acta
geologica
polonica

Vol. 23, No. 3 Warszawa 1973

STANISŁAW OSTAFICZUK

Exogenic anticlines in the Podhale region

ABSTRACT: Small anticlinal forms which occur in the flysch deposits of the synclinorial basin of Podhale (Central Carpathians), as evidenced by their morphology, dimensions and location, have developed simultaneously with erosion along the stream valleys and resulted from such exogenic processes as groundwater swell, initial landsliding, decompression, and squeezing and bulging, all of them coinciding to a variable extent. Despite their insignificant dimensions, these anticlines complicate the tectonic framework of the Podhale flysch and may lead to false geologic diagnoses.

INTRODUCTION

The Podhale synclinorial zone, situated inbetween the High Tatra Mts in the south and the Pieniny Klippen Belt in the north (Fig. 1), is built of the Eocene and Oligocene flysch that consist of predominantly clayey-silty sediments interbedded by sandstones up to one meter in thickness. Some tectonic elevations and depressions and smaller fold structures exist in the synclinorium; dips *c.* 10° prevail in the central part of the basin, but vertical and reversed beds are also noted (*cf.* general data on geology of the Podhale flysch by *e.g.* Radomski 1958; Gołąb 1959; Halicki 1959, 1963; Watycha 1959; Boretti-Onyszkiewicz 1968; Mastella 1972). Aside all these tectonic forms there also occur some minor anticlines which do not show any direct connection with the regional tectonics. Such minor anticlines, being the subject of this paper, were frequently observed by previous workers and believed to had resulted from fold tectonics. It was only Halicki (1963) who regarded these structures, due to their shallow occurrence, as attributable to the slide movements.

Acknowledgements. The author is greatly indebted to Docent A. Radwański for pointing out the subject of the presented paper and helpful discussion.

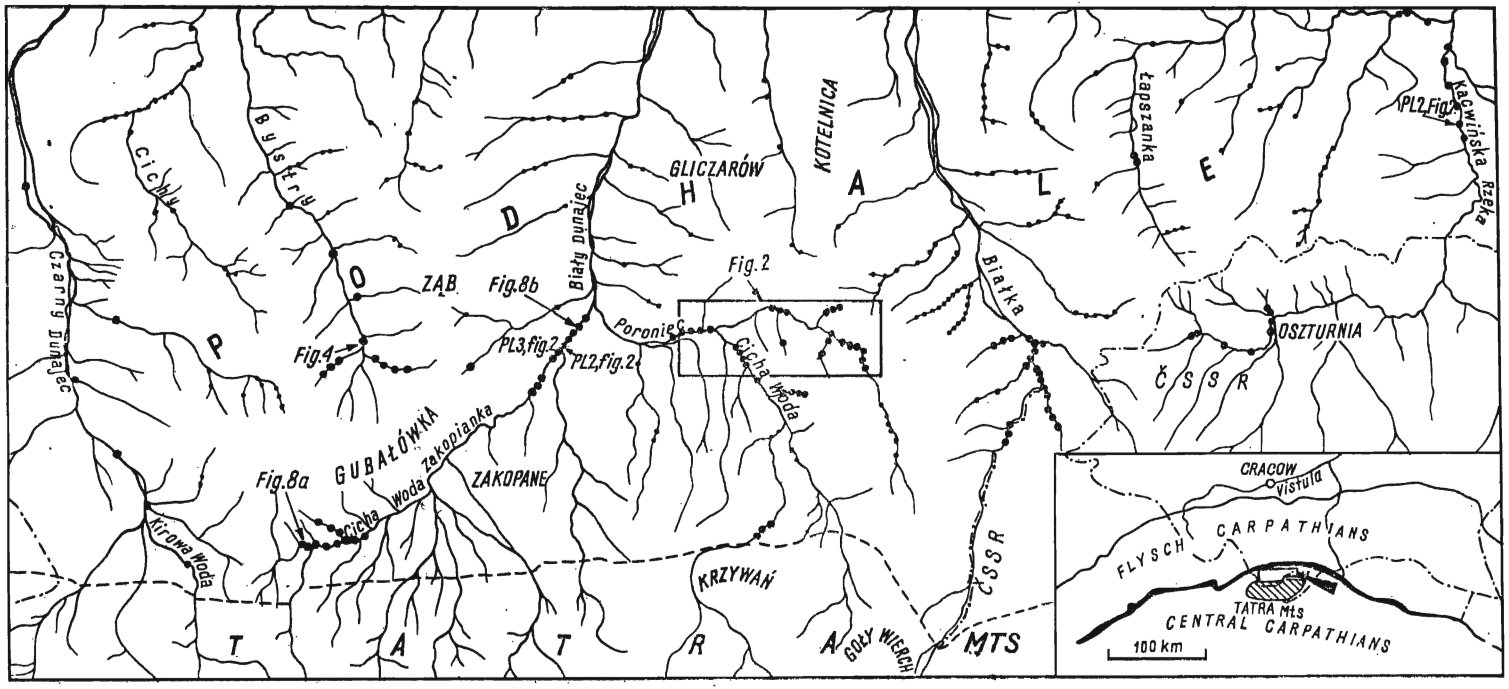


Fig. 1

Location of exogenic anticlines in the Podhale region. Large dots — anticlines stated by the author, small dots — anticlines mentioned by previous workers (unpublished reports in the Institute of Geology, University of Warsaw, by Pokorski 1962, Szymański 1962, Pepol 1970, and Mastella 1972)

MORPHOLOGY OF THE EXOGENIC ANTICLINES

The discussed anticlines (Pls 1—4) are found in outcrops of the Podhale flysch only in the valleys along the stream beds (Fig. 2). It was stated, however, that in most cases, despite fracturing of beds forming the anticlines, the stream beds escape from the anticlinal bend (Fig. 4 and Pl. 4, fig. 2) and the anticline axes are therefore shifted over the stream bottom or even situated within the edges on some height above the bottom. These are strongly limited forms within any flysch sequence, but not associated with any synclines. The anticlines vary from a few to several dozen meters in length, and from several dozen centimeters up to a few meters in height and width. They are dome-shaped in section and their beds are cracked in bends or, they taper with concave limbs and sharp bends, usually asymmetrical with small overthrusts in their cores (Fig. 3). Inclination of asymmetric forms agrees as a rule with the general dip of beds. In both varieties there is lack of such features of tectonic processes as calcite mineralization and slickensides. On the other hand, there appears calcareous sinter or limonitization on crack surfaces in bends. Both flysch sandstones and shales are strongly crushed, seldom bent, the shape of resulting anticlines being angular. Margins of fissures in the anticlinal bends are uneven and rugged (Pl. 2, Fig. 1; Pl. 3, Fig. 1; Pl. 4, Fig. 2).

Interpretation of air photographs from the Podhale region shows a straight course of the boundaries of particular rock complexes over large distances which evidences that the discussed anticlines in valleys do not continue into larger anticlinal forms of greater amplitude off the valleys.

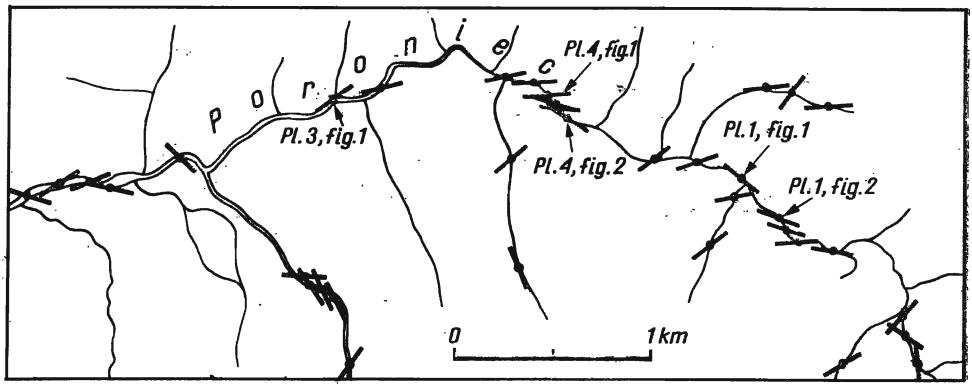


Fig. 2

Magnified part of map of the Podhale region (*cf.* Fig. 1) showing the axes of exogenic anticlines

ORIGIN OF THE EXOGENIC ANTICLINES

The location of the exogenic anticlines, as well as their morphology and size (*cf.* Fig. 3) suggest their genetic connection with erosion in river valleys. As the factors responsible for their development the following should be considered: groundwater pressure, consequent landslides of great extent (Fig. 6), decompression of beds, and marginal squeezing and bulging of shales (Fig. 5) that become plastic close of the stream channels (*cf.* Hills 1961, Handin 1966, Zaruba & Mencl 1969). All these factors coincide to a variable extent during the development of a given form, but they will be separately discussed to be clarified as follows.

Groundwater pressure

In any exogenic conditions, even insignificant groundwater pressure is sufficient for the development of anticlines resulting from hydraulic

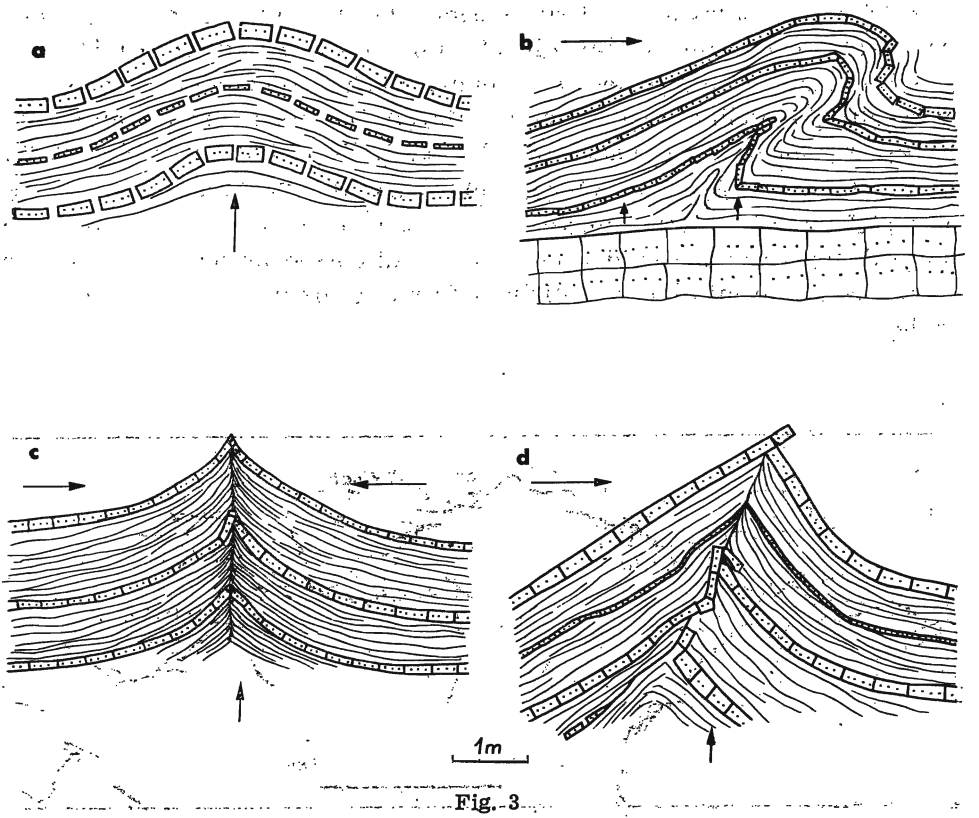


Fig. 3

Exogenic anticlines of various morphology

a symmetrical, dome-shaped; *b* asymmetrical; *c* symmetrical, with sharp bend; *d* asymmetrical, with overthrust
Arrows show direction of pressure

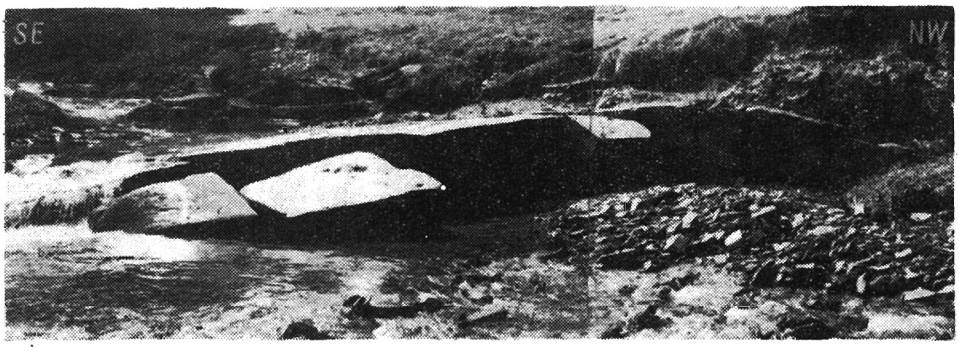


Fig. 4

The escaping of the Bystry stream from the anticlinal bend; thickness of sandstone bed *c.* 80 cm

swell. Sandstone beds, less then one meter thick and densely cracked are unresistant to the bending. The resistance of shales soaked with water under the slow bending depends on the duration of the process, and vanishes when a longer span of time in considered. Thus the hydraulic swell is essential for compensation of rock overburden. For example, if the specific weight of the flysch rock is *c.* 2.5 times larger than of water, the pressure of a impermeable layer 4 m thick is balanced by water pressure equaling 1 bar. In such a case, a subsequent decrease in thickness due to the valley erosion, will cause an uplift of rocks. A dome-shaped anticline will begin to develop successively in the stream bed in such very case as that stated in the Podhale region (*cf.* Fig. 5 and Pl. 3, Fig. 2; Pl. 4, Fig. 1). This process ceases when the water pressure within the impervious layer decreasses. The sandstones of the Podhale flysch contain subartesian water, and the local water supply is related to rainfalls

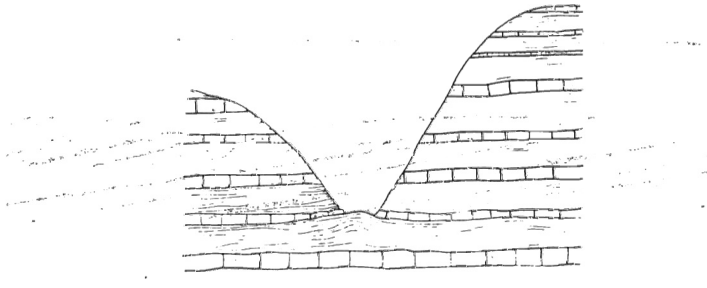


Fig. 5

Squeezing and bulging of shales in erosional incision, and resulting from marginal pressure

and subsequent infiltration through the weathering covers of slopes, and from valley bottoms and terraces (*cf.* Gołąb 1947). Such water occurs in sandstone beds in the axial parts of the Podhale basin, whereas its migration routes are complex as evidenced by an appearance of mineralized sources (*cf.* Macioszczyk 1959). Local fluctuations in water level may suggest a local and periodical rising of the groundwater table resulting from a dammed flow. It may be noted that sporadically, after a heavy rainfall, the outflows from fissures on tops of anticlines are to be observed (Pl. 4, Fig. 1).

Initial landsliding

When erosional incision is too shallow to permit groundwater pressure to overcome the overburden (lithostatic) pressure, a decrease in intraformational friction takes place in consequent slopes in result of partial compensation of vertical pressures. This causes, in turn, a tendency to consequent landslides of large dimensions and slow movement associat-

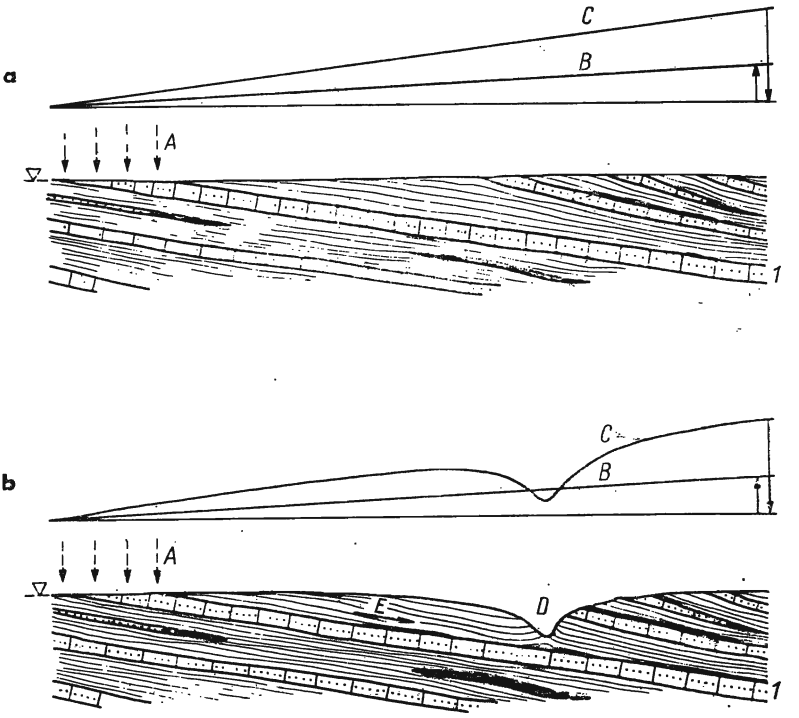


Fig. 6

Action of groundwater pressure and tendency to the consequent slides
a initial stage, *b* after incision of the valley
A infiltration area, *B* pressure distribution within the bed marked *1*, *C* overburden (lithostatic) pressure, *D* erosional incision, *E* tendency to sliding

ed with bendings of layers at the slope base (Fig. 6). Asymmetrical anticlines tend to develop in such case in the valleys, their bends being broken and even overthrusted (*cf.* Fig. 3*b*, *c*, *d* and Pl. 1, Fig. 2; Pl. 2, Fig. 2).

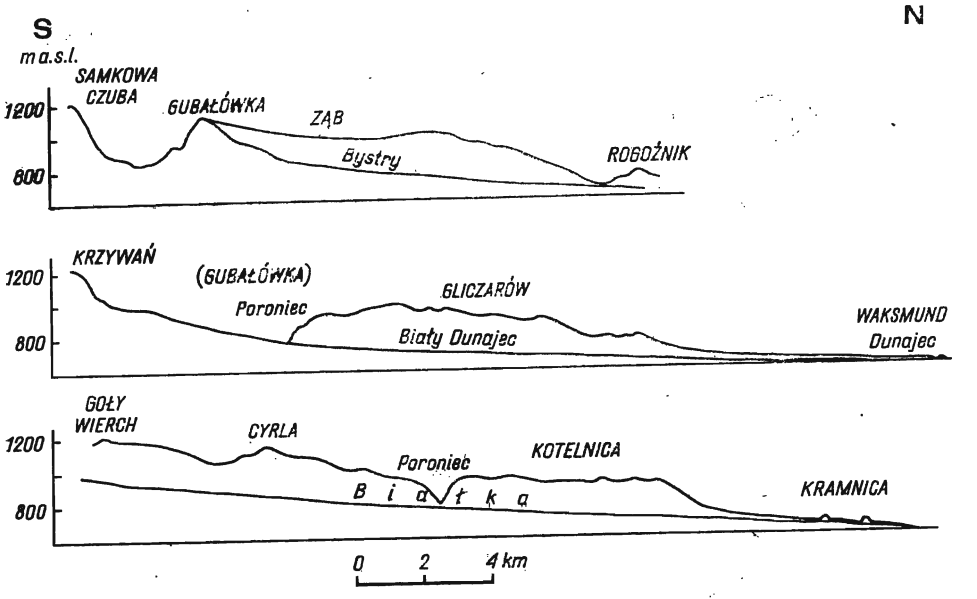


Fig. 7

Long profiles of streams in the Podhale region

Gravitational, slow landslides of greater patches of the flysch rocks develop in the Podhale area in result of the progressing drainage favored both by the consequence of slopes and by lithology. Many landslides of the Podhale area are well developed (complete references *in* Jakubowski 1968), their colluvium being well individualized and strongly displaced.

The anticlines in question are however connected only with the initial stages of landsliding and not with the folding either of colluvium or the foreland of a landslide. The displacements of such landslides are small as compared with dimensions of an average landslide, and the movement is simple and resulting in a "slab" slide of the whole slope undercut at its base. The structure of such a sliding patch remains almost intact, and resulting landslides are hardly observable in the field. Neverthless, the lateral boundaries of the patches that moved may be observed on well exposed surfaces. These boundaries are marked by zones of shale and sandstone jam, up to half a meter wide (Fig. 8), which have been recorded at Cicha Woda, Zakopianka, Łapszanka, Kacwińska Rzeka and other streams.

The permanency and the widespread distribution of consequent "slab" slides along the slopes is proved by the fact that the subsequent valleys are narrow and usually devoid of higher terraces, whereas the exogenic asymmetrical anticlines therein have sharp bends (*e.g.* Poroniec, Cicha Woda, tributaries of the Bystry stream). This may be explained by a permanent tighting of the channel by slide movements, which leads to a rapid erosion of the landslided layers. The streams therefore do not produce any broad, erosional terrace nor they accumulate the material along the broadenings of the channel as such segments are liquidated by the consequent landsliding of the slopes. In the contrary, the consequent valleys in the region are broad, with wide terraces, and the exogenic anticlines are dome-shaped herein (lower part of the Kacwińska Rzeka, Białka and Biały Dunajec streams).

Marginal squeezing and bulging

The valleys of main streams in the Podhale area (Fig. 7) are cut c. 200 m into the Tertiary surfaces (*cf.* Sawicki 1909). The valleys of tributaries are narrow and *V*-shaped. Erosional scarps are several dozen me-

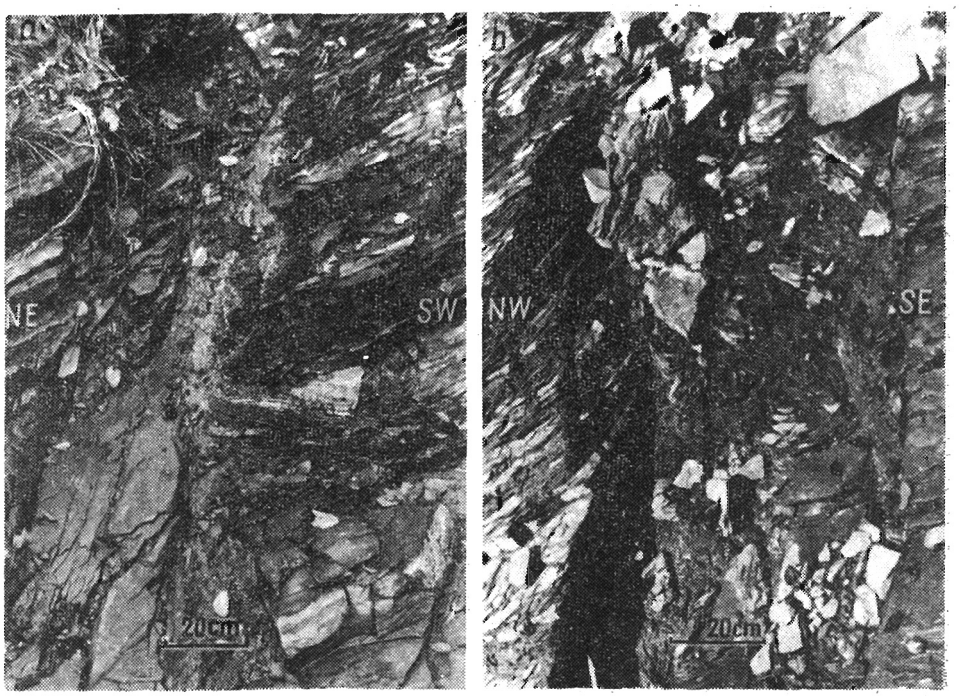


Fig. 8

Lateral boundaries of landsliding patches of flysch strata
a Cicha Woda stream, *b* Zakopianka stream

ters high, their slopes inclining at angles over 50° (Białka, Poroniec, Biały Dunajec and numerous tributaries). Under such circumstances the marginal pressure at the base of scarps may attain a few kilograms per sq cm, which is sufficient for a relatively quick squeezing and bulging of plastic shales (Fig. 5). As the erosion progresses, the concentration of stress results in the formation of anticlines at the base of scarps, regardless of the sequence of layers in the slope and the existence of an aquifer under the valley bottom.

AGE OF THE ANTICLINES

The presented exogenic anticlines started most probably to grow simultaneously with the development of the regional drainage pattern which took place in the uppermost Tertiary and the lowermost Quaternary (*cf.* Klimaszewski 1972). In result of erosion the overburden pressure was gradually lowering in the progressing valleys. The successive aquifers, when incised, caused permanent uplift of the neighboring layers, while at the landsliding and marginal squeezing embraced deeper and deeper flysch beds contributing in result to the formation of exogenic anticlines, the development of which lasts till the Recent times.

FINAL REMARKS

The flysch strata of the Podhale synclinorium are exposed mostly in the stream valleys, *i.e.* in these very areas in which the results of such variable as above discussed exogenic processes appear. The presented attempt is therefore not only to discuss the origin of small anticlinal forms resulting from the exodynamic processes (*cf.* Hofmann 1966), but also to pay an attention to their role in the obscuring and perplexing the actual tectonic framework of the Podhale flysch.

Institute of Geology
of the Warsaw University
02-089 Warszawa 22, Al. Żwirki i Wigury 93
Warsaw, March 1973

REFERENCES

BORETTI-ONYSZKIEWICZ W. 1968. Joints in the flysch of Western Podhale. — Acta Geol. Pol., vol. 18, no. 1. Warszawa.

GOŁĄB J. 1947. Hydrogeological characteristics of the Gubałówka Range near Zakopane. — Biul. Państw. Inst. Geol. 32. Warszawa.

— 1959. On the geology of the Western Podhale flysch area. — *Ibidem*, 149.

HALICKI B. 1959. Contributions to the geology of the Podhale region. — *Ibidem.*

— 1963. The tectonics of Podhale. — Rocz. P. T. Geol. (Ann. Soc. Géol. Pol.), vol. 33, no. 3. Kraków.
HANDIN J. 1966. Strength and ductility. *In:* Handbook of Physical Constants. — Geol. Soc. Amer., Mem. 97. Baltimore.
HILLS E. S. 1969. Elements of structural geology. *Science Paperbacks.*
HOFMANN H. J. 1969. Deformational structures near Cincinnati, Ohio. — Bull. Geol. Soc. Amer., vol. 77, no. 5. New York.
JAKUBOWSKI K. 1968. Shallow debris slides in slope processes in eastern Podhale (South Poland). — Prace Muzeum Ziemi, no. 13. Warszawa.
KLIMASZEWSKI M. 1972. Geomorfologia Polski, vol. 1. *Wydawn. Geol.* Warszawa.
MACIOSZCZYK T. 1959. Some geological problems of sources in the western Podhale region. — Przegląd Geol., no. 8. Warszawa.
MASTELLA L. 1972. Tektonika wschodniego Podhala [The tectonics of Eastern Podhale]. Doctor's thesis, Institute of Geology of the Warsaw University (*unpublished*).
SAWICKI L. 1909. Z fizyografii Zachodnich Karpat. Archiwum Naukowe. Lwów.
WATYCHA L. 1959. Remarks on geology of the Podhale Flysch in the eastern part of Podhale. — Przegląd Geol., no. 8. Warszawa.
ZARUBA Q & MENCL V. 1969. Landslides and their control. *Elsevier and Acad. Publ. House of the Czechoslovak Academy of Sciences. Prague.*

S. OSTAFICZUK

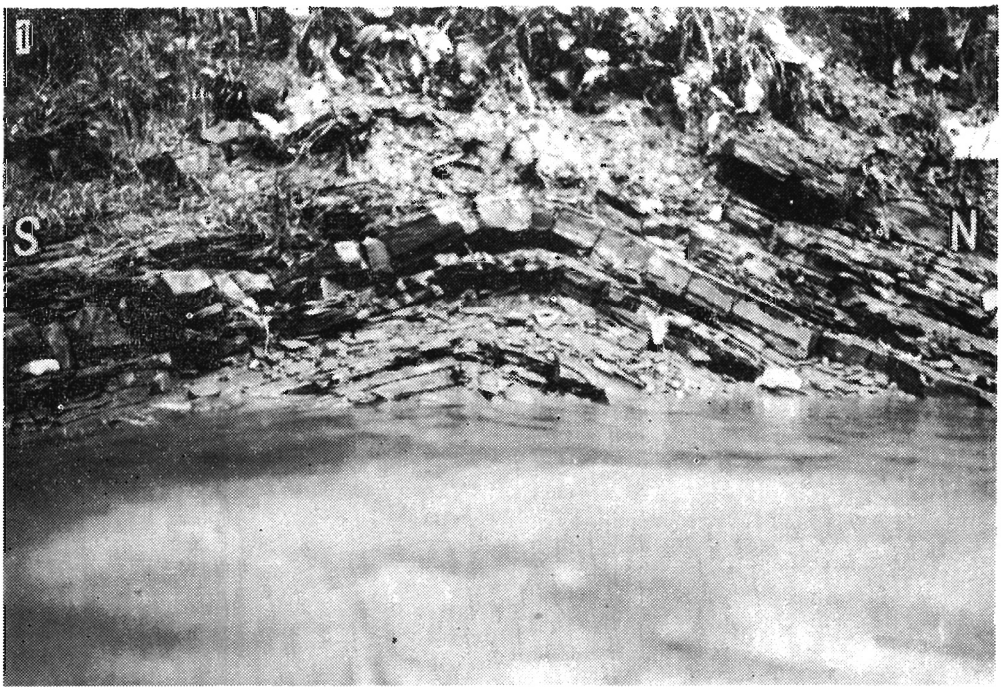
ANTYKLINY POWIERZCHNIOWE NA PODHALU

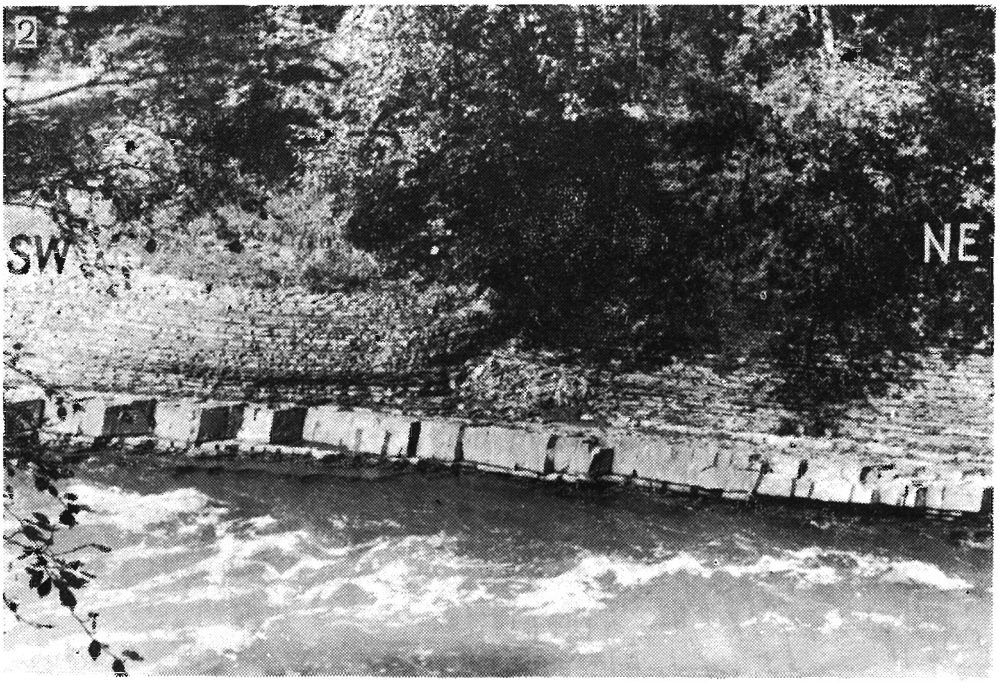
(Streszczenie)

W utworach fliszowych Podhala występują specyficzne drobne formy antyklinalne (*por.* fig. 1—2), które na podstawie kształtu, rozmiarów i lokalizacji (*por.* fig. 3—4 oraz pl. 1—4) uznać należy za związane z rozwojem wcięć erozyjnych. Drobne formy antyklinalne są tutaj rezultatem takich procesów egzodynamicznych, jak wypór hydrauliczny, inicjalny rozwój osuwisk konsekwentnych, oraz odprężenie warstw i przykrawędziowe wyciskanie uplastyczniających się łupków, przy czym wszystkie te procesy współdziałają z różną intensywnością (*por.* fig. 5—8). Proces powstawania antyklin przypowierzchniowych na Podhalu rozpoczął się bezpośrednio po założeniu sieci drenażu powierzchniowego u schyłku trzeciorzędu i trwa do czasów dzisiejszych wraz z rozwojem i pogłębianiem się dolin.

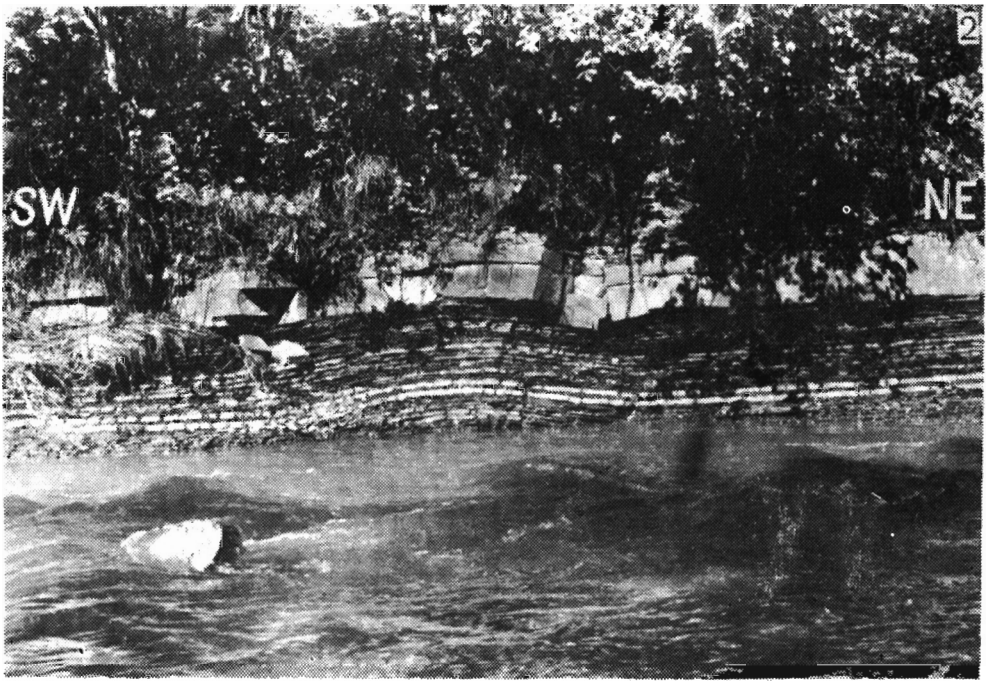
Instytut Geologii Podstawowej
Uniwersytetu Warszawskiego
02-089 Warszawa 22, Al. Żwirki i Wigury 93
Warszawa, w marcu 1973 r.

1 — Domed anticlines; Poroniec stream.
2 — Asymmetrical anticline with sharp bend; Poroniec stream.





1 — Sandstone bed in the bend of an anticline; Kacwińska Rzeka stream.
2 — Asymmetrical anticline, the SW limb of which subjected to a displacement along the surface of water-bearing sandstone; Zakopianka stream.



1 — Massive sandstone bed in the bend of an anticline: irregular fractures in silty sandstone (lower part); Poroniec stream.

2 — Lateral contacts of an uplifted anticline: step-like uplift of particular sandstone blocks; Zakopianka stream.

1 — Distinct disappearance of an anticline merging into the slope: erosion of the bend caused by periodical water outflow; Poroniec stream.

2 — The escaping of the Poroniec stream from the bend of a strongly cracked anticline.