Rudarsko-geološko-naftni zbornik	Vol. 9	str. 17–22	Zagreb, 1997.

UDC 551.24:551.44:621.311:627.824(497.13)

Izvorni znanstveni članak

THE SIGNIFICANCE OF STRUCTURAL AND GEOLOGICAL RELATIONSHIP ASSESSMENT IN THE CONSTRUCTION OF THE OMBLA UNDERGROUND HYDROELECTRIC POWER PLANT

Renato BULJAN[1] and Eduard PRELOGOVIĆ[2]

[1] *Institute of Geology, Sachsova 2, HR-10000 Zagreb, Croatia*
[2] *Mining-Geology and Petroleum Engineering Faculty, University of Zagreb, Pierottijeva 6, HR-10000 Zagreb, Croatia*

Key-words: Structural fabric, Tectonic movements, Underground hydroelectric power plant, Ombla, Dubrovnik

The construction design of the underground hydroelectric plant Ombla required geological and structural investigations to be carried out. Due to past earthquakes in the area permanent tectonic movementst were inferred. Therefore, in the wider and adjacent surroundings of the Ombla spring it was necessary to analyze the structural fabric and the geodynamic characteristics of the area. The most active zone encountered is the front part of a thrust fault belonging to the Dinaricum regional structural unit. The compressive regime is maintained as a response to the regional stress of an approximately S–N orientation. Different displacements of various parts of the Dinaricum unit are present. Along the rim of the structural blocks, the Hum-Ombla fault zone extends, accompanied by left transcurrent faults. Through this zone the main groundwater drainage occurs supplying the Ombla spring. In the local Ombla spring area this zone is characterized by three sub-blocks and three major faults. The most important fault for the vital facilities of the Ombla hydroelectric power plant is the Pločice fault which divides the structural sub-blocks. Along this fault zone there are four mutually connected. The lowest two are active groundwater draining systems supplying the Ombla spring. The data on local stress implies the following deformation of sub-blocks: sub-blocks 2e and 2f are displaced along normal faults from 20° to 30° to the left, downwards, while the sub-block 2 d is displaced along the Pločice thrust fault of 100° to 130° to the left, upwards. The structural data confirmed that the building of an underground dam with a height from 100 to 130 m was feasible. The connection between the caverns and the fault zone was determined. The unfavorable position of the active Pločice fault zone imposes the construction of vital Ombla power plant facilities underground.

Ključne riječi: Strukturni sklop, Tektonska aktivnost, Podzemna hidroelektrana, Ombla, Dubrovnik

Za potrebe izgradnje podzemne hidroelektrane Ombla izvršena su i strukturno-geološka istraživanja. Zbog pojava potresa znalo se za postojanje stalne tektonske aktivnosti. Stoga se u širem i lokalnom prostoru oko izvorišta Ombla pristupilo razradi strukturnog sklopa i geodinamičkih odlika prostora. Najaktivniju zonu predstavlja čelo navlake regionalne strukturne jedinice Dinaricuma. Djelovanje regionalnog stresa približne orijentacije J–S stvara kompresijski režim. Postoje različiti pomaci dijelova jedinice Dinaricuma. Granicom strukturnih blokova proteže se zona rasjeda Hum-Ombla s prisutnim lijevim transkurentnim pomacima. Kroz tu zonu postoji glavni dovod podzemne vode na izvorište Ombla. U lokalnom prostoru unutar te zone izdvajaju se tri strukturna potbloka i tri važna rasjeda. Za vitalne objekte HE Ombla značajan je rasjed Pločice koji odvaja strukturne potblokove. Duž njegove zone u prostoru su formirana četiri povezana nivoa šupljina. Dva donja predstavljaju aktivan dovod vode na izvorište Ombla. Podaci o lokalnom stresu ukazuju na deformacije potblokova i to: potblokovi 2e i f pomiču se duž normalnih rasjeda od 20° do 30° lijevo, dolje, a potblok 2 d duž reversnog rasjeda Pločice od 100° do 130° lijevo, gore. Strukturni su podaci potvrdili mogućnost izgradnje podzemne brane visine od 100 do 130 m. Utvrđena je povezanost šupljina sa sustavima rasjeda. Nepovoljni položaj aktivne zone rasjeda Pločice u prostoru uvjetuje projektiranje vitalnih objekata HE Ombla u podzemlju.

Introduction

The study area is situated in the hinterland of the karstic spring Ombla near Dubrovnik an which supply the headwaters of the Rijeka Dubravačka. The idea that an underground dam and water accumulation should be constructed arises form the cognition on the porosity and permeability of the water saturated carbonate rock complex. The key feature of this complex is that it is underlain by non permeable flysh strata. Because of the damming, the groundwater level is elevated. The accumulating area covers subsurface caverns and conduits, consequent of fault systems, fissures and karstified carbonate rocks. The concept of the barrier profile implies access into the rock mass about 200 m behind the mouth of the spring and the construction of and underground dam 100 to 150 m high and approximately 1000 m wide. The flanks of the dam are positioned on flysh strata which occur to the west and east of the spring at elevations of up to 300 m. All vital hydroelectric power plant facilities will be built underground. Due to this the cliff above **the Ombla spring and the surrounding landscape will be maximally preserved.**

Such a complex civil engineering project requires extensive reconnaissance. The study of geological and hydrogeological relationships is therefore of major importance, with emphasis on the characteristics of the structural fabric and recent tectonic movements. The importance of these features is stressed because of the permanent seizmotectonic activities and earthquakes with magnitudes up to 7,0. Also, hydrogeological and engineering geological solutions require detailed analysis of the structural and geological relationships. The study began in the wider region enclosing the Ombla spring. Data was obtained with reference to the structures both on the surface and subsurface, their displacement, detachment of blocks, active fault zones, and the position of the studied site in this fabric. A detailed structural model was developed for the area of the proposed facilities of the Ombla hydroelectric power plant. The study was focused on the analysis of the fault and fissure systems, their activities, movement types and position. Emphasis was on the geodynamic properties of structural blocks and sub-blocks, the evaluation of stress relationships and possible space deformations and particularly the origin and occurrence of subsurface cavities. The obtained results gave and insight to groundwater flow, the estimate of accumulated groundwater quantities, the existence of possible watersheds or possible groundwater drainage to some other spring. Relevant results are concisely presented in this paper.

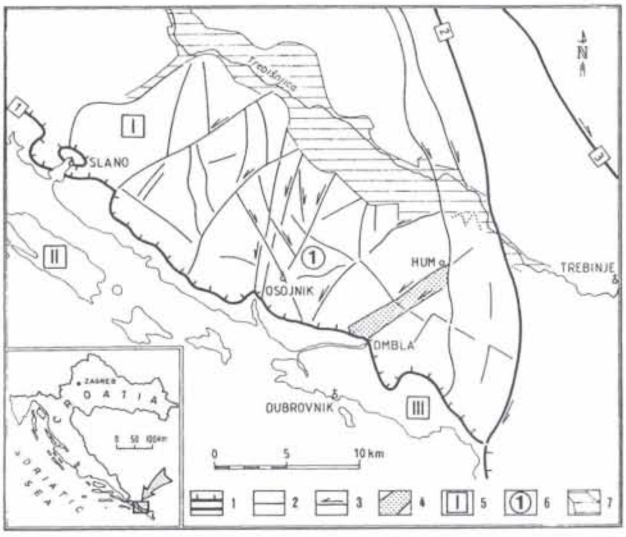

Fig. 1. Regional structural sketch
Legend:
1 the most important faults of the regional structural fabric:
1 fault of the front of the overthrust of the Dinaricum
2 Slivnica fault
3 Zubak fault
2 others more important faults
3 faults with marked displacement
4 zone Hum-Ombla
5 I Adriaticum
II Dinaricum
III Epiadriaticum
6 structural unit Hutovo–Slano–Brgat
7 extension zone

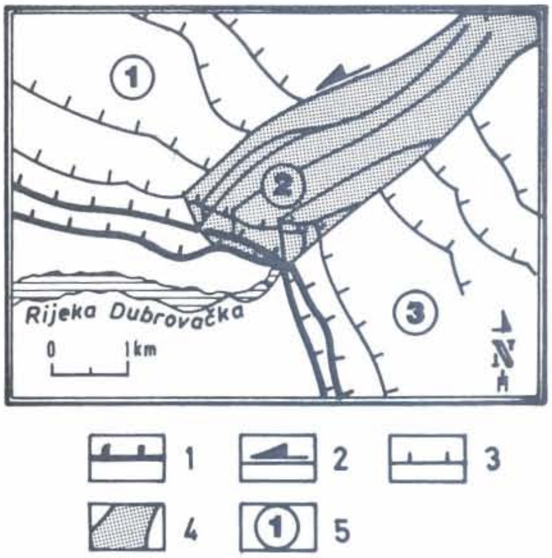

Fig. 2. The most important faults and structural blocks to the front of the overthrust of the Dinaricum
Legend:
1 the main faults of the front of the overthrust of Dinaricum
2 direction of the tectonic transport
3 reverse faults
4 zone Hum-Ombla
5 structural blocks ① ② ③

The structural fabric and recent tectonic activity

The surface rocks, major structures and faults in the wider area of the Ombla spring are presented on geological maps and acompanying explanatory notes of the following sheets: **Dubrovnik** (Marković, 1971), **Trebinje** (Natević & Marković, 1965: Marković & Natević, 1975), and **Ston** (Raić et al., 1980). The spatial structural relationships were determined by analysis of seismic reflection profiling data, gravity maps and geomagnetic maps (exp. Miljush, 1973, Tufekčić & Vadić, 1978: Dragašević, 1978, 1983: Aljinović et al., 1982), and also with the aid of various structral-tectonic interpretations (Marković, 1966; Sikošek & Maksimović, 1971: Prelogović & Kranjec, 1984: Aljinović et al., 1987). There are also numerous unpublished geological, hydrogeological, geotechnical, speleological and geophysical studies that were carried out for the purpose of the Ombla power plant construction.

The origin of the structures in the wider Ombla surrounding is well understood. This is the result of displacement and subduction of the Adriatic platform below the Dinarides. The platform rocks in the studied area are submerged to the depth of 15 to 20 km (Dragašević, 1983: Prelogović & Kranjec, 1983: Aljinović, 1984: Aljinović et al., 1987). Near the surface the tectonic displacements have reverse and overthrust characteristics. According to Herak (1986) it is possible to differentiate three regional overthrust structural units (Fig. 1): the Dinaricum (I), the Adriaticum (II), and the Epiadriaticum (III). For the present study the Dinaricum is of prime importance since the Ombla spring is located on its margin. On the surface a conformable transition exists between the Triassic, Jurassic and Cretaceous carbonate rocks. The structural unit Hutovo–Slano–Brgat (1 in Fig. 1) is characterised by monoclinal beds diping NE at angles of 20°–50°. The key feature of this unit is intensive faulting. Besides rows of reverse faults, two systems of primary tear faults are of essential importance for groundwater flow. It is important to note the strike of a relatively wide fault zone is NE–SW between Hum and Ombla, and it inclines to the Slivnica fault zone (2). Tectonic movements are characterised sinistral displacement. The studies show that this zone represents the main water conduit to the Ombla spring (Fig. 2). In the crest of the thrust two major and several minor faults occur. In the hinterland several reverse faults also succeed. The Hum-Ombla zone consists of a number of parallel faults and branches. The fault planes dip steeply (70–85), and often in the opposite direction, striking from 50° to 230°. The zone intersects the reverse faults and Mesozoic rocks in the frontal part of the Dinaricum thrust. It is important that the Hum-Ombla zone is bounded by structural blocks, and because of its dimensions and special features is also considered as a indipendant block (Fig. 2).

Extensive field measurements were conducted to obtain data on tectonic activity. It was importand to define the relationship between the sress and deformation of structures, blocks and sub-blocks, and to develop an acceptable structural model. Previous studies of Ritsema (1974) and Anderson & Jackson (1987) indicate that regional stress has an approximate orientation of 10°–190°. The performed analysis indicate and existance of two phases: an older stress orientation of 35° (40°) – 215° (220°) and a younger, recent stress orientation of approximately 12°–192° (Fig. 3). The regional

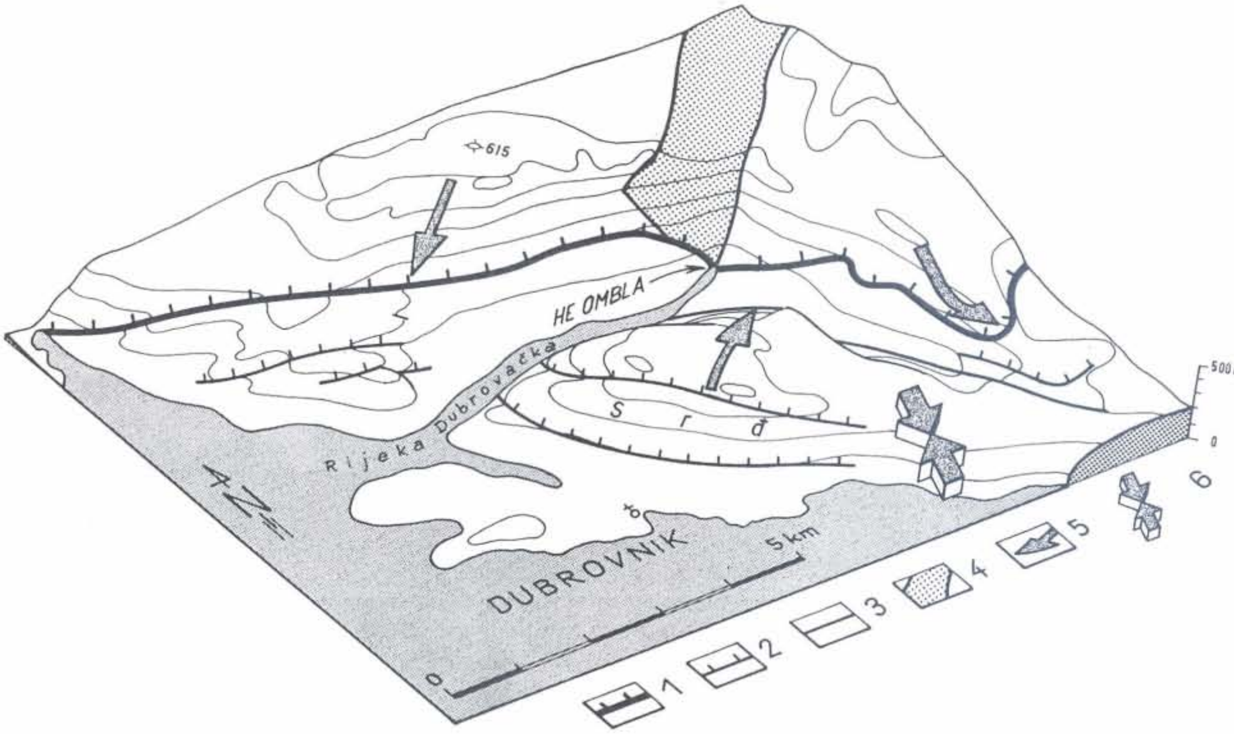

Fig. 3. Area of the Ombla spring
Legend:
1 fault bordering the front of the overthrust of the Dinaricum
2 reverse faults
3 faults with changeable dip
4 zone of Hum-Ombla fault
5 direction of displacement of structures close to the surface
6 stress

stress orientations indicate possible structural fabric deformation.

The basic structural model is presented in Fig. 3. Inside the crest of the Dinaricum thrust a compression regime is established. The rotation of the crest around the horizontal axis is possible. This causes rock displacement in an upward direction and permanent activity of reverse faults. Because the strike of the beds is parallel to the principal faults, reverse interlayer displacements

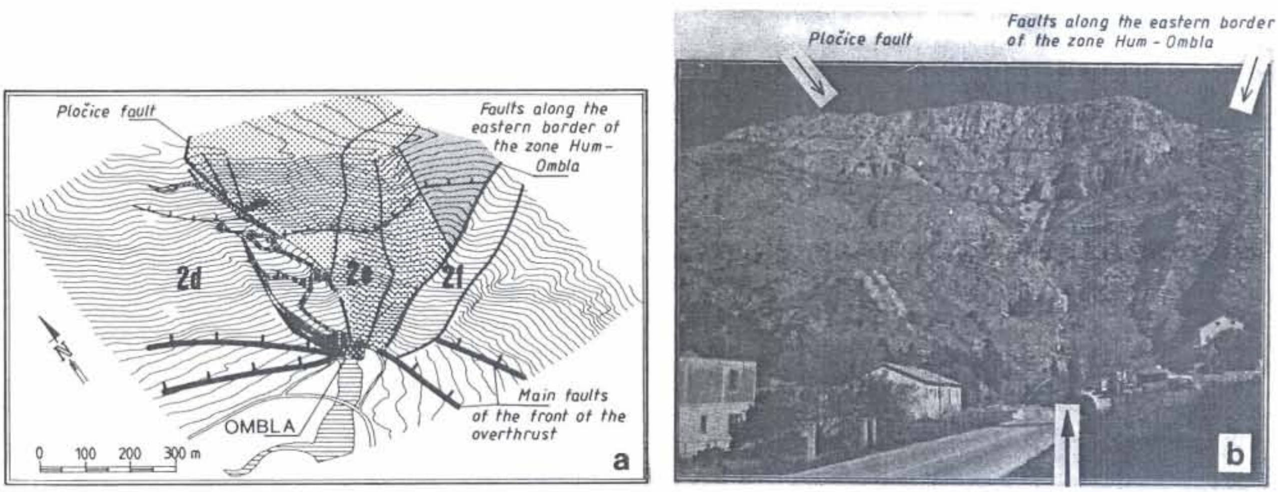

Fig. 4. Faults and structural sub-blocks 2d, 2e and 2f above Ombla spring
a sketch
b photo

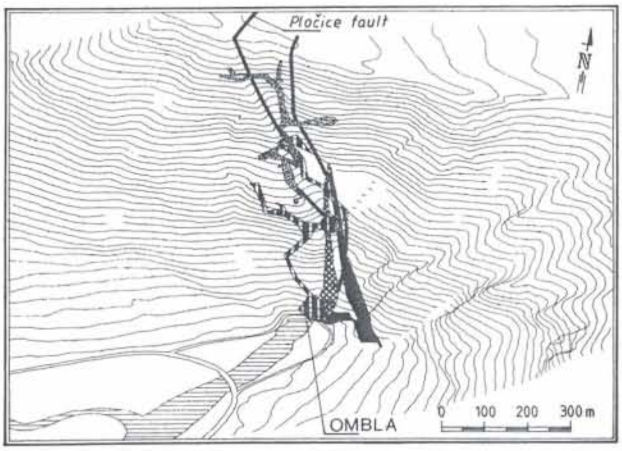

Fig. 5. The comparision of the Pločice fault zone position and four levels of subsurface cavities

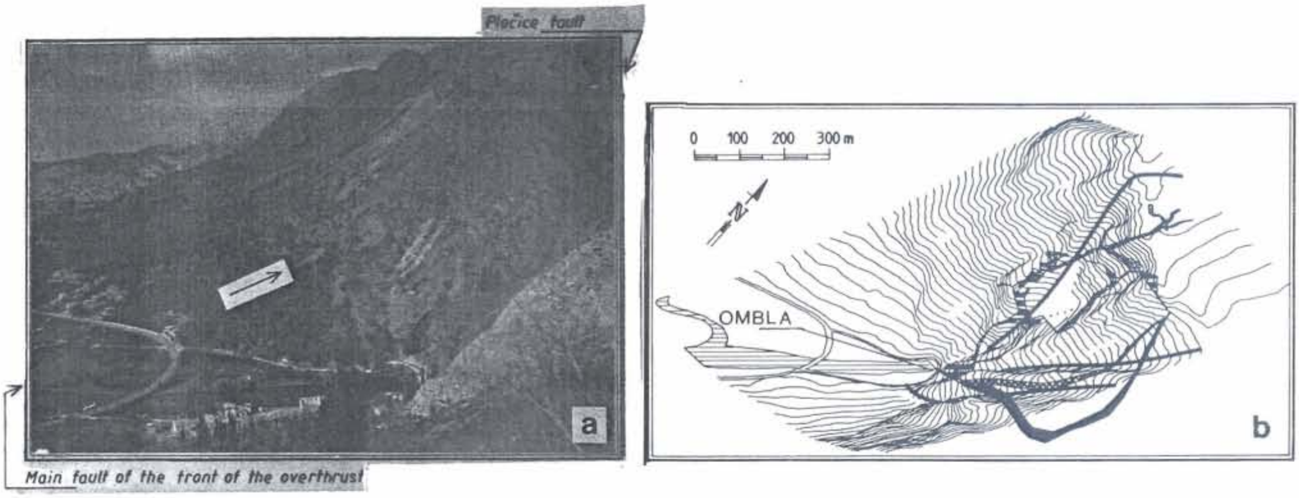

Fig. 6. a) Presentation of structural sub-block 2d (from Fig. 4.) can be noticed the main overthrust and fault zone Pločice
b) In the separate part of the zone Hum-Ombla izohypsos show the position of the segments between faults of opposite dip

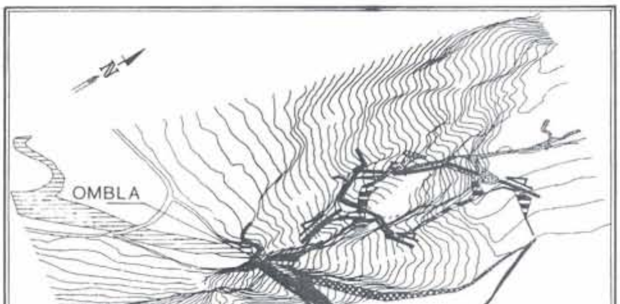

Fig. 7. Presentation four level of the connected parts of cavities with reverse faults from the front of the overthrust of the Dinaricum

also occur. The downthrowing of the Srd rock mass which closes the valley of Rijeka Dubrovačka was also observed. However, the position of the Hum-Ombla zone is very important because it is favorable in regard to the stress orientation which results in sinistral structural displacement. The data indicates that the structures to the west and east of this zone are moving in different directions. This permits permanent expansion of the Hum-Ombla zone, and the formation of lowered rhomboidal duplex structures, and the downthrowing of individual rock segments.

Local spatial structural properties of Ombla spring

In the Hum-Ombla zone five structural sub-blocks are outlined by faults. The area surrounding Ombla spring is confined to sub-blocks 2d, e and f (Fig. 4a), within which the power plant facilities are to be constructed. Therefore, the comprehensive surface structural analysis and subsurface structural measurements in constructed tunnels were performed. Previous studies determined the existence of four subsurface levels of connected caverns. Through the lower two levels (below ± seawater level) there is an active supply of water. The Hum-Ombla zone faults, as well as the thrust faults are exposed on the surface of the cliff above the Ombla spring (Fig. 4b).

The study gave emphasis to the determination of relationships and mutual positions of fault systems and fragmentation in the area confined to the front part of carbonate Dinaricum thrust. Deformation and types of structural block displacement are important for possible influence of tectonic dynamics on the vital facilities of the power plant.

Three major faults delineate the structural sub-blocks. A fault with sinistral tectonic displacement is located along the eastern margin of the Hum-Ombla zone (Figs. 4, 6, 7, and 8). Between the sub-blocks 2d and 2e a zone 15 to 50 m wide exists. The Pločice fault is named according to the locality (Figs. 4, 5, 6 and 8). This fault which is a reverse fault in subsurface, changes character on the surface due to fault plane curving.

The major cavities that are positioned on four levels are shown on Figures 4 to 7 viewed downwards at an angle of 30° in different defections. On Figures 4 and 6 the main faults and sub-block structures are presented together with sinking rock mass segments between antitectic faults. Figure 5 is very indicative. The vertical concordance of all four cavity levels along the Pločice fault is apparent. This means that the above mentioned cavities occur on the boundary between the structural sub-blocks 2d and 2e. However, the cavities are somewhat vertically dislocated. This indicates spatial bending of the Pločice fault zone. Also the branches of this zone determined in the tunnels indicate to the existence of

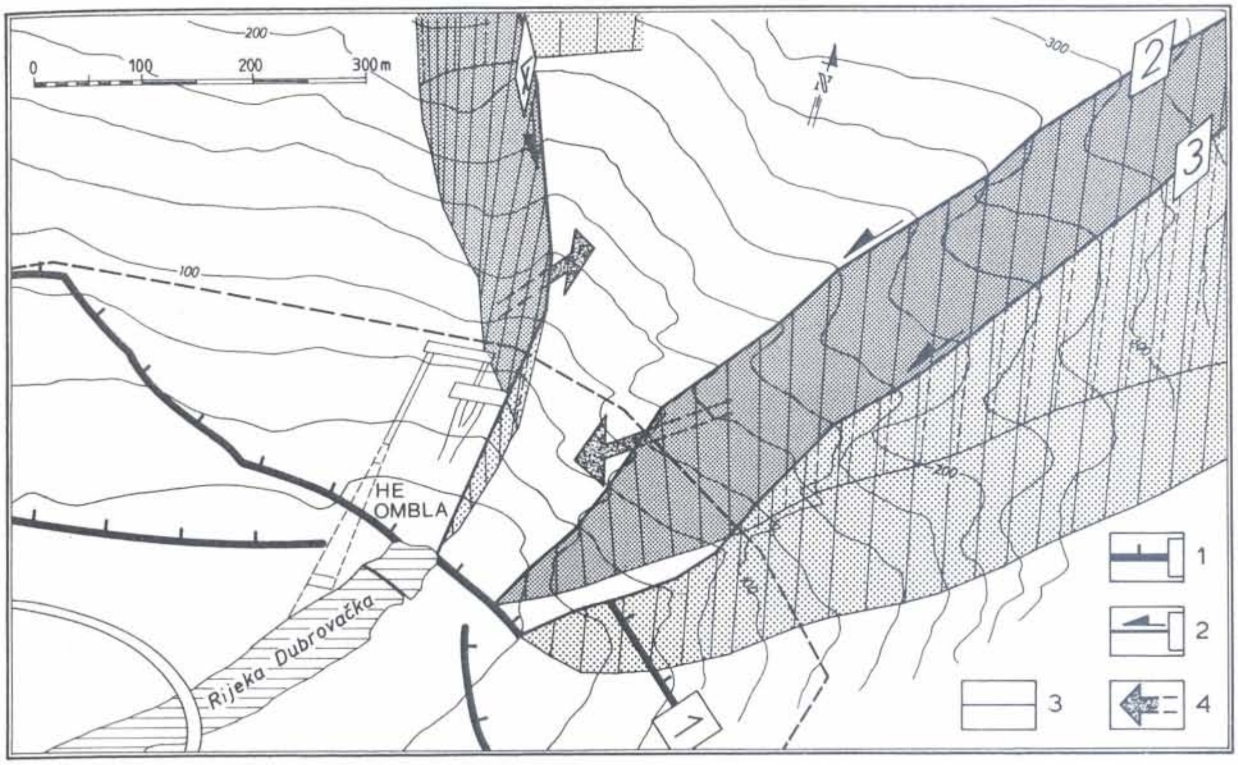

Fig. 8. Presentation of local displacement of fault along three main separated faults of the zone Hum-Ombla
Legend:
1 the main faults of the front of the overthrust [1] on the surface
2 faults bordering structural sub-blocks: the faults along the eastern border of the zone Hum-Ombla [2] and [3]
3 Pločice faults [4]
4 direction of displacement of the fault's hanging wall

Pull-apart structures. These structures are frequently detected in tunnels where they accompany various fault systems, as well as the Pločice fault. Deformation processes that accompany compression can produce cavities parallel to the directions of maximum stress. The smaller cavities that branch from the large cavities and planes with different declination are fault controlled. Figure 7 shows the relationship between cavity parts and reverse faults. The concordance of the two lower cavity levels with the main thrust faults is evident.

Detailed structural analysis provided data on local stress. The directional variations observed indicate that differences in tectonic dynamics exist within the structural sub-blocks. The divergence of the compression directions from north direction are as follows:

- structural sub-block 2d: 283°–293°;
- structural sub-block 2e: 310°–343°;
- structural sub-block 2f: 7°.

The resulting structural deformations characterize the properties of the structural sub-blocks as follows:

- within sub-blocks 2e and 2f the fragmentation is induced by normal faults and sinistral dislocation;
- the faults parallel to the major thrust faults are substantial;
- reverse faults with a NW fault plane dip occur within the sub-block 2f, and are perpendicular to the local stress direction.

The most important data obtained are those related to the Pločica fault, because of the future position of vital facilities of the Ombla hydroelectric power plant. Additional compression was observed in the structural sub-block 2d as a result of left transcurent movements along the Hum-Ombla zone boundary faults. As a consequence sub-block 2d is displaced along the Pločice fault in the SE direction. This is why the direction of local stress is different, thet reverse movements prevail, spatial divergence of the fault zone occured and the shape of the cavities is related to the high intensity of the stress. This emphasizes the importance of the Pločice fault zone in the local structural fabric.

Conclusion

The data collected signify the marked recent tectonic activity. The evidence for this can be summarized as follows: spatial compression, tangential thrust displacements and sinistral displacement along the Hum-Ombla zone. Three sub-blocks where identified within the Hum-Ombla zone in the neighboring area around Ombla spring. These three sub-blocks exhibit different dynamic properties: in the extent and direction of displacement, change of local stress orientation, and the magnitude of boundary zone sub-block activity. The extent of displacement is pronounced along major faults (Fig. 8): the sub-blocks 2e and 2f are displaced along normal faults 20° to 30° to the left and downwards, while the sub-block 2d is displaced along the Pločice reverse fault 100° to 130° to the left and upwards.

Structural and geological investigations confirmed that there is a basis for the construction of a subsurface dam 100 to 130 m high. It is extremely important that the structural properties of the Hum-Ombla zone were determined, as well as the relationship between the cavity levels and fault systems. The obtained study results should be corroborated during the final design of vital facilities of the Ombla hydroelectric power plant. The location of these facilities is determined by the Pločice fault zone. The pronounced activity and fragmentation of this zone makes it neccessary to dislocate the facilities within the more stable structural sub-block 2d.

Received: 1997–03–12
Accepted: 1997–07–10

REFERENCES

Aljinović, B. (1984): Najdublji seizmički horizont NE Jadrana. Dissertation, PMF, p. 513, Zagreb.

Aljinović, B., Cvijanović, D., Labas, V., Prelogović, E. & Skoko, D. (1982): Geološka građa područja Dubrovnika na temelju seizmotektonskih i geofizičkih istraživanja. Zb. radova X kong. geol. Jug., Knj. 1, 527–540, Budva.

Aljinović, B., Prelogović, E. & Skoko, D. (1987): Novi podaci o geološkim strukturama u dubini i seizmotektonski aktivnim zonama Jugoslavije. *Geol. vjesnik*, 40, 255–263, Zagreb.

Anderson, H. & Jackson, J. (1987): Active Tectonics of the Adriatic Region. *Geoghys. J.R.A.S., 91*, 937–983.

Dragašević, T. (1978): Strukturne i naftno-geološke karakteristike jugoistočnog dijela Jadranskog mora. Zb. radova IX kong. geol. Jug., 862–877, Sarajevo.

Dragašević, T. (1983): Oil geologic exploration in the Montenegro offshore in Yugoslavi. *Nafta 34/7–8,* 397–404, Zagreb.

Herak, M. (1986): A new Concept of Geotectonics of the Dinarides. *Acta geol., JAZU, 16*, 1–42, Zagreb.

Marković, B. (1971): Tumač Osnovne geološke karte K 34–49, list Dubrovnik, 5–43, Zavod za geol. i geofiz. istraž., Sav. geol. zavod, Beograd.

Marković, B. & Natević, LJ. (1975): Tumač Osnovne geološke karte, K 33–49, Trebinje, 5–40, Geol. zavod, Sarajevo, Sav. geol. zavod, Beograd.

Miljush, P. (1973): Geologic-Tectonic Structure and Evolution of Outer Dinarides and Adriatic Area. *Bull A.A.P.G.*, 57/5, 913–929, Tulsa.

Natević, Lj. & Marković, B. (1965): Osnovna geološka karta K 33–49, list Trebinje 1:100.000. Geol. zavod, Sarajevo, Sav. geol. zavod, Beograd.

Prelogović, E. & Kranjec, V. (1983): Geološki razvitak područja Jadranskog mora. *Pomorski zbornik, 21*, 387–405, Rijeka.

Raić, V. & Papeš, J. (1980): Tumač Osnovne geološke karte, K 33–48, list Ston, 5–39, Geoinženjering, Sarajevo, Institut za geol. istraž., Zagreb, Sav. geol. zavod, Beograd.

Raić, V., Papeš, J., Ahac, A., Korolija, B., Borović, I., Grimani, I. & Marinčić, S. (1980): Osnovna geološka karta K 33–48, list Ston 1:100.000. Geoinženjering, Sarajevo, Inst. za geol. istraž, Zagreb, Sav. geol. zavod, Beograd.

Ritsema, R. A., (1974): Fault Plane Mechanism on of Balkan Earthquake. Proc. of Sem. on the Seismotect. Map of the Balkan Reg., Dubrovnik. 17–26, April 1973. UNESCO, Skoplje.

Sikošek, P. & Maksimović, B. (1971): Geotektonska rajonizacija jadranskog pojasa. *Nafta, 22/4–5*, 298–304, Zagreb.

Tufekčić, D. & Vadić, R. (1978): Neke geološko-tektonske karakteristike JI dijela Jadrana izvedene iz podataka refleksivne seizmike. Zb. radova IX kong. geol. Jug., 972–976, Sarajevo.