Rudarsko-geološko-naftni zbornik	Vol. 3	str. 23–28	Zagreb, 1991.

UDC 553.492.1:550.834

Izvorni znanstveni članak

GEOLOGICAL-GEOPHYSICAL EXPLORATION OF THE BAUXITE DEPOSITS APPLICATION OF THE SHALLOW SEIZMIC REFLECTION METHOD

Ivan DRAGIČEVIĆ[1], Miroslav ANDRIĆ[2], and Ivan BLAŠKOVIĆ[1]

[1] *The Faculty of Mining, Geology and Petroleum Engineering of Zagreb University, Pierottijeva 6, YU-41000 Zagreb*
[2] *Geofizika, Savska c. 64, YU-41000 Zagreb*

Key-words: Bauxite deposits, Bauxite-bearing sedimentary basin, Upper-Cretaceous rudist limestones, Promina formation clastic deposits, Paleorelief, Tectonic-erosional discordance, Shallow seizmic reflection method

The exploration of bauxite deposits in the region of the carbonaceous Dinarides has been performed by using different geological and geophysical methods. Deposits laying shallower or deeper below the roof sediments have so far most often been discovered by expensive drilling methods in a corresponding grid. Complex geological explorations have led to a series of valuable data thus enabling the application of other much more economical methods as well. In the region of the bauxite sedimentary basin Mesihovina–Rakitno, western Herzegovina, at the site of Studena vrila – after extensive geological explorations – a conclusion was drawn that the shallow seismic reflection geophysical method as well might be successfully applied in locating new bauxite deposits. In the paper, the geological framework of the bauxite deposits occurrences, stipulating the selection of this methode, will be presented. Measurements were performed on a known deposit (L-84, Povaljenica), completely defined by exploration drilling. The obtained results justify the selection of the shallow seismic reflection method as one of the methods for exploring bauxite deposits beneath the roof beds.

Ključne riječi: Ležišta boksita, Boksitonosno-sedimentacijski bazen, Gornjokredni rudistni vapnenci, Klastiti Promina formacije, Paleoreljef, Tektonsko-erozijska diskordancija, Plitka seizmička refleksija.

Istraživanje ležišta boksita, u području karbonatnih Dinarida, obavlja se uz pomoć različitih geoloških i geofizičkih metoda. Ležišta pliće ili dublje ispod krovinskih sedimenata do sada su najčešće pronalažena skupim metodama bušenja u odgovarajućoj mreži. Kompleksnim geološkim istraživanjima došlo se do niza vrijednih podataka koji omogućuju primjenu i drugih ekonomičnijih metoda. U području boksitonosnog sedimentacijskog bazena Mesihovina – Rakitno, zapadna Hercegovina, na lokalitetu Studena vrila nakon obimnih geoloških istraživanja došlo se do spoznaje da bi se pri pronalaženju novih ležišta boksita mogla s dosta uspjeha koristiti i geofizička metoda plitke seizmičke refleksije. U radu su izloženi geološki okviri pojavljivanja ležišta boksita koji su uvjetovali odabir ove metode. Mjerenja su izvedena na poznatom ležištu (L–84, Povaljenica) koje je u potpunosti definirano istražnim bušenjem. Dobiveni rezultati opravdavaju izbor plitke seizmičke refleksije kao jedne od metoda kod istraživanja ležišta boksita ispod krovinskih naslaga.

Introduction

In the carbonaceous Dinarides, during the exploration of bauxite deposits, situated beneath the roof beds, numerous geological and geophysical methods have so far been used. As the bauxite requirements have been growing, adequately the existing methods have been improved and new methods have been introduced.

Geological mapping in different scales, studying the structural relations, appraisal of the prospectiveness of individual ore deposits, as well as the locating and elaboration of structural bore holes, represent standard geological methods.

As for geophysical methods, mainly different variations of geoelectrical methods (sounding, profiling, challenged polarization method and others), as well as magnetic measurements (on the surface and airborne) and airborne infrared surveys of prospective areas, have so far been applied. The said methods have till now given no significant results due to the unsufficient distinction among the physical parameters of different lithological members in the subsurface, which parameters represent the key magnitudes for the mentioned methods (geoelectrical resistivity, susceptibility, infrared radiation).

Carrying out complex geological explorations in the bauxite sedimentary basin of Mesihovina–Rakitno, aiming at as much as possible faster and cheaper discovery of new bauxite deposits beneath the roof, we have arrived at significant facts which at certain locations indicate the application of the shallow reflection method as one of the methods connecting geological explorations with expensive exploratory drilling.

Geological frameworks of the bauxite deposit occurrence at Studena vrila locality

Numerous bauxite deposits in the bauxite-bearing sedimentary basin *Mesihovina-Rakitno* (Dragičević et al., 1985, 1986, 1987) are located between the Upper-Cretaceous limestones in the basement and different lithological members of the Promina formation in the roof (Raić et al., 1976). It is a question of a typical tectonic-erosional discordance stipulated by events in the framework of Laramian movements.

The bauxite-bearing locality *Studena vrila* is characterized by comprehensive geological explorations which enabled a verification of the shallow reflection geophysical method for the purpose of detecting bauxite deposits beneath the roof beds.

The immediate basement of the bauxite deposits consists of different types of shallow-water marine limestones of the Upper-Cretaceous age. They are usually well layered. The layer thickness ranges between 30 and 60 cm. In the area of deposits themselves the stratification is most often covered by diagenetic processes.

An expressive paleorelief was created in these limestones during the protracted terrestrial regime, stipulated by Laramiàn movements. Basic features of this paleorelief are the »irregular« negative forms and paleorecesses respectively, into which the bauxite material accumulated. The shapes and dimensions of paleoforms depended on paleostructures (gentle anticlines and synclines) and on the chemical weathering of limestones as well (B l a š k o v i ć et al., 1990).

The transgressive sedimentation of the basal part of Promina formation started in the central part of the Lower Eocene (D r a g i č e v i ć et al., 1985). In the area of *Studena vrila*, on the bauxite deposits, marls and silty marls respectively are being deposited regularly. The thickness of the basal series of marls on the bauxite deposits depends on the dimensions and deepness of paleorecesses. The deeper negative forms regularly contain also a thicker column of marl on the bauxite. Subsequently the heterogeneous series of clastic deposits are being deposited. Three lithological members are predominant: conglomerates, sandstones (calcarenites) and silty marls. They are characterized by exceptionally quick lateral and perpendicular alternations. Conglomerates are the most represented and the most noticeable. The shapes and dimensions of conglomeratic bodies vary substantially. There are lenticular forms, sometimes spacious, stretching over one hundred meters and more, but there are frequent thickset of canal type as well. Their thickness varies from half a meter to some thirty meters.

It should be said that in the areas situated laterally of the paleorecesses, on the Upper-Cretaceous limestones, any of the three mentioned lithological members can transgressively be deposited.

The bauxite-bearing locality of *Studena vrila* is characterized by ore-depositing of a high degree. Deposits are frequent and they are different in shapes and dimensions. The reserves vary from a few hundreds of tons to those with even over half a million tons. They stretch over an area of a few tens of sq. meters to areas of a few tens of thousands of sq. meters. The thickness of ore bodies ranges from 1 to some 40 meters and it represents the most unstable magnitude. As for their forms, depending on the paleorelief, irregular lens and canals are the most frequent. Deposits can be formed on the surface (uncovered by erosion) as well as at different depths (even beyond 200 m) beneath the roof sediments (Fig. 1).

Geological relations in the area of Povaljenica deposit

The basement of the deposit consists of the Turonian-Senonian rudist limestones. Different types of biomicrites and microcoquinites are predominant. They are well layered. Most often the thicknesses of the layers range between 30 and 60 cm. Due to intensive structural changes (joint systems) and diagenetic events, the stratification is simetimes hard to recognize.

The deposit developed in the paleorelief which represents the result of a long-lasting continental phase between the Upper-Cretaceous and the Lower Eocene periods. The creation of a specific form of paleorecess resulted from the pre-ore structural changes and the paleokarst modelling. Regarding the recent structural relations, the deposit occurs in the north-east wing of anticline. The shape, dimensions and the structural position were established by numerous bore holes. The longer axis of the deposit stretches in NE–SW direction and its length amounts to 330 m, whereas the average width comes to about 60 cm. The ore body has a form of a very irregular lens and is striking towards the north-east tilted at 15° (Fig. 1). The ore body itself is disarranged by a few subvertical and vertical faults of relatively small throw.

The greatest thickness of the bauxite amounts to 37 m and the smallest to 1 m. The deposit extends over an area of 21500 sq. meters.

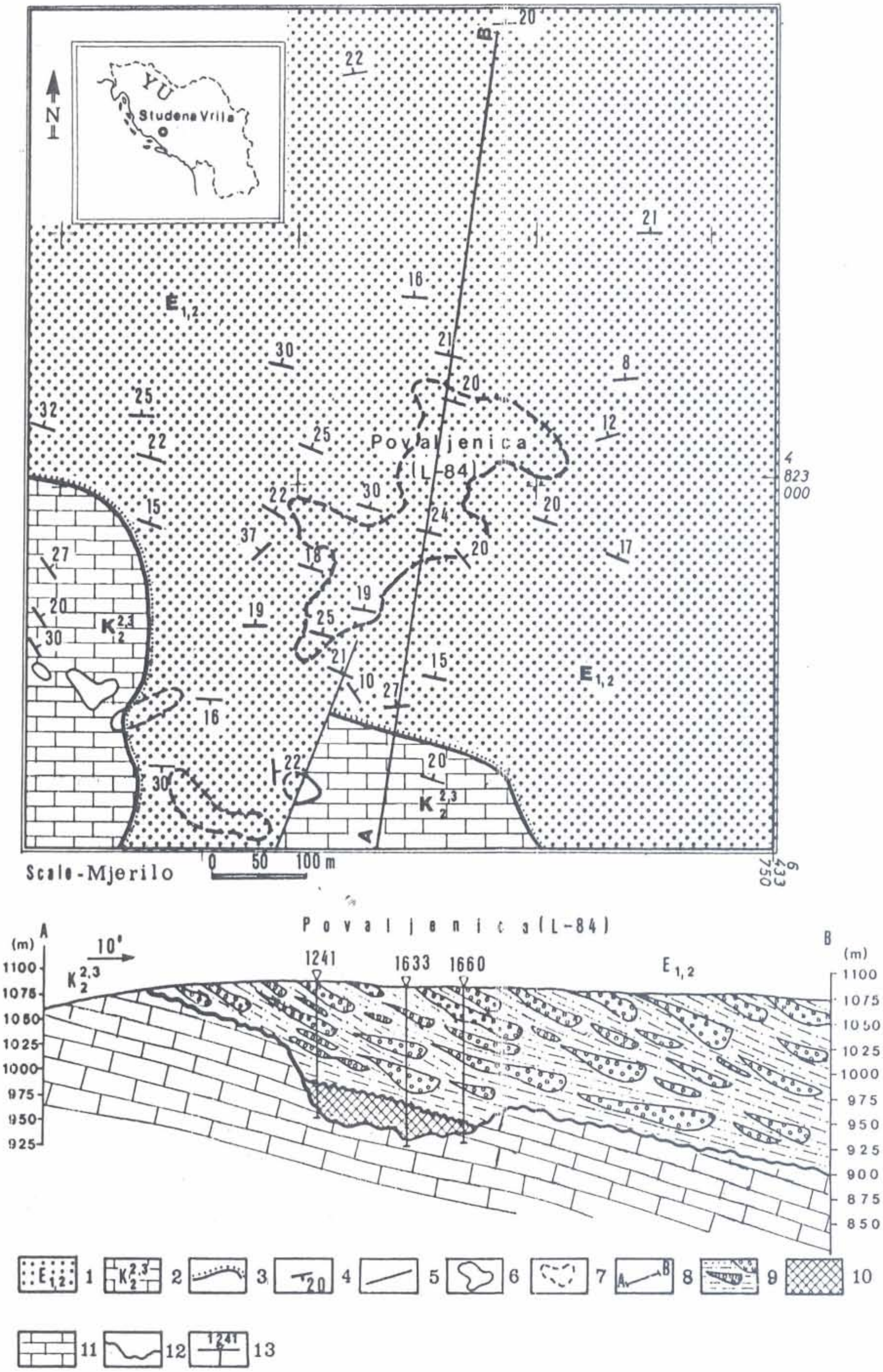
Immediately over the ore body in the paleorelief lay a series of marls representing the basal part of the Promina formation. Further in the column follows a heterogeneous series of sediments of the same formation. Conglomerates, silty marls and sandstones are the main lithotypes very quickly alternating laterally and perpendicularly (Fig. 1). The unconformity between the basement and the roof sediments is small and comes to 5°.

Geological parameters relevant for the selection of the geophysical method

In the bauxite-bearing area of *Studena vrila*, where the explored micro-locality (Povaljenica deposit) occurs as well, the geological conditions of the bau-

Fig. 1 *Geological map of the Povaljenica bauxite deposit area*
Sl. 1 *Geološka karta područja boksitnog ležišta Povaljenica*

Legend – Legenda
1. *Promina formation clastic deposits (bauxite deposit roof)*
   klastiti Promina formacije (krovina ležišta boksita)
2. *turonian-senonian rudist limestones (bauxite deposit basement)*
   turon-senonski rudistni vapnenci (podina ležišta boksita)
3. *transgressive demarcation*
   transgresivna granica
4. *layer position elements*
   elementi položaja sloja
5. *fault*
   rasjed
6. *contour lines of the bauxite deposit without the roof*
   konture ležišta boksita bez krovine
7. *contour lines of the bauxite deposit beneath the roof*
   konture ležišta boksita ispod krovine
8. *geological and geophysical profile lay-outs*
   trasa geološkog i geofizičkog profila
9. *marls, silty marls, sandstones and conglomerates*
   lapori, siltozni lapori, pješčenjaci i konglomerati
10. *bauxite (ore body)*
    boksit (rudno tijelo)
11. *limestones*
    vapnenci
12. *tectonic-erosional discordance (paleorelief plane)*
    tektonsko-erozijska diskordancija (ploha paleoreljefa)
13. *bore hole*
    bušotina


YU
Studena Vrila
N
$E_{1,2}$
Povaljenica
(L-84)
$K_2^{2,3}$
A
B
Scale-Mjerilo
0 50 100 m
4 823 000
6 433 750
Povaljenica (L-84)
(m)
10°
1241
1633
1660
1100
1075
1050
1025
1000
975
950
925
900
875
850
1 2 3 4 5 6 7 8 9 10
11 12 13

xite deposit occurrence enabled the verification of the shallow seismic reflection method on a geologically well-known place.

The following parameters had the most significant influence on the selection of the method:
- distinction in the petrographic composition between the basement limestones and the roof clastic deposits,
- different lithification degree of the basement and the roof sediments,
- developed paleorelief in the basement limestones, representing an extraordinarily well defined demarcation plane of the basement and the roof, on which plane the bauxite deposits occur,
- sedimentological characteristics of the roof sediments of the Promina formation, primarily taking into consideration the shape, dimensions and the lay-out of the sedimentary bodies,
- structural position of the bauxite deposit and the demarcation plane of the basement and the roof, respectively.

Pilot seismic reflection profile – measurement, processing, interpretation

The shallow seismic reflection method (especially its CDP variation) was introduced into practical work in solving engineering assignments only a few years ago. Not long afterwards, regarding the manner and the circumstances of the bauxite deposits occurrences on individual localities, the idea was born that this method might be applicable in their explorations. The method should and, as proved after test measurements, can fill up the gap between the first cheap geological explorations (mapping) and the performance of expensive exploratory drilling.

First bits of information about the prospectiveness of the application of the shallow reflection method in bauxite explorations, in *Posušje* area, were obtained after the measurements of the longitudinal wave propagation velocities by using the ultrasonic method on samples. The samples comprised the main lithotypes occurring in the deposit area: the basement Cretaceous limestones, bauxite, sandstones, marls and the roof conglomerates. Although, regarding the number of samples comprised by measurements, they cannot be taken as representative for a broader exploration area, the obtained distinctions in velocities were encouraging and they led to the decision to perform a pilot profile by using the seismic reflection method at the *Studena vrila* site (Fig. 1).

The intention of test measurements was to prove the reliability of the shallow seismic reflection method in a situation where in the roof of Cretaceous limestones, with bauxite in the negative paleorecesses, the Promina formation occurs in a heterogeneous sequence. In order to meet this requirement, the lay-out of the profile was located over the explored bauxite deposit with the clastic roof.

The acquisition of measurements data on the selected pilot profile was carried out according to the well-known CDP method. »CDP« stands short for Common Depth Point. To put it briefly, the method consists of the overlapping of individual points on the demarcations of wave reflection in the subsurface by consecutive measurements; this favourably influences the final processing results in terms of the improvement of the signal-noise ratio.

Not getting into the field techniques itself, it should be mentioned that the measurement parameters were chosen after the initial tests. In the field stage of work data were gathered and stored in a digital form on a magnetic medium (diskettes). They were further used as input data for the processing stage.

The processing was performed on an IBM PC compatible computer. For this purpose a specially developed program package VESNA was used. Except for the specific qualities linked with the seismic behaviour of the shallower subsurface, the processing takes place according to the same algorithms as the deep reflection data processing, which method – as known – represents the basic geophysical method in oil explorations. Data processing, especially by the shallow seismic reflection, cannot be a fully automatized process; it is an interactive one and it is understood that the geophysicist performing this processing possesses the knowledge of an expert in this field.

After the performed field measurements and the digital data processing, the time and depth cross-sections of the subsurface along the profile lay-out were obtained (Figs. 2 and 3).

The interpretation of the time and depth cross-sections consisted firstly in the designation of the reflection demarcation lines and the tectonic lines. The following stage was to attribute their geological significance to the detached demarcation lines with the emphasis on the identification of the demarcation between Cretaceous limestones and the Promina formation clastic deposits, and perhaps on the detection of paleorecesses in the basement limestones.

On the time and depth cross-sections along the profile lay-out at *Studena vrila* location (*Povaljenica* deposit), the demarcation zone of the Cretaceous limestones and and the clastic roof can be clearly recognized (Figs. 2 and 3). The negative form in its relief between the profile points Nos. 27 and 44 is also clearly noticeable. Between these points, as seen from the map, a known bauxite deposit occurs as well. The derangement zone of the basement-roof demarcation form is so expressive that, even when the existence of this deposit were unknown, drilling – which should normally follow the interpretation of the reflection data – would in the first place be directed to it.

Conclusion

In the *Mesihovina-Rakitno* bauxite-bearing sedimentary basin (central part of the carbonaceous Dinarides) at the locality of *Studena vrila,* in the broader area of the known bauxite deposit *Povaljenica,* the shallow seismic reflection method was tested aiming at the most efficient detection of new bauxite deposits beneath the roof sediments.

Numerous deposits are placed next to the tectonic-erosional discordance on the demarcation line between the Upper-Cretaceous limestones (basement) and the Promina formation clastic deposits (roof).

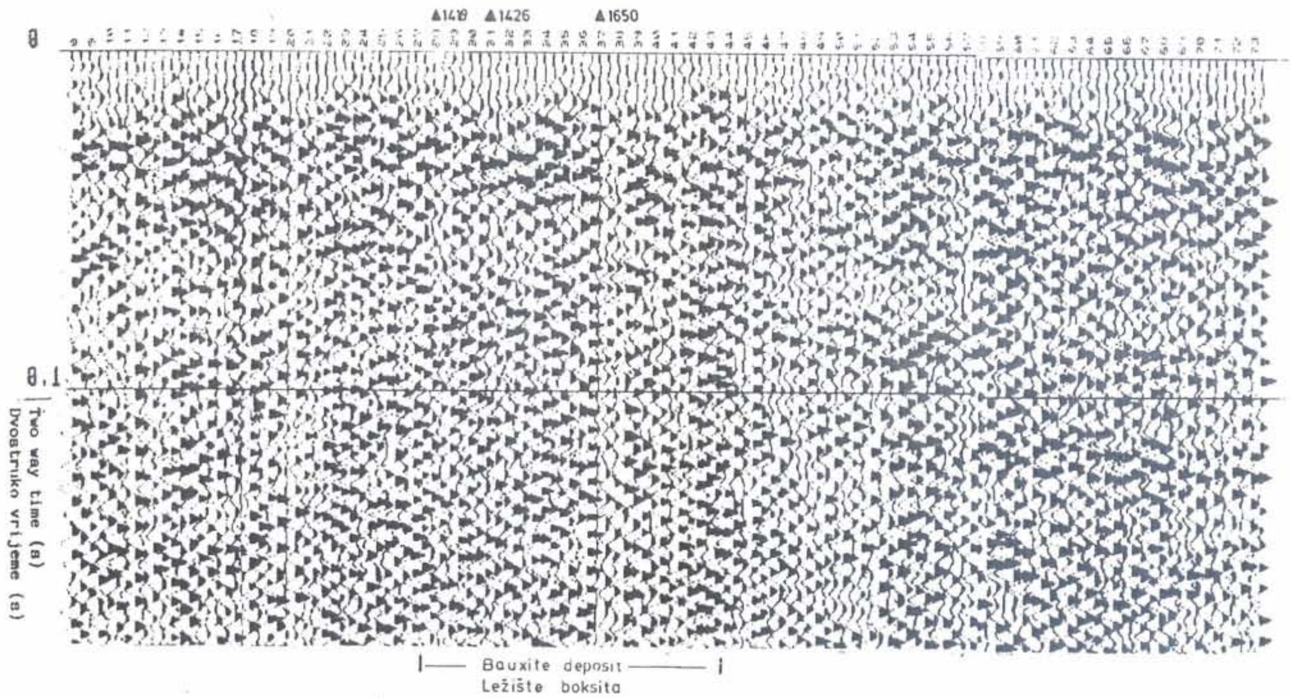


Fig. 2 Studena vrila – time cross-section

Sl. 2 *Studena vrila – vremenski presjek*

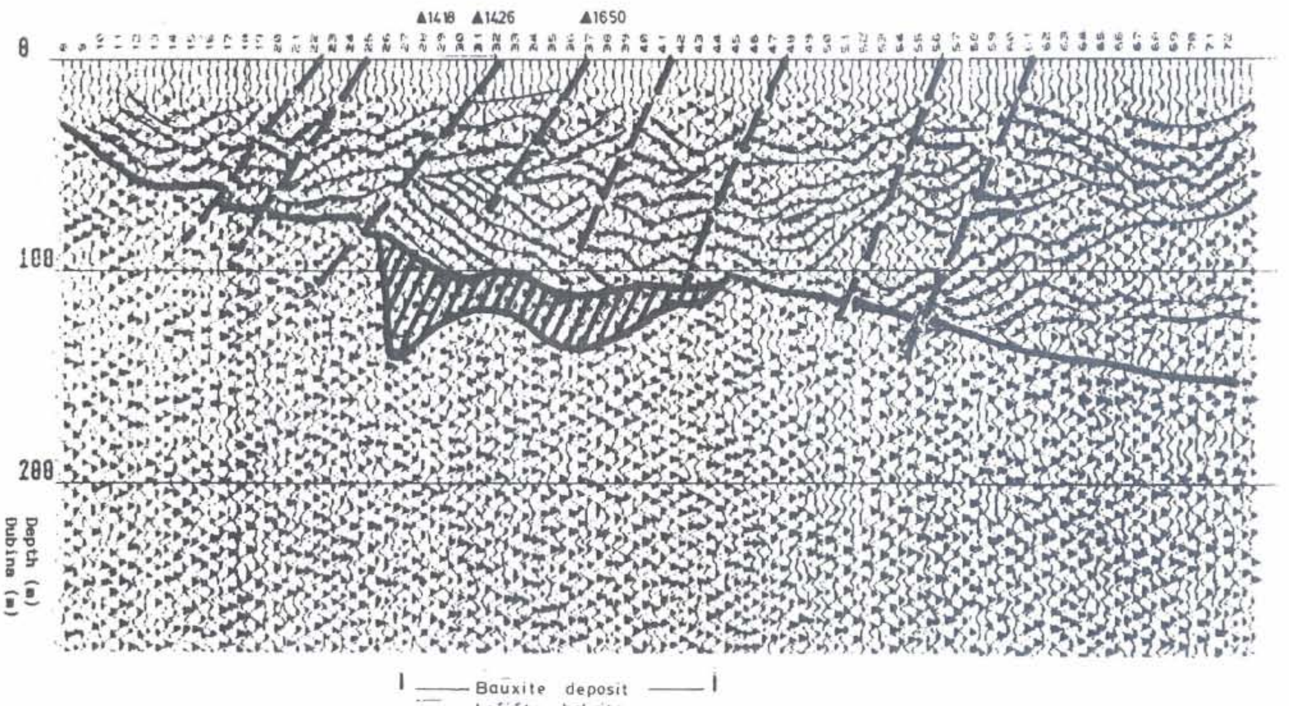


Fig. 3 Studena vrla – depth cross-section

Sl. 3 *Studena vrila – dubinski presjek*

The deposits vary very much in shapes, thicknesses and dimensions and occur in the recesses of the paleorelief formed in limestones.

The selection of the shallow seismic reflection, as the method which in the future might contribute to the bauxite deposits exploration in regions with similar geological relations, was stipulated by the following geological parameters:

- essentially distinctive petrographic composition of the basement and the roof of the deposit,
- different lithification degree of the basement and the roof sediments,
- developed paleorelief in the basement limestones representing the demarcation plane of the basement and the roof, on which plane the bauxite deposits are placed,
- lithological characteristics of the roof sediments,
- structural position of the bauxite deposit and the demarcation plane of the basement and the roof, respectively.

After the completion of the field measurements, digital data processing and interpretation, the time and depth cross-sections gave satisfactory results thus enabling the distinction of the basement and the roof sediments, and the identification of the paleorelief plane respectively. These results represent very important indicators in the exploration of the bauxite deposits beneath the roof.

Acknowledgement

The presented results were obtained within the framework of the study entitled »Complex geological explorations in the region of *Mesihovina-Rakitno* bauxite-bearing sedimentary basin«, which is – at the request of the *Posušje* Bauxite Mine – carried out by the Faculty of mining, geology and petroleum engineering of the University in Zagreb, together with associates outside the Faculty. On this occasion we wish to express our gratitude to the Mine Management for allowing us to publish this paper.

Received: 3. IV. 1991.

Accepted: 25. VI. 1991.

BIBLIOGRAPHY

Published

Blašković, I., Dragičević, I. and Pokrajčić, I. (1989): Tectonic control of the origin of the paleorelief of bauxite deposits in Western Herzegovina, Yugoslavia. *Travaux ICSOBA*, 19, 231–238, Zagreb

Dragičević, I., Benić, J. and Blašković, I. (1985): Novi stratigrafski podaci o paleogenskim klastitima Studenih Vrila – Zapadna Hercegovina. *Geol. vjesnik*, 38, 31–34, Zagreb.

Raić, V., Ahac, A. and Papeš, J. (1976): Osnovna geološka karta SFRJ, 1:100000, list Imotski. Savezni geološki zavod, Beograd.

Unpublished

Andrić, M. (1990): Izvještaj o probnim geofizičkim radovima u području Posušja. fond dokumenata Geofizike, Zagreb.

Dragičević, I., Blašković, I. and Tišljar, J. (1985): Mogućnost utvrđivanja zakonitosti pojavljivanja ležišta boksita u Hercegovini – područje Studena Vrila. RGN fakultet, Zagreb.

Dragičević, I., Blašković, I. and Tišljar, J. (1986): Kompleksna geološka istraživanja u području Studena Vrila – Vučipolje (studija). RGN fakultet, Zagreb.

Dragičević, I., Blašković, I., Tišljar, J., Benić, J., Papeš, J. and Trubelja, F. (1987): Kompleksna geološka istraživanja u boksitonosnom sedimentacijskom bazenu Mesihovina-Rakitno (zapadna Hercegovina), studija. RGN fakultet, Zagreb.

Geološko-geofizička istraživanja ležišta boksita
Primjena plitke seizmičke refleksije

I. Dragičević, M. Andrić i I. Blašković

U boksitonosno-sedimentacijskom bazenu Mesihovina – Rakitno (središnji dio karbonatnih Dinarida) na lokalitetu Studena Vrila u širem prostoru poznatog ležišta boksita Povaljenica testirana je geofizička metoda plitke seizmičke refleksije u cilju što efikasnijeg pronalaženja novih ležišta boksita ispod krovinskih sedimenata.

Brojna ležišta su smještena uz tektonsko-erozijsku diskordanciju na granici gornjokrednih vapnenaca (podina) – klastiti Promina formacije (krovina). Ona su veoma različita po obliku, debljini i veličini, a nalaze se u udubljenjima paleoreljefa koji je formiran u vapnencima.

Odabir plitke seizmičke refleksije kao metode koja bi ubuduće pripomogla kod istraživanja ležišta boksita u područjima sa sličnim geološkim odnosima, uvjetovali su slijedeći geološki parametri:

- bitno različiti petrografski sastav podine i krovine ležišta,
- različiti stupanj litifikacije podinskih i krovinskih taložina,
- razvijeni paleoreljef u podinskim vapnencima koji predstavlja graničnu plohu podine i krovine, a na kojoj se nalaze ležišta boksita,
- litološka obilježja krovinskih taložina,
- strukturni položaj ležišta boksita, odnosno granične plohe podine i krovine.

Nakon provedenih mjerenja na terenu, te digitalne obrade podataka i interpretacije na vremenskim i dubinskim presjecima, dobiveni su zadovoljavajući podaci koji omogućuju razdvajanje podinskih i krovinskih taložina, odnosno prepoznavanje plohe paleoreljefa. Ovi podaci predstavljaju veoma važne pokazatelje kod istraživanja ležišta boksita ispod krovine.