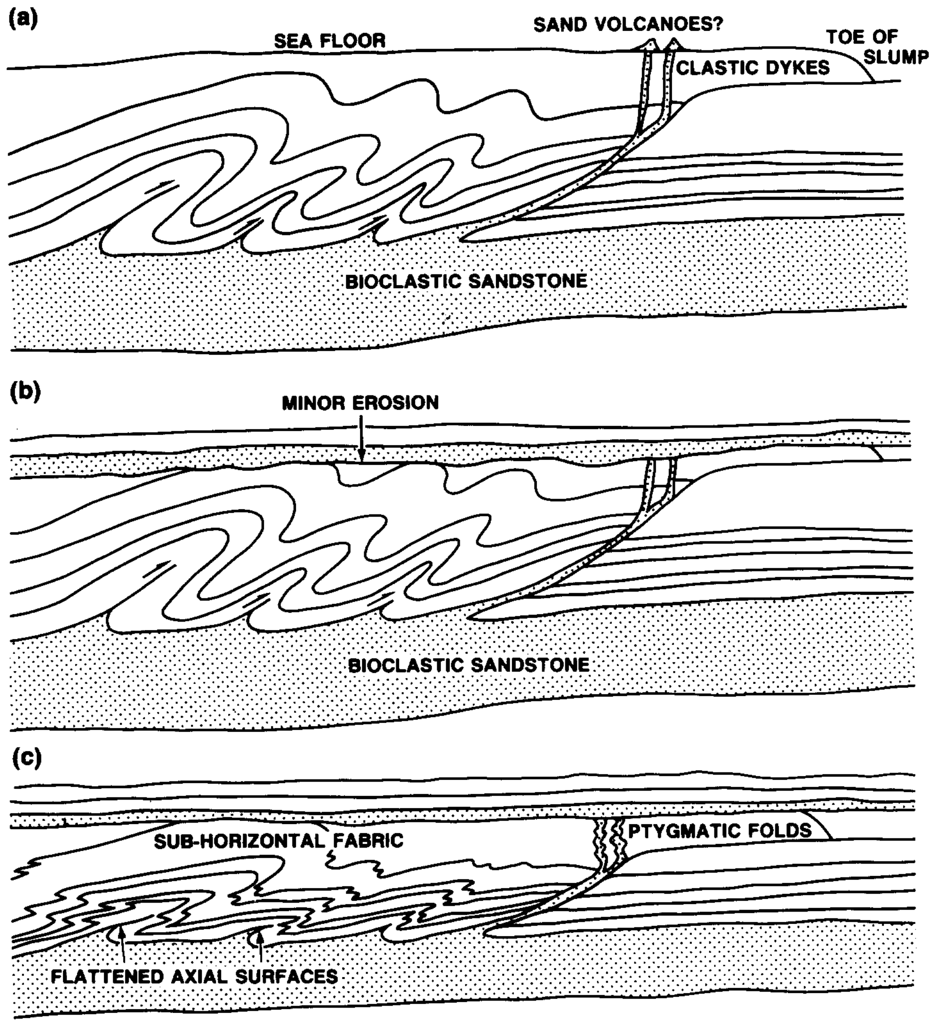

Fig. 12. Evolution of Slump B. (a) Slope failure produced F_1 folds and mobilization of bioclastic sandstone into fold cores, faults and clastic dykes. Liquefaction of the slump generated a pervasive flat-lying microscopic fabric. (b) Minor erosion of slump surface. (c) Continued sedimentation buried the slump. During compaction steeply-dipping bedding and clastic dykes are folded with flat-lying axial planes. Compaction enhances the pervasive flat-lying microscopic fabric.

A developmental scheme for Slump A (Fig. 12) involves (a) the emplacement of a liquefied slump that dewatered through clastic dykes, and the initiation of a microscopic sub-horizontal liquefaction fabric defined by inequant grains; (b) erosion of the top of the slump and continued sedimentation; and (c) development of a sub-horizontal fabric, defined by the axial surfaces of refolded slump folds and ptygmatically-folded clastic dykes, by compaction throughout the slump. Flat-lying micro-fabrics were accentuated by consolidation.

CONCLUSIONS

The investigation of slump-related fabrics in lithified sediment is problematical because of the variety of fabric-forming processes that can operate during slumping, compaction and diagenesis.

The presence of steeply-dipping shear-zone fabrics in some of the slumps investigated indicate that slumping is an effective process in producing localised fabric modification. However, the absence of a micro-fabric parallel to the steeply-dipping axial surfaces in Slump A does not answer the question as to whether slumping is an effective process in generating pervasive steeply-dipping fabrics parallel to axial surfaces. As slumping commonly precedes liquefaction and compaction, fabrics formed through slump strain may frequently be overprinted by later fabrics. Liquefaction and thixotropy are important processes because they allow soft sediment deformation to take place under the influence of weak deforming stresses. They are also important processes because a phase of liquidization can generate flat-lying micro-fabrics. Slumping to produce upright folds may, therefore, commonly take place when the development of steeply-dipping slump-strain fabrics is suppressed by liquefaction. In contrast, the development of recumbent fold geometries will produce strain fabrics co-planar with liquefaction and compaction fabrics.

Most slumps show no obvious compactional fabric defined by refolding of steeply-dipping bedding. This may be because many slumps consist of recumbent isoclinal folds with fold limbs parallel to compactional fabrics and where compaction in the hinge region produces thickening and not refolding. Alternatively slumping may affect sediment in variable states of consolidation so that many slumps of semi-consolidated sediment are not prone to the development of compaction fabrics.

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