Geogr. Fis. Dinam. Quat.
20 (1997), 5-12, 9 figg., 1 tab.

DAVID E. ALEXANDER (*)

«STRUCTURAL GRAIN» IN LANDSCAPES AND ITS RELATIONSHIP TO LARGE-SCALE SLOPE DEFORMATIONS

ABSTRACT: ALEXANDER D.E., *«Structural grain» in landscapes and its relationship to large-scale slope deformations.* (IT ISSN 0391-9838, 1997).

High relief is often endowed with a «structural grain» of topographic highs and lows obtained by selective erosion of tectonic and structural lineaments. Rock-mass fracture patterns exert a major influence on slope stability both at the surface and at various depths beneath it. This paper discusses some of the endogenous causes of deep-seated gravitational deformations and relates them to morphostructure and lithological weaknesses produced by tectonics. Using examples from peninsular Italy, it examines the structural and tectonic setting of deep (and associated shallow) slope movements on an anticline, at a mountain front, and on the rim of an overthrust syncline. All of the movements occur in sedimentary material of varied coherence and resistance to erosion. Lastly, a simple conceptual model is proposed to relate deep-seated gravitational deformations to shallow slope movements. It is concluded that morphotectonic conditions must often be studied before deep-seated slope movements can be understood, but the subtle interplay of forces between deep and shallow mass movements leads to an equifinality that complicates the explanation of both phenomena and obscures their relationship with crustal stresses.

KEY WORDS: Deep-seated gravitational deformation, Lineament, Mass movement, Rock slope, Sackung, Tectonic geomorphology.

RIASSUNTO: ALEXANDER D.E., *La «Patina strutturale» nel paesaggio naturale e il suo rapporto con le deformazioni gravitative profonde.* (IT ISSN 0391-9838, 1997).

La fisiografia ad alto rilievo presenta spesso una «patina strutturale» di alti e bassi topografici che deriva da un'erosione selettiva di lineamenti tettonici e strutturali. L'assetto della fratturazione nelle masse rocciose esercita un'effetto notevole sulla stabilità dei versanti sia in superficie che a varie profondità nella litosfera. Questo articolo considera alcune delle cause endogene della deformazione gravitativa profonda e le mette in rapporto con la morfostruttura e con le debolezze litologiche indotte dalla tettonica. Utilizzando alcuni esempi provenienti dall'Italia peninsulare, questo studio esamina l'assetto strutturale e tettonico dei movimenti profondi di versante, tenendo conto di associati movimenti superficiali. Gli esempi si riferiscono a vari assetti litostrutturali, compresi un asse anticlinale, un piedimonte, e l'orlo di una struttura sinclinale accavallata per via di un'eccesiva deformazione compressionale. Tutti questi movimenti accadono in materiale sedimentario di varia coerenza e resistenza all'erosione. Per concludere, viene proposto un semplice modello concettuale per trarre un rapporto tra i movimenti gravitativi profondi e le instabilità superficiali di versante. In sintesi, un'accurata conoscenza delle cause dei movimenti gravitativi profondi necessita di uno studio delle condizioni morfotettoniche del sito, sebbene il sottile rapporto tra i meccanismi che legano i movimenti di versante profondi con quelli superficiali comporti un'equifinalità che complica la spiegazione di entrambi i fenomeni e che oscura il loro rapporto con le forze della tettonica.

TERMINI CHIAVE: Deformazione gravitativa profonda, Geomorfologia strutturale, Insaccamento, Lineamento, Movimento di massa, Versante in roccia.

INTRODUCTION

In many parts of the world the pattern of faulting and jointing closely reflects the strength and direction of the dominant tectonic forces (Hancock & Engelder, 1989). Discontinuity patterns have two principal influences on local geomorphology. First, at the land surface, selective erosion tends to accentuate weaknesses and thus to create a «structural grain» of topographic highs and lows which reflects the orientation, location and density of discontinuity systems. At all scales landslides can be initiated or guided by such physiography (Tricart, 1974). Secondly, subsurface fracture traces may influence the size, rate and direction of mass movement (Hencher, 1987). Thus the study of families of discontinuities can illuminate, not only the characteristics of tectonic stress fields, but also some of the fundamental causes of slope instability (Alexander & Formichi, 1993). This is especially the case regarding large, slow deep-seated deformations that lack a clear and unified basal shear plane. The mechanisms governing such movements are sufficiently endogenous to encourage careful consideration of the role of rock mass discontinuities in their genesis and evolution.

This paper will first present some reflections on the causes and development of gravitational deformations. Next, lineaments will be considered in terms of their potential contribution to mass movement and their geomorphological role as the creators of a structural pattern that may influence slope stability. Causal links will be hy-

---

(*) *Department of Geosciences, University of Massachusetts, Amherst, MA 01003-5820, USA.*

pothesized between lineament patterns, structural grain and gravitational deformations, and several examples of deep mass movements in the Italian Apennines will be presented to illustrate them. Lastly, the experience gained from analysis of field examples will be adduced into a model of the relationship between deep-seated movements and associated variables of slope and environment.

THE NATURE OF DEEP-SEATED GRAVITATIONAL DEFORMATIONS

Deep-seated gravitational deformations (*Sackungen,* Zischinsky, 1969; *spreading ridges*, Radbruch-Hall, 1978; *depth creep*, Ter-Stepanian, 1974) have tended to confound the taxonomists of mass movement. Varnes (1978) placed them in several categories of his well-known classification, including bedrock slides, spreads and flows, earth block slides, and complex slump-flow-topple phenomena. Nemcock & *alii* (1972) included them in landslide classes involving creep and sliding motions; while Goodman & Bray (1976) placed them in the block flexure toppling category. The root of the problem is the difficulty of defining mode of movement in the field, and the vagueness of these classifications regarding the size and velocity of the mass movements that they deal with. Table 1 gives some of the elements of a classification (Alexander, currently unpublished) in which deep-seated gravitational movements most naturally fall into the categories fractured rock (AD - see tab. 1), dry or unhydrated conditions (41, 42 - see tab. 1), and translational or roto-translational movement. Given that they occur in ductile but relatively coherent solids, such movements are likely to fall into Varnes's «very slow» to «extremely slow» categories (Varnes, 1978).

TABLE 1 - Elements of a mass movement classification

COHERENT	A rock (massive unit)
	AA rock column (e.g., vertically jointed)
	AB rock wedge (e.g., defined by inclined joints)
	AC rock block (e.g., defined by orthogonal joints)
	AD rock mass (fractured)
DETRITAL	B debris
	BA talus (scree)
GRANULAR	C sediment
	CA sand
	CB silt
	CC loess
	D regolith
	DA earth
	DB soil
COHESIVE	DC mud
DRY	1 fall
	2 topple
	21 buckle
	3 slide (translational, planar)
	4 slump (rotational, arcuate)
	41 gravitational fault
	42 Sackung
DRY	5 creep
	51 shear deformation
	52 intergranular creep
	6 camber
	61 spread
	62 glide
	7 avalanche
	8 flow
SATURATED	81 solifluction
ROTATIONAL	topple
	camber
	slump
ROTO-TRANSLATIONAL	[intermediate]
TRANSLATIONAL	slide
	glide
	spread
	fall
	creep (coherent)
PLUG-FLOW	flow-slide
	viscous flow
TURBULENT	flow
	avalanche
	creep (granular, detrital)

Causally, gravitational deformations belong to a class of phenomenon that falls inconveniently between several more straightforward and clearly identifiable end members. At one extreme, faulting and jointing can usually be related to particular stress regimes that have produced regional and local patterns of fracturing (Hancock & Engelder, 1989). At the other, mudflows and slumps can generally be correlated with aspects of climate and the erosional development of slopes (fig. 1), even though there is increasing evidence that they may be conditioned indirectly by tectonic factors. Sand boils caused by liquefaction can be attributed to seismic forces, while rock topples from an evolving cliff face can be related to stress release and undercutting (Evans, 1981). However, Sackungen and other forms of gravitational deformation do not fit into a simple mould, for in most cases they are neither overtly tectonic nor the direct result of climatic inputs of kinetic energy. They result instead from gravitational influences upon terranes that have been conditioned structurally by tectonics (and other forms of diastrophism) and landscapes that ha-

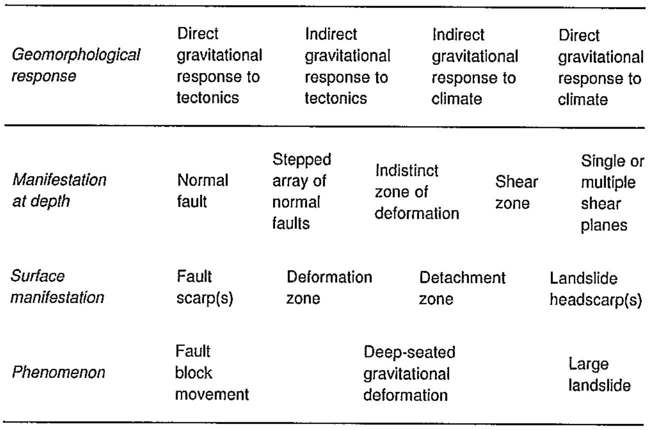

FIG. 1 - Morphogenetic position of deep-seated gravitational deformation between faulting and landsliding.

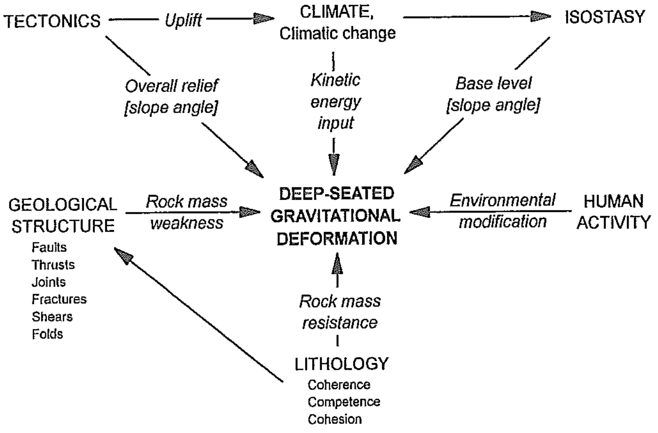

FIG. 2 - Influences on deep-seated gravitational deformation.

ve been prepared morphologically by erosion. They thus pertain neither wholly to tectonic nor entirely to climatic geomorphology (see fig. 2). They are instead a function of the ways in which gravity can act upon rocks of given resistances and particular diastrophic and morphoclimatic histories. Hence, and given their ostensible similarity to blocks disturbed by faulting, they may more accurately be described as pseudo-morphotectonic processes (fig. 3) (Guerricchio & Melidoro, 1981).

There are grounds for arguing that tectonic forces are the principal influence upon gravitational deformation. Though major tectonic pulses are periodic, rather than continuous, they not only account for the presence of surface relief, but also leave behind residual forces in the neotectonic stress field which continue to influence morphogenesis long after orogeny has abated. Contemporary or recent stress fields create or remobilize faults, joints and fractures in brittle rocks, folds in ductile ones and overthrust fronts in semi-rigid terranes. Given their relationship to the stress field, folds and lineaments show a high degree of preferred orientation, and the latter tend to exhibit spatial clustering.

THE RELATIONSHIP OF DEEP-SEATED SLOPE DEFORMATION TO LINEAMENTS AND STRUCTURAL GRAIN

Lineaments can be divided into those that result directly from tectonic stress in its compressional, extensional or relaxational modes, those that represent a delayed response to past phases of tectonic activity, and those that result simply from erosional activity (e.g. stress-release joints in cliffs). The last of these may also respond to tectonics, in the sense that the presence of relief or landforms (such as stream valleys) conducive to stress-release may be a result of tectonic conditioning of the landscape.

One way of considering lineaments geomorphologically, rather than purely as tectonic elements, is to conceptualize them as *structural grain*. This represents the erosional response of the landscape to selective erosion of discrete weaknesses in geological materials (Gerber's *selectivity principle*, Scheidegger, 1985). Thanks to tectonics, linear weaknesses such as joints and faults (and often associated folding) tend to be aligned in sets that follow particular directions. Selective erosion attacks these preferentially and hence gives a topographic emphasis to the directions imposed by past and present tectonic stresses. The result will be particularly evident where fractures are the principal source of weakness in the landscape, where discontinuities are numerous, deep-seated, and well-aligned with each other, where climatic agents favour erosion over deposition (e.g. slope development is *weathering-limited*, Carson & Kirkby, 1972), and where fractures and folds have a parallel or orthogonal relationship with each other. Structural grain is often the surface expression of tectonic compression, extension or wrenching, but it can also be induced by topography if stress-release occurs, or by lithological contact if weaker layers weather out preferentially. Figure 4 offers a

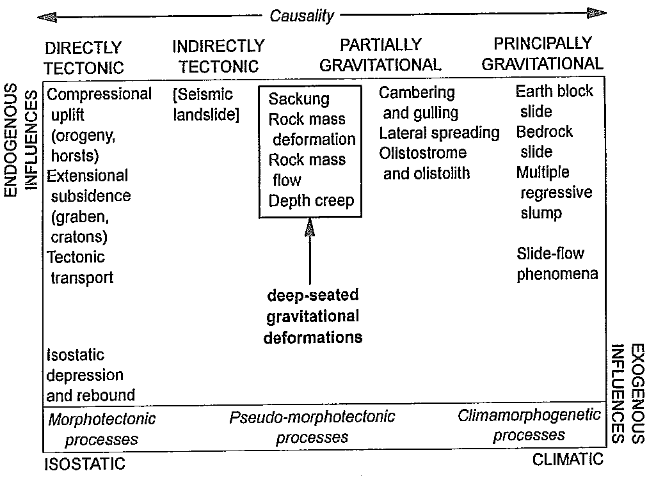

FIG. 3 - The family of diastrophic and gravitational morphotectonic processes, with particular reference to the position of deep-seated gravitational deformation.

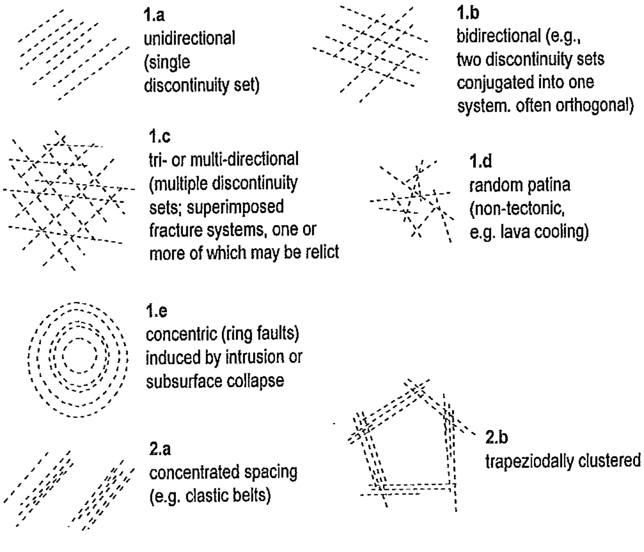

FIG. 4 - Types of structural grain.

tentative classification of types of structural grain, and figure 5 shows the pattern and dominant directions of structural grain in the hard Silurian slates of the Andean Eastern Cordillera of Peru, where both deep and shallow gravitational movements tend to be guided by the dominant direction of lineaments.

Geological structure (represented by faults, folds and rock-unit blocks) will be discordant with structural grain in only a few cases, of limited spatial extent, where the forces that created it were anomalous, smaller than, or asynchronous with those that give rise to the structural grain. Topography will be discordant with structural grain where selective erosion is unimportant in forming the contemporary landscape, when selective erosion responds to a different phase of tectonics to the one that produced the dominant fracture pattern, where weak sediments produce few or only muted fractures, and where a sedimentary cover obscures the structural imprint, as occurs when deposition dominates over erosion.

There are several reasons why lineaments can be associated with mass movements in general and deep-seated gravitational deformations in particular. First, they are usually low-strength discontinuities and thus can lead to selective erosion. Secondly, through the migration and concentration of groundwater, they give rise to high pore and cleft pressures, especially where faulting brings rock units of differing permeability into juxtaposition. Thirdly, where sapping, tunnelling, piping or karstic development occur, fractures can harbour deep sources of weathering. Lastly, faulting can abruptly define scarps, horst blocks or graben and thus create local relief that is inherently unstable. Research by Scheidegger & *alii* (1986) and Alexander & Formichi (1993) has suggested that shallow landslides tend to be orientated in relation to the dominant neogene tectonic stress field (opinions differ concerning whether the axes of slides are parallel or orthogonal to the main horizontal stress). It therefore follows that deeper movements are even more likely to be conditioned by the patterns and recent histories of tectonic forces observed at the local scale. Moreover, deep-seated gravitational deformations may take place in areas of widespread surface instability (e.g. a Sackung may occur in concert with talus production, debris flows or slumps). Either the surficial phenomena result from instability produced by the deeper movement, or the two are joint manifestations of an external cause.

Deep-seated gravitational deformations are common throughout Italy (e.g., Cancelli & *alii,* 1987; Casagli & *alii,* 1993; Colombelli & Tosatti, 1987; Dramis, 1984; Dramis & *alii,* 1983; Guerricchio & Melidoro, 1979) and have been documented in a variety of other places (e.g., Holmes & Jarvis, 1985; Nemcok & Baliak, 1972; Radbruch-Hall & *alii,* 1976, 1977). Some Italian examples will now be considered.

AN EXAMPLE OF GRAVITATIONAL DEFORMATION IN THE GEOMORPHIC EVOLUTION OF AN ANTICLINE

In models of anticlinal evolution propounded by Giannini (1951), Harrison & Falcon (1934) and Schultz (1986) topographic adjustment to folding occurs relatively rapidly by mass movements that are sometimes very large (Schultz, *op. cit.*, documented Appalachian examples up to 400 million m^3 in size). These require a layer of relatively soft material, such as a plastic clay, upon which more coherent materials can slide. Slope angles (i.e. the inclination of the anticline's limbs) must be sufficient to permit mass movement to take place, but tectonic activity does not have to continue for topography to adjust, though if it does the geomorphic activity will generally be enhanced.

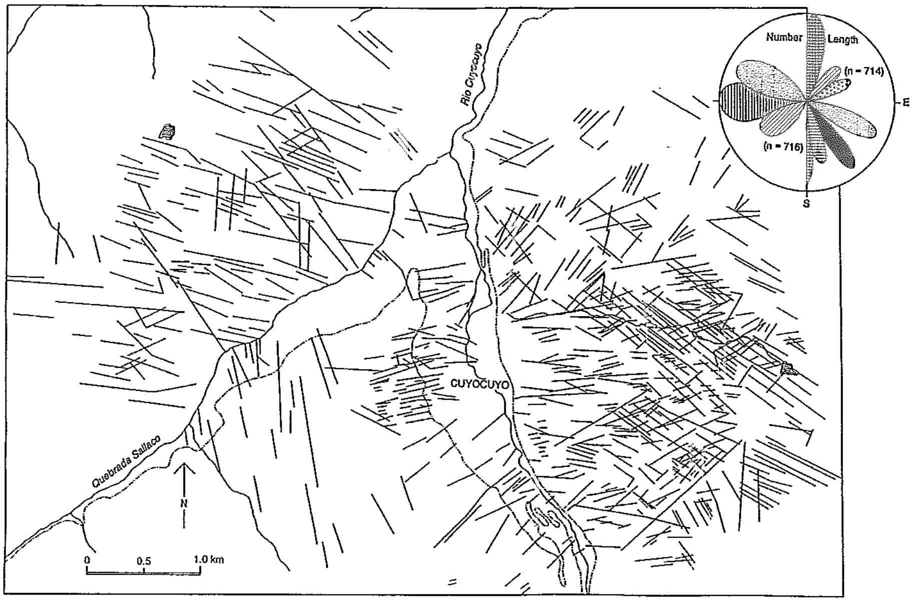

FIG. 5 - Structural grain in Silurian slates of the Sandia Formation in the Eastern Cordillera of the Peruvian Andes. The dominant lineaments condition wedge failures and deep-seated listric gravitational faulting in the main valleys.

On the western limb of the boxfold anticline at Monte Nerone (PS) *scaglia* units of the Umbro-Marchean Condensed Pre-Miocene Sequence have moved as discrete plaques on the more plastic, impermeable beds of fucoidal marls that underlie them. The principal joint and fault sets, which run parallel and orthogonal to the fold, define the moveable blocks of *scaglia rosata* and *scaglia bianca* and orthogonal faults guide the process of movement. As the *scaglia* tend to be flaggy or highly brecciated, bedding shows a general angle of inclination conversant with that of the fold (i.e., 20-35° degrees) but no preferred orientation (eigenvector tests on 471 bedding measurements yielded no significant clustering around the principal poles, Alexander, 1988). As the sheets of scaglia beds detach themselves from the hinge of the fold and slide slowly down the limb, they compress and therefore buckle into a corrugated or concertina form (*cfr.* Hu & Cruden, 1993). No basal shear planes can be observed, but the fracture patterns that define the blocks are clearly outlined in the morphology and stratigraphy of the area. They have Apennine and anti-Apennine strikes and thus represent a fairly straightforward structural cross-grain. By governing the direction of streams that are actively dissecting the anticline's limbs, anti-Appenine faults guide the movement of detached scaglia blocks (fig. 6; Alexander, 1988).

AN EXAMPLE OF GRAVITATIONAL DEFORMATION IN THE EVOLUTION OF PIEDMONT LANDFORM

The margins of tectonically active graben structures are often the sites of alluvial fans. In many cases these emanate from the mouths of valleys which are guided by faults that conjugate with the set represented by the graben master fault. This is the case at Senerchia (AV), where the remnants of a largely relict alluvial fan, currently 0.75 km^2 in size, are being dismantled by slow, deep processes of deformation. Plio-Quaternary tectonics have been responsible for the rapidity of deposition and dissection of the fan. Young normal faults form two sets striking respectively ESE and NNE (i.e., approximately orthogonal to each other). Structural analysis (Alexander & Coppola, 1989) showed that neotectonic extension has occurred in both directions. Antiappennine faults feed groundwater to the alluvial fan, where it concentrates at the base of the fan sediments above the underlying allochthonous variegated clays unit. Plastic deformation of the clays occurs under the lithostatic pressure of an overburden of 50-55 m of fan sediments and a phreatic zone tens of metres thick. This has caused subsidence of parts of the fan, lending it a stepped morphology and a pronouncedly steep distal end. Faults with an Apennine strike that cross the fan have guided the subsidence of parts of it and have indirectly acquired a surface expression through the pseudo-segmentation of fan morphology (cf. Bull, 1977). In this instance, the driving force of surface instability is much more tectonic than it is gravitational, though gravitational pull is the instantaneous cause of slope subsidence (fig. 7; Alexander & Coppola, 1989).

AN EXAMPLE OF GRAVITATIONAL DEFORMATION IN THE DISSECTION OF A SYNCLINE

The urban core of Tricarico (MT) is located on the rim of an exposed syncline in weakly-cemented Plio-Pleistocene organigenic calcarenite strata. Neotectonic activity shortly after deposition deranged the bedding of the calcarenite unit, which already exhibited strong clinostratification, and thrust it onto blueish-grey marly clays. Together with subsidence of the Fossa Bradanica foretrough, several pha-

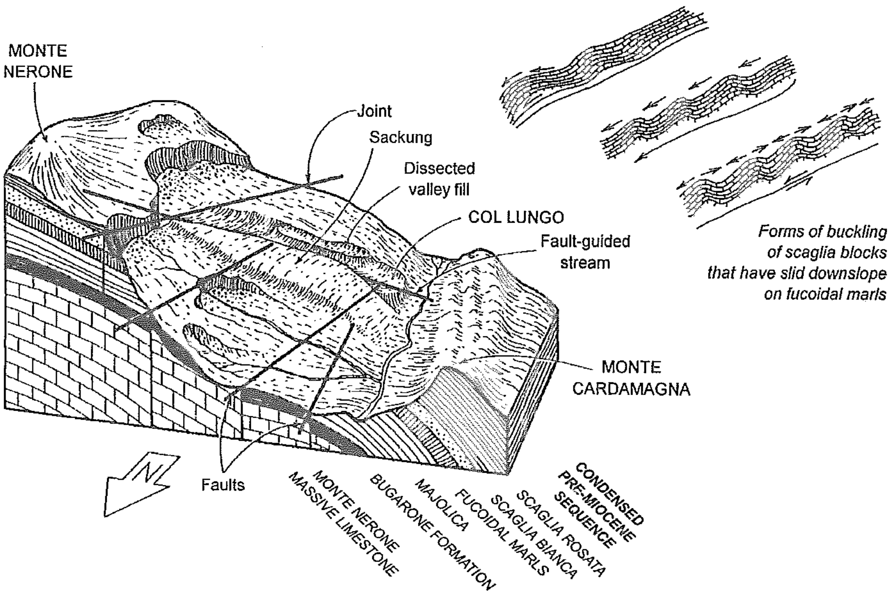

FIG. 6 - Detachment and buckling of a block of Scaglia bianca and Scaglia rosata (Condensed Pre-Miocene Umbro-Marchean Series) on the western limb of the Monte Nerone anticline (modified from ALEXANDER, 1988, fig. 18).

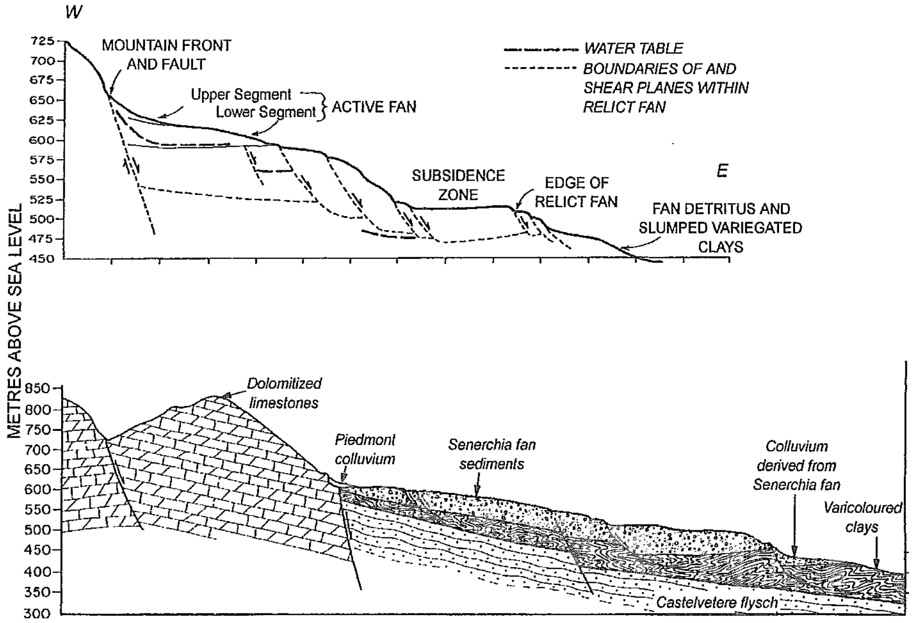

FIG. 7 - Topographic and geological sections through the Senerchia alluvial fan and underlying lithostratigraphic units, showing slumps and pseudo-segments associated with slow movement upon the underlying disturbed plastic clays (modified from ALEXANDER & COPPOLA, 1989, figs. 6 and 9).

ses of Quaternary uplift have resulted in the incision of the rim of the syncline by affluents of the River Bradano and the development of stress release joints some tens of metres deep in the calcarenite.

Seepage down the joints concentrates at the base of the calcarenites, where these contact the underlying blue clays. Systems of intersecting subvertical joints strike N/NNE and E. They can be related to the pattern of tectonic stresses that developed at the end of the Calabrian period (σ_1 sub-vertical, σ_2 subhorizontal at N148°E, σ_3 subhorizontal at N058°E). Later, extensional tectonics created fractures and reactivated earlier structures orientated in the N020±20°E direction. These correlate well with the attitude of bedding only at the rim of the syncline, but it is here that mass movement is slowly dismantling the structure. This is also where subvertical jointing most closely approximates an orthogonal pattern (fig. 8). *Cambering* (or *valley rebounding*, Hawkins & Privett, 1981) is enlarging the joints into *gulls*, and the resulting blocks, some of them tens of metres in width and depth, are slowly being transported downslope on the plastic clays which are squeezed out beneath by the weight of their overburden. This has led to notable damage in the urban area (Bromhead & *alii*, 1994), and to the development of a band of calcarenite detritus around the outer margin of the elevated synclinal ridge (Alexander & Rendell, 1986; Rendell, 1985).

CONCLUSIONS

None of the movements described above is short term with a clearly defined beginning and end. Hence it is difficult to consider them in terms of thresholds of movement crossed and equilibria regained (Francis, 1987). Most occur with smaller, faster and more surficial movements such as mudflows, debris flows and blockfalls: for example, detachment zones are commonly prey to columnar rock top-

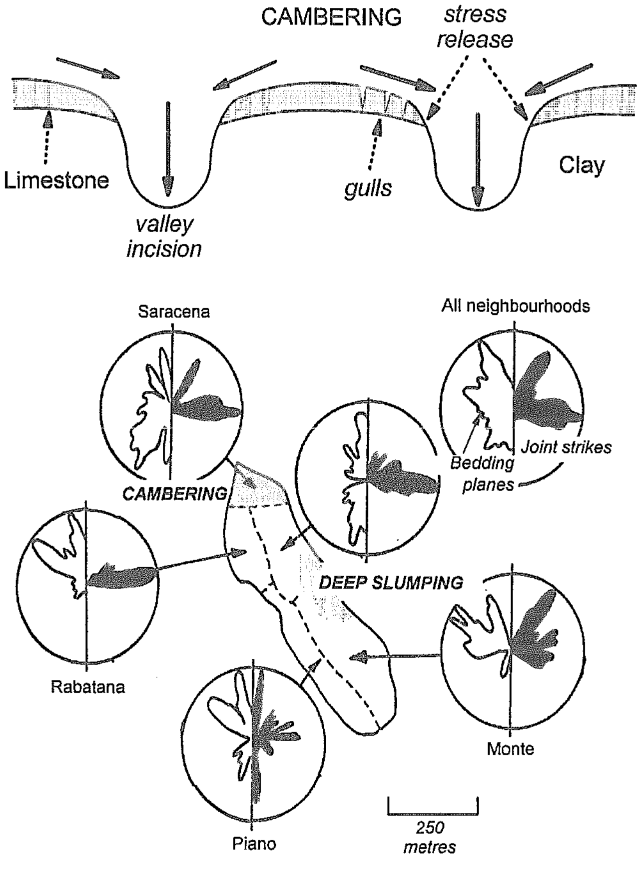

FIG. 8 - Jointing and cambering at Tricarico (partly after ALEXANDER & RENDELL, 1986, fig. 6).

ples, and deep subsidence may cause slumping by locally oversteepening a slope. Thus, where upland rock units are unstable at depth, the selective erosion of structural grain occurs by a dual process of endogenous deformation and exogenous erosion, a pair of processes which cannot be dissociated from one another. While deep-seated deformation alters the form of slopes and hence their susceptibility to surficial mass movement, landslides alter the balance of forces that affect the slope's propensity to undergo deep-seated deformation. This leads to considerable equifinality. In one notorious instance, the concerted movement of 3.4 km^2 of land at Ancona on 12-13 December 1982, the slight deformation of blue clays at depth appears to have occurred in concert with a considerable variety of more surficial movements in more highly weathered material. The net result is a situation that has defied unequivocal geomorphic interpretation (Coltorti & *alii*, 1955; Dramis & Sorriso-Valvo, 1994), as a result of the complex influence of deep movement on the threshold parameters for shallow movements, and vice-versa.

Figure 9 illustrates the dual role of deep and shallow movement in slope evolution under tectonic and gravitational duress. At Monte Nerone, fractured limestones are sliding and buckling on a base of plastic fucoidal marls, giving rise to debris flows, falls and topples. At Senerchia, deep movements in disturbed and highly plastic variegated clays give rise to shallower slumps and debris slide-flows that are slowly dismantling an alluvial fan. At Tricarico, deep weathering, stream incision and post-tectonic adjustment of fissured blue clays have resulted in cambering, slumping and block falls. The common thread that links these examples is the clear and relatively simple relationship of slope evolution to structural grain, which at its simplest is conceptualized by directions that are parallel and orthogonal to the orogen and are manifest in the selective erosion of folds, thrusts and associated fractures.

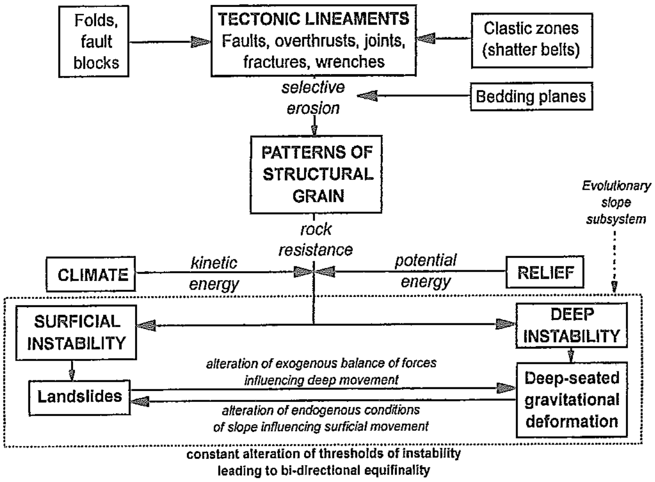

FIG. 9 - A simple conceptual systems model of the place of deep-seated gravitational deformations in slope evolution.

Lastly, given that there are so often intimate links between deep and surficial movements, if follows that Sackungen and other forms of endogenous slope deformation are hardest to interpret in morphological and morphogenetic terms where lithology is highly varied, especially where unstable plastic rocks are overlain by more coherent units, which is so often the case in the recent sedimentary terranes of peninsular Italy (*cfr.* Casagli & *alii*, 1993).

REFERENCES

ALEXANDER D.E. (1988) - *Relief inversion by denudation of the Monte Nerone anticline, Central Italy.* Geomorphology, 1, 87-109.

ALEXANDER D.E. & COPPOLA L. (1989) - *Structural geology and the dissection of alluvial fan sediments by mass movement: an example from the southern Italian Apennines.* Geomorphology, 2, 341-361.

ALEXANDER D.E. & FORMICHI R. (1993) - *Tectonic causes of landslides.* Earth Surf. Proc. Landf., 18 (4), 311-338.

ALEXANDER, D.E. & RENDELL H.M. (1986) - *Quality of construction, surficial geology and mass movement: the effect of the 1980 earthquake in southern Italy.* Geol. Appl. Idrogeol., 21 (3), 41-56.

BROMHEAD E.N., COPPOLA L. & RENDELL H.M. (1994) - *Geotechnical background to problems of conservation of the mediaeval centre of Tricarico, Southern Italy.* Quart. Journ. Eng. Geol., 27 (4), 293-307.

BULL W.B. (1977) - *The alluvial fan environment.* Progr. Phys. Geogr., 1, 222-270.

CANCELLI A., PELLEGRINI M. & TOSATTI G. (1987) - *Alcuni esempi di deformazioni gravitative profonde di versante nell'Appennino settentrionale.* Mem. Soc. Geol. It., 39, 447-466.

CARSON M.A. & KIRKBY M.J. (1972) - *Hillslope Form and Process.* Cambridge University Press, Cambridge, 575 pp.

CASAGLI N., FAZZUOLI M. & FOCARDI P. (1993) - *Deformazioni Gravitative Profonde in Toscana.* Soc. Geol. It. & Un. St., Firenze, 72 pp.

COLOMBELLI A. & TOSATTI G. (1987) - *Un esempio di deformazione gravitativa profonda di versante nell'Appennino bolognese: la frana di Rocca di Roffeno (Comune di Castel d'Aiano).* Mem. Soc. Geol. It., 39, 467-476.

DRAMIS F. (1984) - *Aspetti geomorfologici e fattori genetici delle deformazioni gravitative profonde.* Boll. Soc. Geol. It., 103, 681-687.

DRAMIS F., MANFREDI P. & SORRISO-VALVO M. (1983) - *Deformazioni gravitative profonde di versante: aspetti geomorfologici e loro diffusione in Italia.* Geol. Appl. Idrogeol., 18 (2), 377-390.

EVANS R.S. (1981) - *An analysis of secondary toppling rock failures: the stress redistribution method.* Quart. Journ. Eng. Geol., 14 (2), 77-86.

FRANCIS S.C. (1987) - *Slope development through the threshold concept.* In: Anderson M.G. & Richards K.S. (eds), *Slope Stability: Geotechnical Engineering and Geomorphology.* Wiley, New York, 601-624.

GIANNINI E. (1951) - *Alloctonia del macigno nella regione Bagni di Casciana-Chianni in Provincia di Pisa.* Boll. Soc. Geol. It., 70.

GOODMAN R.E. & BRAY J.W. (1976) - *Toppling of rock slopes.* Proc. Specialty Conf. Rock Engineering for Foundations and Slopes, Am. Soc. Civ. Engrs, Boulder, Colo., 2, 201-234.

GUERRICCHIO A. & MELIDORO G. (1979) - *Deformazioni gravitative profonde del tipo Sackung nei monti di Maratea.* Geol. Appl. Idrogeol., 14, 13-22.

GUERRICCHIO A. & MELIDORO G. (1981) - *Movimenti di massa pseudo-tettonici nell'Appennino dell'Italia meridionale.* Geol. Appl. Idrogeol., 16, 251-294.

HANCOCK P.L. & ENGELDER T. (1989) - *Neotectonic joints.* Bull. Geol. Soc. Amer., 101 (10), 1197-1208.

HARRISON J.W. & FALCON N.L. (1934) - *Collapse structures.* Geol. Mag., 71, 529-539.

HAWKINS A.B. & PRIVETT K.D. (1981) - *A building site on cambered ground at Radstock, Avon.* Quart. Journ. Eng. Geol., 14 (3), 151-167.

HENCHER S.R. (1987) - *The implication of joints and structures for slope stability*. In: Anderson M.G. & Richards K.S. (eds), *Slope Stability: Geotechnical Engineering and Geomorphology*. Wiley, New York, 145-186.

HOLMES G. & JARVIS J.J. (1985) - *Technical note: large-scale toppling within a sackung-type deformation*. Quart. Journ. Eng. Geol., 18 (3), 287-289.

HU X.Q. & CRUDEN D.M. (1993) - *Buckling deformation in the Highwood Pass, Alberta*. Can. Geotech. Journ., 30, 276-286.

NEMCOK A. & BALIAK F. (1977) - *Gravitational deformation in Mesozoic rocks of the Carpathian mountain range*. Bull. Int. Assoc. Eng. Geol., 16, 109-111.

NEMCOK A., PASEK J. & RYBAR J. (1972) - *Classification of landslides and other mass movements*. Rock Mech., 4, 71-78.

RADBRUCH-HALL D.H. (1978) - *Gravitational creep of rock masses on slopes*. In: Voight B. (ed.), *Rockslides and Avalanches I*, Elsevier, New York, 607-657.

RADBRUCH-HALL D., VARNES D.J. & COLTON R.B. (1977) - *Gravitational spreading of steep-sided ridges («Sackung») in Colorado*. U.S. Geol. Surv. Journ. Res., 5 (3), 359-363.

RADBRUCH-HALL D., VARNES D.J. & SAVAGE W.Z. (1976) - *Gravitational spreading of steep-sided ridges («Sackung») in the western United States*. Bull. Int. Assoc. Eng. Geol., 14, 23-35.

RENDELL H.M. (1985) - *Earthquake damage in Tricarico, Southern Italy*. Environ. Manage., 9 (4), 289-302.

SCHEIDEGGER A.S. (1985) - *Garlands of Heads*. Zeit. Geomorph., N.F. 29, 223-234.

SCHEIDEGGER A.E. & AI N.S. (1986) - *Tectonic processes and geomorphological design*. Tectonophysics, 126, 285-300.

SCHULTZ A.P. (1986) - *Ancient, giant rockslides, Sinking Creek Mountain, southern Appalachians, Virginia*. Geology, 14, 11-14.

TER-STEPANIAN G. (1974) - *Depth creep of slopes*. Bull. Int. Assoc. Eng. Geol., 9, 97-102.

TRICART J. (1974) - *Structural Geomorphology*, Longman, London, 305 pp.

VARNES D.J. (1978) - *Slope movement types and processes*. In: Schuster R.L &. Krizek R.J. (eds), *Landslides: Analysis and Control*. Transportation Research Board, Washington, D.C., 11-33.

ZISCHINSKY U. (1969) - *Uber Sackung*. Rock Mech., 1, 30-52.