acta
geologica
polonica

Vol. 23, No. 2 Warszawa 1973

STANISŁAW OSTAFICZUK

Large-scale landslides in north-western Libya

ABSTRACT: A distinct zone of large-scale landslides occurs in the north-eastern border of the Hammada al Hamra in NW Libya. It embraces horizontally lying rocks of Upper Cretaceous and Lower Paleogene age. The main displacement zone is within a clay bed, c. 20 m thick, which contains gypsum and salt interbeds and creeps under the overburden pressure, whereas the role of vadose water is of subordinate importance. Comparing the corrasion of the ancient Roman ruins with that of the landslide scarps it was found that the landslide movement has begun in the Pleistocene.

INTRODUCTION

Large-scale landslides frame the plateau of Hammada al Hamra in step-like manner from the north-east, and Wadi Sofeggin from the south. The landslides occupy an area c. 250 km long in W-E direction and over 50 km broad (Figs 1—2). Because of their enormous size and untypical climatic conditions, these landslides are difficult to identify in the field which may lead to erroneous interpretation of the geology of that area.

The landslide area was studied by the present author in 1971. Afterwards, a photointerpretation was undertaken the result of which is the morphological sketch-map of the NE margin of Hammada al Hamra to scale 1 : 1 000 000 of the area of c. 30 000 sq km (Fig. 2). Detailed field-work was done in the area near Wadi Marsit, Wadi Zemzem, and Bir Talah and El Gattar in Wadi Sofeggin (*cf.* Figs 1—2). In result of these investigations a registration of many landslide phenomena was done and it was connected with the geology of the escarpment of Hammada al Hamra, which gave a basis to establish the age and development of the landslides.

Acknowledgements. The author wishes to express his sincere thansks to Dr. J. Lefeld and Dr. J. Uberna for showing interesting sections in the field, and for useful discussion on many problems of the geology of north-western Libya. Thanks are also due to Docent A. Radwański for reviewing the manuscript and useful remarks.

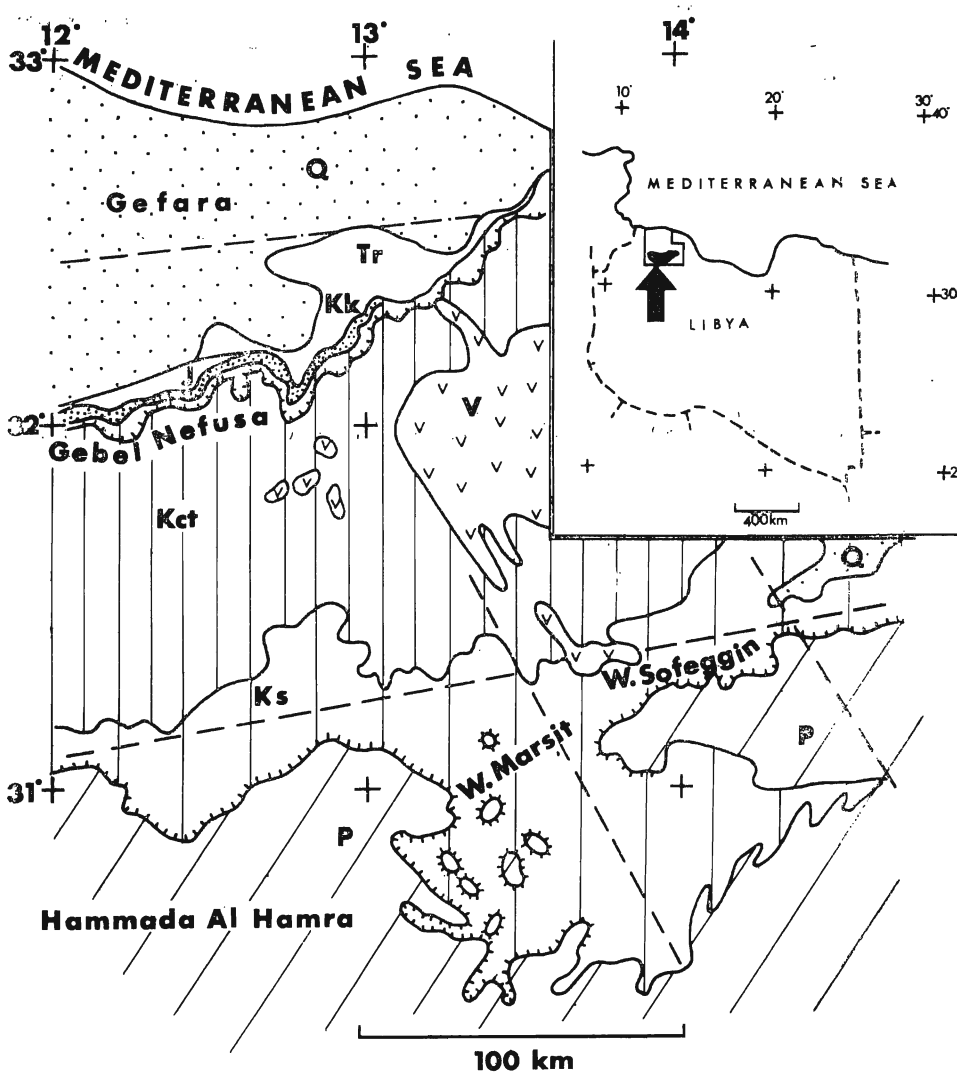
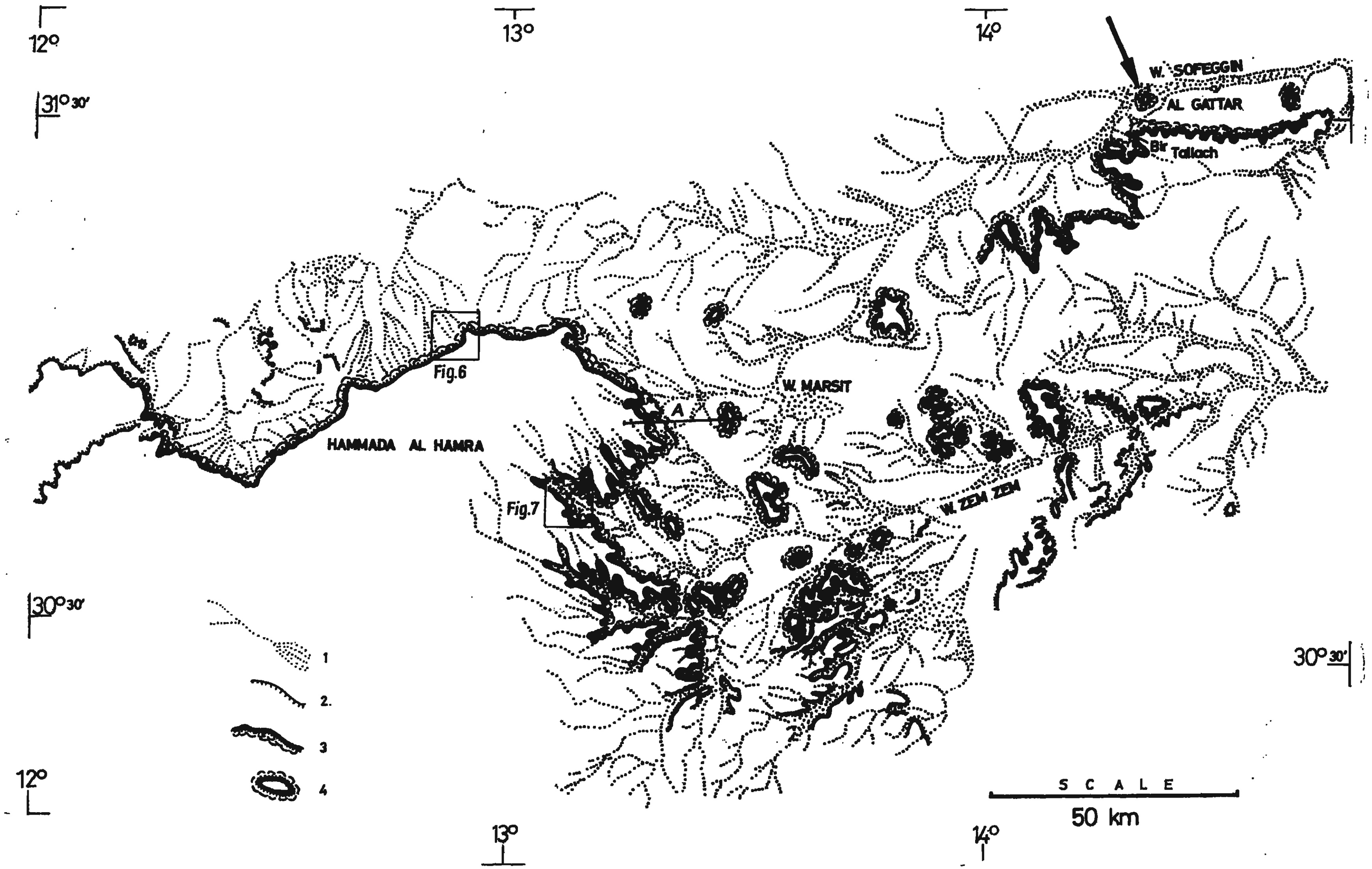


Fig. 1

Geological sketch map of the landslide region (arrowed in the inset presenting its situation in Libya)

Tr — Middle and Upper Triassic (Azizia Formation); *J* — Jurassic (Bu Gheilan Limestones overlaid by the Cabao Formation); *Kk* — Lower Cretaceous (Chicla Formation); *Kct* — Upper Cretaceous (Cenomanian and Turonian): Ain Tobi Limestones, Jefren Marl, Garian Dolomite and Limestones, limestones and marls of the Tigrinna Formation, dolomitic limestones, marls, shales and gypsum of the Mizda Formation; *Ks* — Upper Cretaceous (Senonian): higher part of the Mizda Formation, Mazuza Limestone, Thala Limestone and Marl, Lower Tar Marl (with Socna Mollusc Bed), Upper Tar Marl; *P* — Paleocene: limestones and dolomitic limestones of the Had Limestone Member; *V* — basalt and phonolite of post-Eocene age (?mostly Quaternary); *Q* — ?Pliocene and Quaternary — shallow marine (calcarenites) and continental deposits (sand, loess, alluvium); dashed lines — direction of main lineaments and faults



Morphological sketch of the north-eastern border of the Hammada al Hamra region

1 wadis and depressions, *2* escarpments, *3* landslide area, *4* inselbergs
Squares present the areas of air photographs (Figs 6 and 7); arrow in right-top corner points to the areas presented in terrestrial photographs (Figs 9 and 10); line *A* marks the cross-section presented in Fig. 4

GEOLOGY OF NORTH-WESTERN LIBYA

An outline of the geology of north-western Libya (*cf.* Burollet 1963; Conant & Goudarzi 1964, 1967; Hecht & al. 1964) is given on the sketch-map (Fig. 1) and schematic cross-section (Fig. 3). The plateau of Hammada al Hamra, on the north-eastern slopes of which the large-scale landslides occur, is built of uppermost Cretaceous and Paleocene rocks. Its escarpment faces north and east there and is *c.* 200 metres high. The top of Hammada al Hamra attains altitudes of 660—700 m a.s.l. Farther eastward, near Wadi Marsit only inselbergs remained after the dissected and then denuded Tertiary plateau of Hammada. There exists a network of wadis and small depressions with many sand dune fields and even farther east — the plateau lowers to *c.* 300 m a.s.l. and its escarpment 150 m high faces north to Wadi Sofeggin.

Almost horizontal Cretaceous and Paleocene sediments are dissected by numerous vertical tectonic cracks rather than faults. The dips of beds do not exceed few degrees toward S and SE. Three direction of cracks dominate there.

The first one (*c.* 150°) is common in North Africa, and corresponds *i.a.* to great faults which border the Sirte Basin from the south near the area in question (Hecht & al. 1964; Chain 1971). In the area itself, only parallel fractures of this direction occur which are marked by dark desert varnish. They run tens of kilometres across the Hammada what is clearly observable on air photographs.

The second direction (70—90°) does not form distinct fracture system, but it is well marked in the morphology. These are probably tension fractures caused by tilting of the Hammada Basin substrate toward the south (Hoffmann-Rothe 1966). It coincides with the Gebel Nefusa escarpment and Wadi Sofeggin as well as the northern scarp of the Hammada.

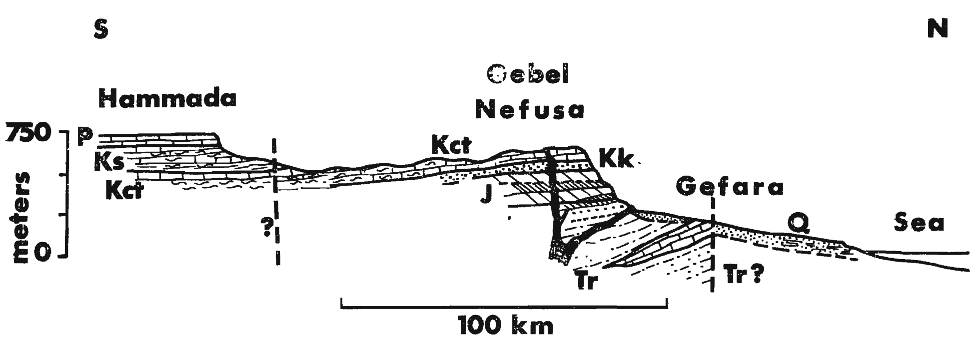
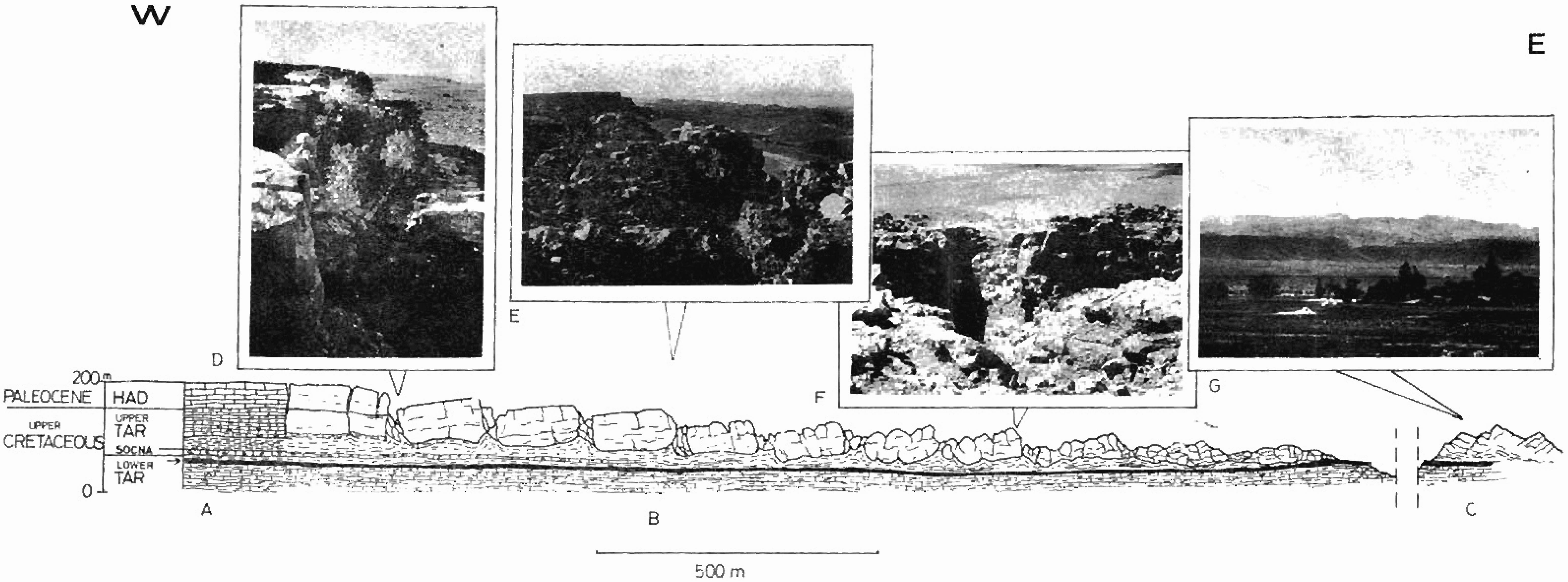


Fig. 3

Schematic geological cross-section from Hammada al Hamra to the Mediterranean Sea; explanation the same as for Fig. 1

Schematic geological cross-section of the landslide area (*cf.* Fig. 2)



A lithological sequence: arrowed is a correlation level (explained in the text), *B* — morphological and geological cross-section, *C* and *G* — inselbergs, *D* — landslide crack at the top of the slope, *E* and *F* — different stages of weathering of the colluvium

The third direction (c. 40°) may be seen as indistinct fractures and it hardly influences the main morphological features there. Fracture of this direction are slightly open and filled in with gypsum, less frequently with salt derived from oozing.

In the eastern part of the area, the fractures of 150° direction are filled with limy crusts.

All these tectonic lines are presumably connected with young volcanic activity (Burollet 1963) and recent earthquakes (Gorshkov 1963). Nevertheless, the origin of the landslides is not connected with the seismicity of the area.

CLIMATIC CONDITIONS

The climate of the Hammada is arid to semi-arid. The influence of the Mediterranean Sea practically ends in the Nefusa escarpment over which relatively abundant rainfall during winter time is normal. Near Wadi Sofeggin rainfall is considerably smaller and in the Hammada proper it is insignificant which is proved by scanty vegetation and only few erosion furrows (*cf.* Butzer 1966).

GEOLOGY OF THE LANDSLIDE AREA

The geological section of the landslide slope in the NE escarpment of the Hammada al Hamra, compiled from paper by Jordi & Lonfat (1963), oral information of Dr. J. Uberna and the author's own observations, is as follows (see *A* in Fig. 4).

The lowest member, the Lower Tar Marl is composed of calcareous shale, marl and marlstone, *c.* 40 metres thick. It is overlaid by brown-red, compact, massive limy mudstone. Because of its high resistivity to weathering processes the latter member is a good marker in photointerpretation (arrowed in Fig. 4). Higher up there is a complex of marls and marlstone which is knobby and very fossiliferous. It contains also dark green, slightly gypsiferous shale. It is overlaid by the Socna Mollusc Bed — dark green shale with thin intercalations of fossiliferous limemudstone. Socna Bed is the lowest member of the Upper Tar Marl (Jordi & Lonfat 1963) and is tentatively assigned to the Paleocene. Higher up there are mudstone, and dark green, partially reddish, gypsiferous and salty shale and clays. These lithological members, *c.* 20 metres thick, are poorly exposed and has been observed by the author entirely in faces of fresh landslides in the lower part of the slope. Overlying are fossiliferous silty and marly limestones interbedded with dark green shales. Capping bed of the Hammada escarpment is formed by dolomites, limestones and dolomitic limestones, *c.* 50 m thick; this is the so-called Had Limestone Member. These rocks form vertical high cliffs and directly underlie the plateau of the Hammada al Hamra. All the strata of the Upper Tar Marl and the Had Limestone Member are subjected to landslide movement.

ZONE OF THE LANDSLIDE MOVEMENTS

The zone of landslide movements is mainly developed in soft salty and gypsiferous clays occurring over the Socna Mollusc Bed (*A* and *B* in Fig. 4). Gypsum which interbeds clays and silstones shows in some cases fine folded-entherolitic texture (*sensu* Hills 1969), the microfolds of which are inclined toward NE, *i.e.* out of the slope. Particular gypsum laminae

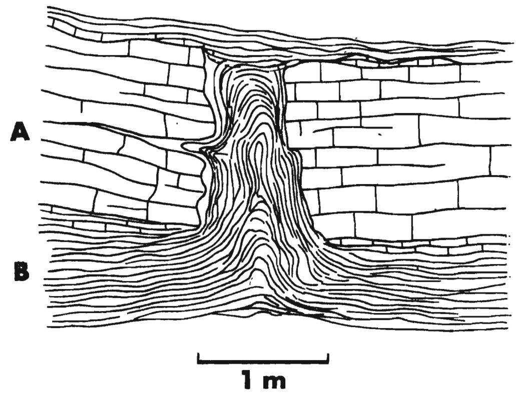


Fig. 5

Landslide boudinage in Hammada al Hamra

A limestone, *B* salt-gypsiferous mudstone

are folded with clays and silts. Clays penetrate fissures in harder rocks, as *e.g.* limestones which form sporadic interbeds in clays; edges of such limestone blocks are sharp (Fig. 5).

MORPHOLOGY OF THE LANDSLIDES

The landslides of the Hammada al Hamra form a continuous zone *c.* 2 km broad (Figs 6—7), and they surround the escarpment and nearby inselbergs (Fig. 1). Mean inclination of landslide slopes is 5°. The particular landslide "steps" are 10—20 m high, 50—200 m broad (see *B* in Fig. 4) and stretch over 1 km along the Hammada escarpment (see Figs 6—7). Ten to twelve steps occur in the slope, or even up to 14 in the highest part of the escarpment. Higher steps are bordered with vertical walls which do not show differences in their resistivity to weathering, despite of the presence of marly interbeds in limestones, and dolomitic limestones. The length of steps is limited by transversal wadies developing together with the landslide phenomena. The upper surfaces of the particular landslide blocks are formed of resistant limestones and dolomitic limestones of the Had Limestone Member. The state of preservation of the blocks varies with altitude (Fig. 4*B*-*E*). The lowest ones and some inselbergs (which do not posess capping bed in situ) are disturbed with secondary landslides and weathering processes to such an extent that field identification of their lithology is very difficult, and the sequence of the landslide forms may be observed only on air photographs (Fig. 6). Tilt of the upper surface (primarily horizontal — concordant to bedding) in the uppermost block agrees with that of the slope and does not exceed 5°, whereas that of lower blocks is directed against the slope and is twice as large.

LANDSLIDE FISSURES

The direction of the particular landslide blocks coincides with that of the escarpment, and the landslide fissures bordering the blocks are zigzag-shaped. The direction of fissures agrees with the three above

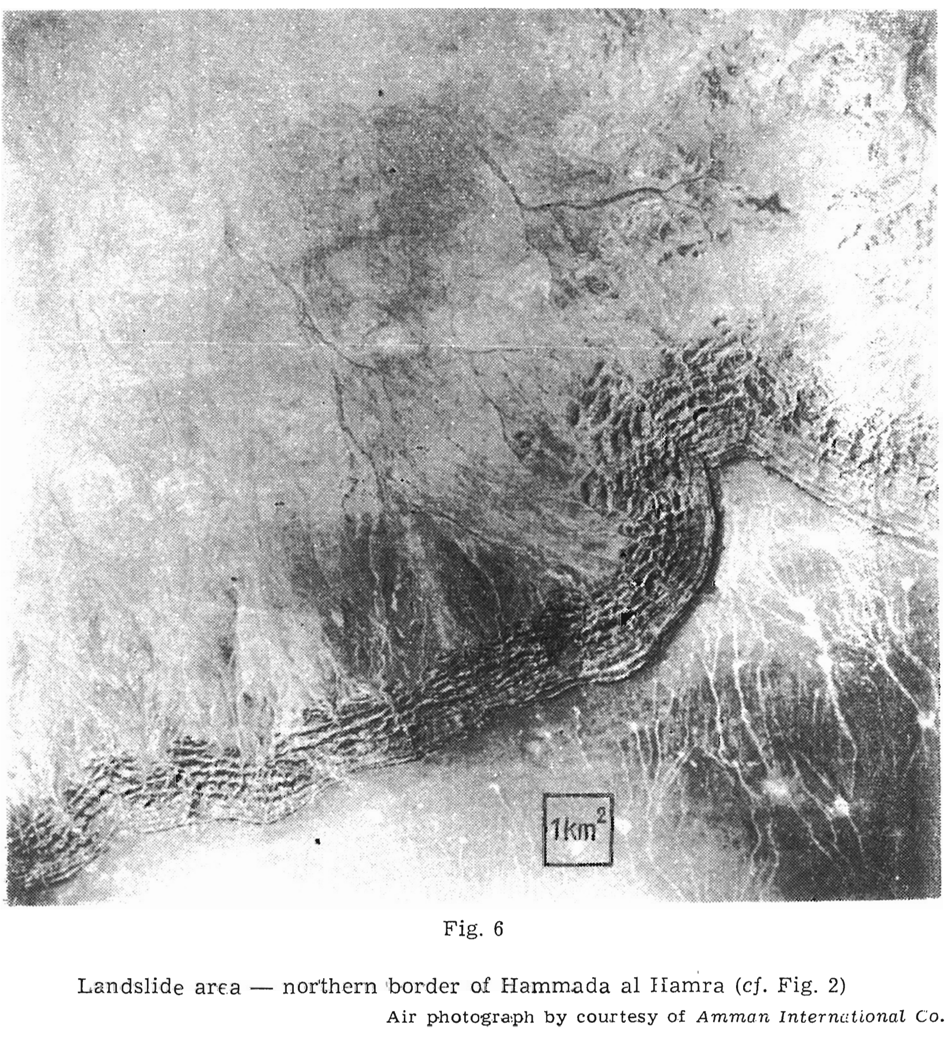


Fig. 6

Landslide area — northern border of Hammada al Hamra (*cf.* Fig. 2)

Air photograph by courtesy of *Amman International Co.*

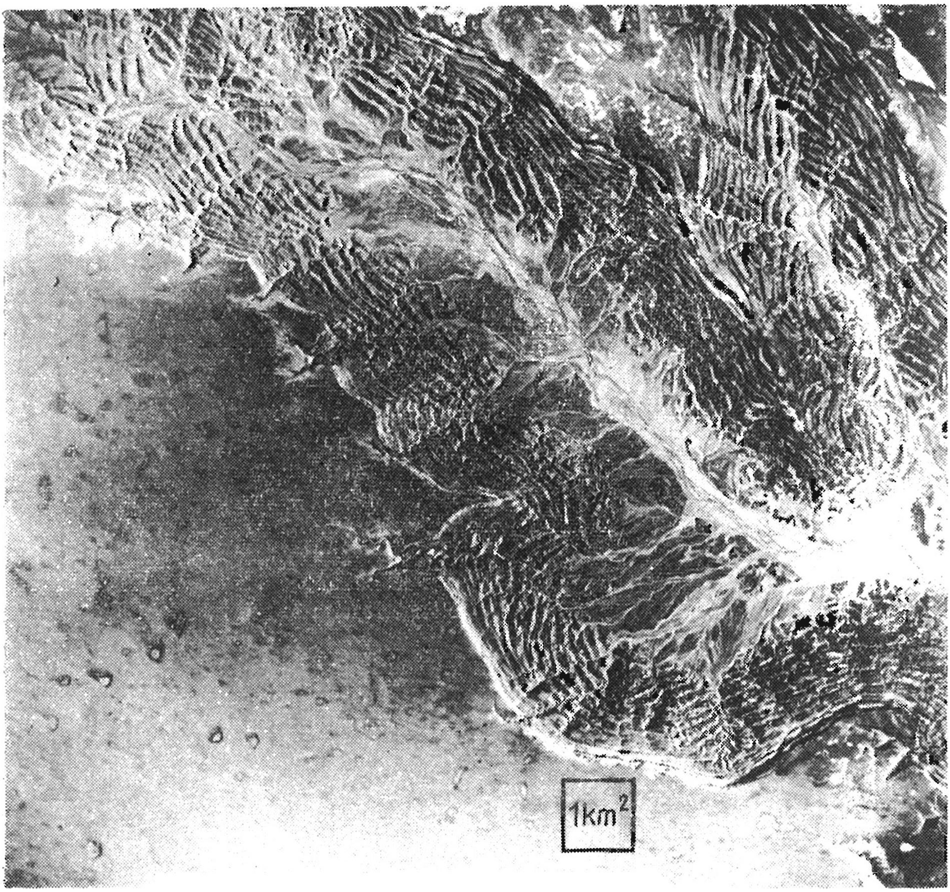


Fig. 7

Landslide area — eastern border of Hammada al Hamra (*cf.* Fig. 2)

Air photograph by courtesy of *Amman International Co.*

mentioned tectonic directions along which the landslide blocks originate. Length of straight parts of these fissures changes depending on resultant direction of the slope direction — from several dozen of centimetres up to a dozen of metres. Variously open fissures occur over the plateau (from some centimetres up to few metres). They are filled in with weathering debris to various extent. They may be locked by wedges of small blocks or cobbles. In some cases such blocks are clearly crushed in result of vertical movements of fissure walls (Fig. 8). Because of their zigzag shape, the fissures form a labyrinth a dozen or so metres deep stretching along the scarp. The spaces between the fissures and the scarp are smaller than the width of the landslide blocks. Some fissures continue in the weathering cover and wind-blown clays common in leeward sides. Quite new landslide fissures were observed cutting alluvial sediments filling in the niches inbetween the lower steps.

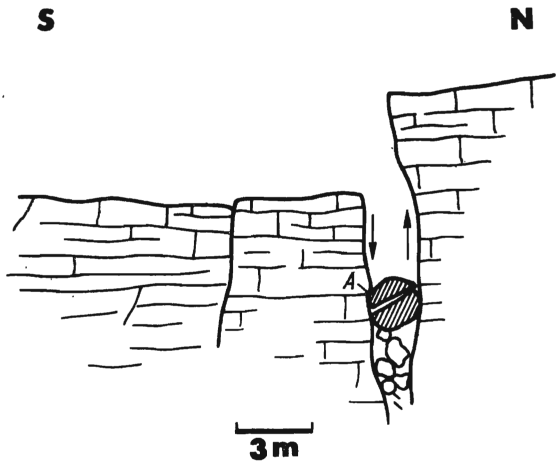


Fig. 8

Boulder crushed by a landslide movement (*A* fresh crushing of of its corner); arrows show relative motion of walls

DRAINAGE

Depressions existing inbetween the landslide steps are drained to various degree. Surface drainage forms a network of wadis parallel to the slope, connected with (over the landslide blocks) gap wadis perpendicular to the escarpment. Characteristic suffosion depressions were noted in larger niches eroded in clayey weathering cover.

WIND ACTION

Wind action is clearly observable on the landslide slope. Fine particles derived from disintegration of colluvium are blown away easily. Deflation pavements occur at the base of escarpment. Less resistant beds exposed in walls of the lower part of slope are carved by corrasion. The profile of walls clearly depends on the resistivity of the particular beds to corrasion, which leads to formation of overhanged ledges, on which in turn secondary landslides and collapses occur. In most cases, however, secondary landslides and collapses are connected with the wadis cutting the slope.

LANDSLIDES IN THE WADI SOFEGGIN AREA

Landslide slopes in the Wadi Sofeggin area reveal somewhat different morphology than those of the Hammada al Hamra region, despite of similar geological conditions in both areas (Fig. 9). The particular landslide blocks do not form so regular steps as in the Hammada and are

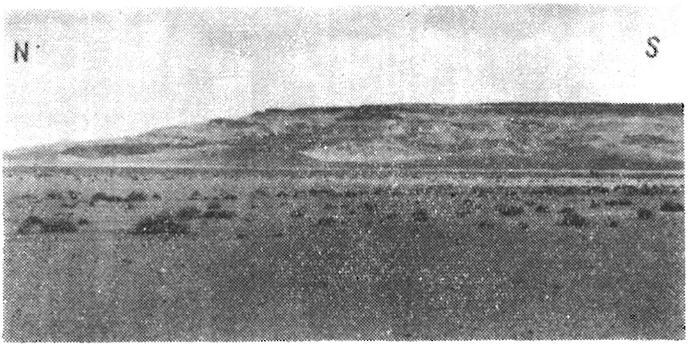


Fig. 9

General view of the landslide area near Wadi Sofeggin (*cf.* Fig. 2)

strongly crushed. The marginal zone at top of slope is densely cut with landslide clefts (Fig. 10). Tilt of the highest blocks, concordant with slope inclination is *c.* 20°; length of the particular landslide steps does not exceed 300 m, and width is 20—40 m. Secondary landslides are very common there. Outwash of weathering debris by surface waters is evi-

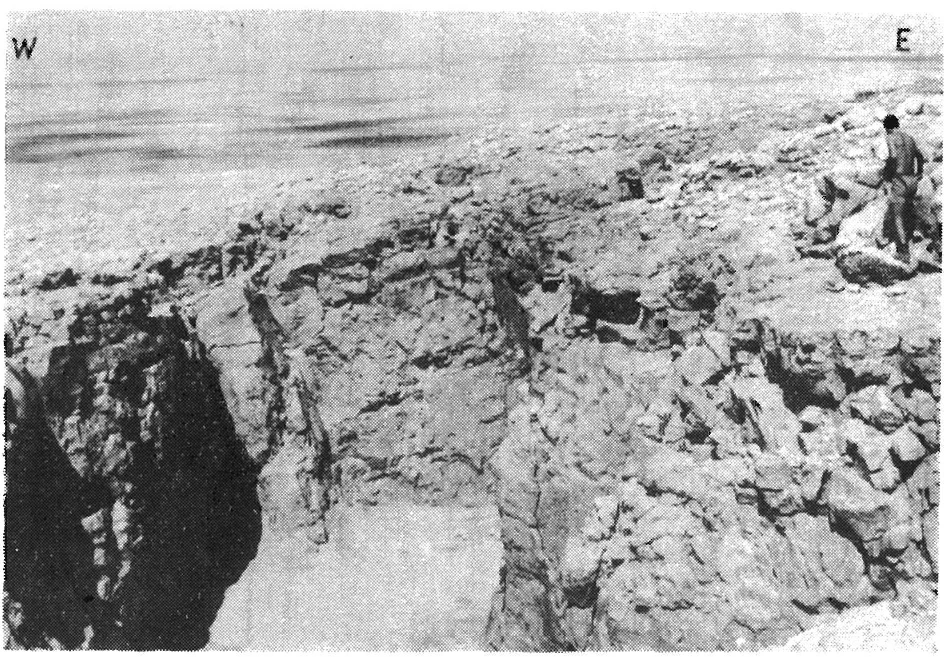


Fig. 10

Landslide cleft at the top of Al Gattar in Wadi Sofeggin dent: there are numerous alluvial fans, starting in landslide clefts. Also in this area the aeolian processes are very active which is reflected in stripping off the bases of slopes. The walls of blocks are cut by corrasion and fine weathering material is blown away. The pediments are covered with deflation pavement.

ORIGIN OF THE LANDSLIDES

Certain regularities in landslide slope morphology such as constant slope angle, similar size of the particular steps down the slope, increasing degree of weathering of the steps down and lack of piling up of colluvium at the base of slope — prove long lasting equilibrium of the landslide processes denuding the slope, and of the eroding processes such as wash--out and blow-out the disintegrated weathering debris and colluvium which support the slope. Opening of fissures near the edge of landsliding plate and tilt of blocks off the slopes may be caused by compaction and near edge squeezing of wet clays and siltstones from underneath the blocks (Fig. 11). Loosing of rocks — mainly of the capping bed of the Had Limestone Member and formation of the subsequent blocks separated from the main massif by a system of new fissures are farther effects in this process. Water, rarely percolating the system of fissures, undoub-

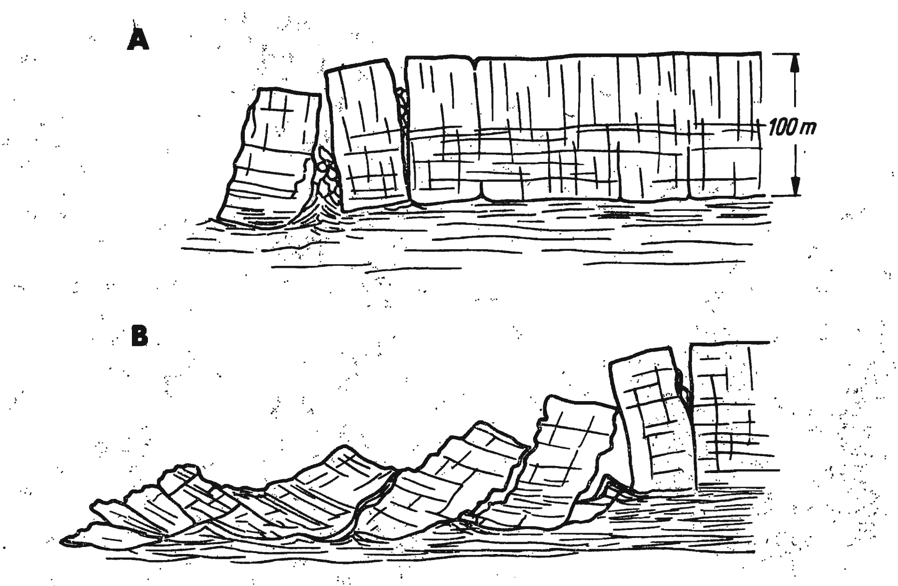


Fig. 11

Schematic diagram of successive separation of the landslide steps

A initial stage, *B* evolutionary stage tedly makes the clays and siltstones plastic thus accelerating the landslide movement of the blocks. Creeping of gypsum and salt which form interbeds among the clays and siltstones is another landslide factor. A gradual increase of tension takes place in result of slow slope deformations and recrystallization of gypsum (possibly with a role of salt solutions brought in by occasional rains). An overburden about 100 metres thick produces sufficient pressure to make these sediments plastic (Handin 1966), thus leading to a slow sliding of the blocks. The landslide blocks are disintegrated during their path down the slope, through opening of cracks and secondary landslides and stone-falls. Distinct losses of landslide mass in older, lower situated blocks (see *F* in Fig. 4) are caused by wind action and intermittent removing of the disintegrated rock material.

Earthquakes may accelerate the landslide movement, nevertheless, it seems more probable that activation of secondary landslides would be the main result of that. A stripping-off process on slopes, caused by earthquakes and resulting in cleaning of the slopes from loosened material, must lead in effect to hampering of the formation of secondary landslides for longer period of time.

Landslides similar in character, developed in Pliocene sediments in the northern margin of the Hammada du Dra in Marocco (Choubert 1963) have developed in similar morphological, geological and climatic conditions, but these, however, are much smaller. Comparable great landslides of similar morphology are known to occur on the Black Sea coast (Kamenov & al.1969), Siberia (Trzhtsinski & al. 1969), and in some sites in Europe (Zaruba & Mencl 1969); in all these cases the plastic bed is thick and water plays considerable role in the colluvium movement.

AGE OF THE LANDSLIDES

High regularity in the development of the main landslides over large distances and similar size of the landslide steps prove the uniformity of the process and its recurrence over a period of time. These processes started after the development of scarps reaching down to the base of the Upper Tar Marl. According to Desio (1953), the main morphological features of the eastern margin of the Hammada al Hamra were established at the decline of the Lower Miocene. It may therefore be assumed that the main landslides began to develop presumably during the Pleistocene which was characterized by pluvial conditions in northern Africa.

In order to obtain at least rough age evaluation of the discussed landslides the present author has compared corrasion forms on walls of Roman ruins that show but slight traces of corrasion (Fig. 12) despite

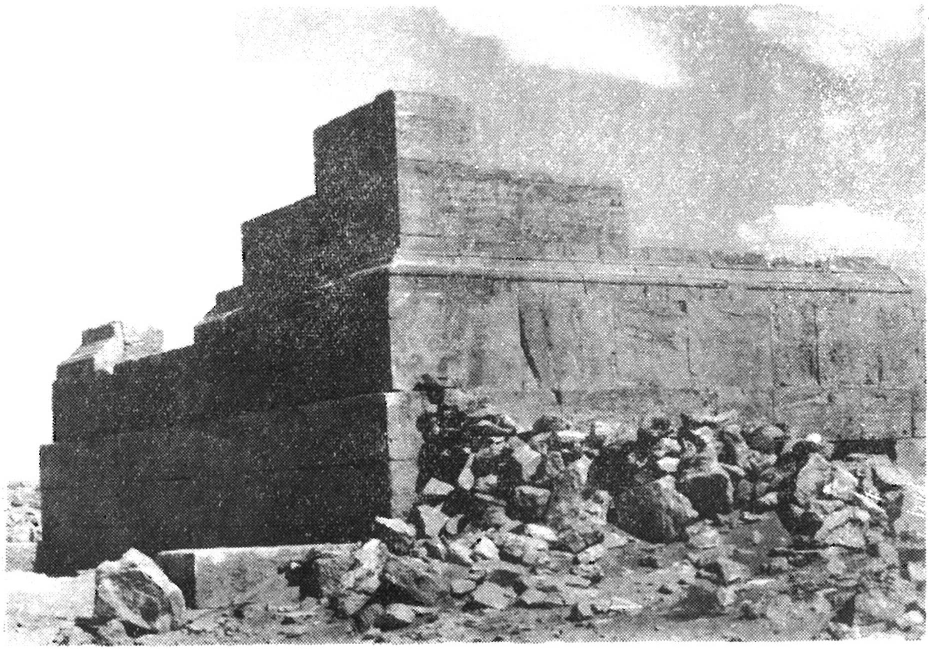


Fig. 12

Ancient ruins of a Roman building: the walls without traces of corrasion

almost 2,000 years of their history (*cf.* Haynes 1965). Thus it seems reasonable to evaluate the age of strong corrasion on landslide scarps as at least ten times longer than that of the ruins. The age of the landslides may consequently be estimated as about a dozen or so to more than twenty thousands of years in the case of the lowest blocks; this age corresponds to the end of the Pleistocene. Time span required to the development of the subsequent blocks, originating along the regularly spaced fractures, may be estimated as about 1,000—1,500 years. The latter value in case of landslide processes is rather great, and the discussed landslides may therefore be classified as chronic.

Such phenomena as the presence of splitted blocks in the landslide fissures (*cf.* Fig. 8), penetration of fissures into blown-in ooze at the base of walls, as well as landslide cracks cutting the alluvial sediments, prove the persistence of landslide movement in the upper part of slopes till the Recent times.

Institute of Geology
of the Warsaw University
Warszawa 22, Al. Żwirki i Wigury 93
Warsaw, October 1972

REFERENCES

BUROLLET P. F. 1963. Field trip guide book of the excursion to Jebel Nefusa. *In:* Petroleum Explor. Soc. Libya. Tripoli.

BUTZER K. W. 1966. Climatic changes in the arid zones of Africa during early to mid-Holocene times. *In:* World Climate from 8 000 to 0 B. C.; Proc. of the Intern. Symp. Meld at Imp. Coll. London 18 and 19 April 1966. *Roy. Heteorogi Coll. Society.* London.

CHAIN B. E. 1971. Regionalnaya geotektonika, part 1. Moskva.

CHOUBERT G. 1963. Carte Géologique du Flanc Sud de l'Anti-Atlas occidental et des plaines du Dra. Foum el Hassane-Assa (1 : 200 000). — Serv. Géol. du Maroc. Notes et Mémoires 159.

CONANT L. C. & GOUDARZI G. H. 1964. Geologic map of the Kingdom of Libya (1 : 2 000 000). — U. S. Geol. Surv. Washington.

— 1967. Stratigraphic and tectonic framework of Libya. — Bull. Amer. Assoc. Petrol. Geol., vol. 51, no. 5. Tulsa.

DESIO A. 1953. Brève synthèse de l'évolution morphologique du territoire de la Libya. — Inst. di Geol., Paleont., e Geogr. Fisica della Univ. di Milano. Milano.

GORSHKOV G. I. 1963. O seysmichnosti Afriki. — Bull. Soveta po Seismologii, vol. 13. Moskva.

HANDIN J. P. 1966. Strength and ductility. Handbook of Physical Constants. — Geol. Soc. Amer., Memoir 97. Baltimore.

HAYNES D. E. 1965. The antiquities of Tripolitania. *Antiquities Museums and Archives of Tripoli.*

HECHT F., FÜRST J. M. & KLITZSCH E. 1964. Zur Geologie von Libyen . — Geol. Rundschau, Bd. 53, H. 2. Stuttgart.

HILLS E. S. 1969. Elements of structural geology. Science Paperbacks. Repr. Bungay.

HOFFMANN-ROTHE J. 1966. Zur Stratigraphie und Tektonik des Paläozoikum der Algerischen Ostsahara. — Geol. Rundschau, Bd. 55, H. 3. Stuttgart.

JORDI H. A. & LONFAT F. 1963. Stratigraphic subdivision and problems in Upper Cretaceous — Lower Tertiary deposits in North-Western Libya. — Rev. Inst. Franc. Petrole, vol. 18, no. 10. Paris.

KAMENOV B. & al. 1969. Les glissements sur le litoral de la Mer Noire aux environs du village de Sarafovo, arr. de Bourgas. — Bull. Geol. Inst., Series Engineering Geol and Hydrogeol., vol. 17/18. Sofia.

TRZHTSINSKI Y. B., BUDZ M. G. & ZARUBIN N. E. 1969. Landslides, mud streams, thermokarst of eastern Siberia and their engineering-geologic importance. *Publ. House „Nauka".* Moscow.

ZARUBA Q. & MENCL V. 1969. Landslides and their control. *Elsevier and Academia Publ. House of the Czechoslovak Academy of Sciences.* Prague.

S. OSTAFICZUK

WIELKIE OSUWISKA KONTYNENTALNE W PÓŁNOCNO-ZACHODNIEJ LIBII

(Streszczenie)

Przedmiotem pracy jest analiza rozległej strefy lądowych osuwisk strukturalnych usytuowanych w północno-zachodniej Libii (*por.* fig. 1—11). Długość tej strefy wynosi przeszło 250 km, zaś szerokość — ok. 2 km, przy różnicy wysokości osuniętych mas rzędu 100—150 m. Ruchom osuwiskowym podlegają tutaj prawie poziomo leżące wapienie margliste formacji *Upper Tar Marl* oraz wyżejległe wapienie i dolomity formacji *Had Limestone* (?górny senon — dolny paleogen). Strefa przemieszczeń osuwiskowych znajduje się w utworach dolnej części formacji *Upper Tar Marl* (tuż nad poziomem *Socna Mollusc Bed*), wykształconych w postaci wapnistych mułowców oraz iłów solo- i gipsonośnych, które pełzną pod wpływem ciśnienia nadkładu. Do powstania osuwisk przyczynia się także działalność wiatrów i okresowych deszczów, które usuwają koluwium gromadzące się u podnóży osuwających się zboczy. Na podstawie porównania śladów słabej korazji budowli rzymskich (fig. 12), z wyraźną korazją skarp osuwiskowych sądzić należy, iż początek ruchów osuwiskowych sięga plejstocenu. Jak wynika natomiast z obserwacji szczelin osuwiskowych, tnących współczesne osady na zboczach, ruchy te trwają aż do czasów dzisiejszych.

Instytut Geologii Podstawowej
Uniwersytetu Warszawskiego
Warszawa 22, Al. Żwirki i Wigury 93
Warszawa, w październiku 1972 r.