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BALL COALS FROM ALTO CHICAMA (PERU)

(Pl. I—II and 2 Figs.)

Węgle kuliste z Alto Chicama (Peru)

(Tabl. I—II i 2 fig.)

Abstract. Ball coals from Alto Chicama occur in coal seams of the Chimu Formation (Lower Cretaceous). They are ellipsoidal, spheroidal or cylindrical in shape and have a smooth, lustrous surface. Their size varies from a few to 40 cm. They have been found in a tectonically disturbed area where intrusive rocks have noted.

INTRODUCTION

In the years 1973-1974 a Polish-Peruvian geological expedition carried out investigations in the nothern part of the Peruvian Andes (Cordillera Occidental) with a view to documenting the Alto Chicama anthracite coal deposit (Fig. 1). The prospecting works were conducted in the area between the localities Coina and Callacuyan in the La Libertad department, the Otuzco de Chuco province, at an altitude of 1950--4150 m above sea level. In the coal seams, spheroidal bodies made up of coal have been found. They are frequently referred to as ball coals[1] (Piddington, 1848; fide Chandra and Chatterjee, 1969, 1971), but are also known by other names, e.g. niggerhead coal (Moore 1922), Kugelkohle (Potonié, 1924), Mugelkohle (Stutzer, 1923), coal pebble (Stutzer, and Noé, 1940).

Ball coals have been observed in coal seams in various parts of the world. Because of their shape, geological conditions of their occurrence and an interesting yet still obscure origin, they rouse lively interest among the geologists. So far, they have been reported from Hungary (Zincken, 1877), England (Chandra, Hodge, 1962; fide Chater-

[1] This name must not be confused with „ball coal", which is synonymous with Torfdolomitenknolle, since the latter represents mineralized plant fragments with preserved cellular structure.

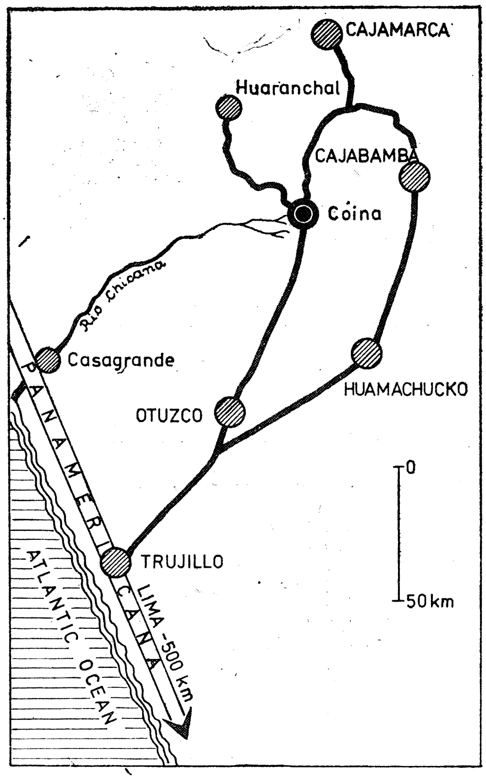

Fig. 1. Location of the Alto Chicama deposit (Peru)
Fig. 1. Loaklizacja złoża Alto Chimaca (Peru)

jee 1971), Scotland (Smith, 1900; Masterson, 1920), Alaska, Colorado and Washington, USA, Australia (Moore, 1922) and India (Piddington, 1848; Chandra, Chatterje 1971).

The present paper gives a brief petrographical description of the ball coals from Alto Chicama (I. Lipiarski) and discusses the geological conditions of their occurrences (R. Szymoniak).

GEOLOGICAL CONDITIONS OF THE BALL COALS OCCURRENCES IN ALTO CHICAMA

The Alto Chicama deposit is built of Jurassic, Lower Cretaceous and Quaternary rocks. Coal seams are located in the Chimu Formation (Lower Valanginian), which attains a thickness of about 1000 m. The Cretaceous sediments are folded and cross-cut by numerous faults. The general strike of the fold axes is NW-SE. The tectonic dislocations are accompanied by intrusions of igneous rocks. Volcanic activity is also responsible for contact metamorphism.

The Chimu Formation consists of rocks of limnic origin that were subject to intensive diagenetic and metamorphic processes. They are: quartzites, quartzite sandstones, quartz sandstones, mudstones, claystones, coal shales and coal. The quartzites have usually a light-grey colour and a medium-grained texture, while the quartzite sandstones are grey in colour and their texture is fine-grained. Both the quartzites and quartzite sandstones are compact and show massive structure. The quartz sandstones, grey or dark-grey in colour and of very fine-grained texture, have random or, in places, parallel or undulant structure. Both the quartzite sandstones and quartz sandstones show a high degree of sorting. The mudstones, grey or dark-grey in colour, have aleuritic texture and a random or oriented structure, accentuated in places by streaks of coarser quartz grains, mica or coal detritus. The claystones, usually dark--grey or grey in colour, are locally bedded. Occasionally, thin laminae of coal shales may be encountered among them. Coalified plant fossils are very rare in the described rocks.

In the 500 m thick coal-bearing series, which as part of the Chimu Formation, ten coal seams denoted by numbers from 1 to 10 (from the top of the series to its bottom) and coal shale beds have been noted. The coal seams are, as a rule, not more than 1.5 m thick. Only seam 4 attains a thickness of 2 m and locally even of 4 m; seam 5 has a thickness greater than average as well. Coal shale beds and beds barren rock over 0.3 m thick occur in some coal seams, dividing the seam into two or three layers. In the top and the bottom of the coal seams there are usually claystones or coal shales.

The coal seams are generally made up of compact coal which is in places tectonically disturbed. The bulk of the reserves is anthracite coal and anthracite (types 41 and 42 acc. to the Polish coal classification) and coal with a degree of coalification higher than type 42. Lean coal (type 38) has been found as well.

The content of volatile matter in coal varies from some to 24 per cent, averaging 6,6%. The average bulk density is about 1.6 g/cm^3. The net calorific value of coal ranges from 3800 to 6600 cal/g whereas its gross calorific value varies from 5600 to 7600 cal/g. The average ash content in the coal seams is 12%, varying from 8 to 18% in seams 4 and 5. An essential mineral component of coal is sulphur. The analysis of several samples from seams 4 and 5 has shown that total sulphur content in coal ranges from 0.50 to 4.50%, the average being less than 1%. It is predominantly combustible sulphur.

THE PETROGRAPHIC CHARACTERIZATION OF BALL COALS

Ball coals have been found mainly in coal seams 4 and 5. Their occurrence in other seams is sporadic. In seams 4 and 5 ball coals are present in the whole seam or only in its part. They are ellipsoidal, spheroidal or cylindrical in shape and their surface is smooth and lustrous (Plates 1, 2). The longest of the three axes of the ball coals specimens is from some to a dozen or so centimetres long, attaining a maximum length of 40 cm. It is generally perpendicular to the coal seam bedding (Plate 1, Fig. 2). Only a few out of 20 specimens that have been thorougly investigated show bedding, which is very indistinct and hardly discernible even in polished sections. Megascopically, two coal varieties may be distinguished. One of them displays features characteristic of vitrain, i.e. black colour, intense glassy lustre and conchoidal fracture; moreover, it has fissures and contraction joints. The other, prevalent variety bears the closest resemblance to durain; it is black with a grey tinge and, in comparison with vitrain, shows a less intense lustre. Vitrain appears in durain usually in the form of irregular lenses (Fig. 2). The thickness of

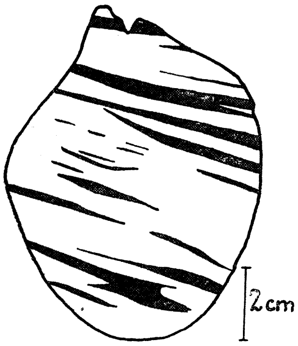

Fig. 2. Section across a ball coal specimen. Polished surface. Black — vitrain, white — coal with the durain characteristics

Fig. 2. Przekrój przez jeden z okazów węgla kulistego. Barwa czarna — witryn, bez szrafury — węgiel o charakterze durynu

larger vitrain lenses varies from 2 to 5 mm, up to 10 mm at the most. Apart from vitrain lenses of larger size, there appear in coal numerous but small lenses, streaks and inclusions which, intercalating durain, from clarain. Larger and thicker vitrain lenses are from 5 to 30 mm apart from one another.

The coal investigated in polarized reflected light between crossed Nicols exhibits strong optical anisotropy. Vitrain is made up of collinite in which small inclusions of mineral matter occur locally. Typical telinite has not been recorded, yet the presence of regular though indistinct hollows in collinite implies that the latter owes largely its origin to transformation and coalification of plant tissue fragments. In places, fragments of fusinite occur in collinite. Collinite is also in contact with larger fragments of that maceral. The difference between the reflectance of collinite and fusite is insignificant. The mean reflectance of collinite measured in oil with a refractive index of $n_{25^0C} = 1.5150$ in non-polarized light of a wave length $\lambda = 546$ mm is $R^\circ = 5.46\%$. The basic component of coal with the durain characteristics is collinite. Fragments of fusinite with destroyed and empty cells or cells filled with mineral substance are found quite frequently. Mineral matter is abundant in collinite; it appears in the form of fine grains, lenses, streaks or laminae.

Optical and X-ray examinations have revealed the presence of small amounts of kaolinite, pyrite and, presumably, of siderite and muscovite in one sample. Optical identification of these minerals is difficult due to their small size.

Table — Tabela 1

Dimensions of some ball coals from Alto Chicama

Rozmiary wybranych egzemplarzy węgli kulistych z Alto Chicama

The longest axis or the axis perpendicular to bedding of coal seam Oś najdłuższa lub prostopadła do warstwowania pokładu węgla	The axes parallel to bedding of coal seam Osie równoległe do warstwowania pokładu węgla	
	intermediate axis oś większa	shorter axis oś mniejsza
21,5 cm	17,4 cm	12,5 cm
14,2	12,0	7,9
10,4	6,8	5,3
9,2	6,9	5,0
6,4	5,7	4,3
6,4	4,3	3,4
5,4	4,3	2,5
5,2	4,4	3,7
5,2	3,8	3,4
5,0	4,2	3,7
3,7	7,0	6,3
2,3 *	1,4	1,3

Explanation: * — cylindric form of ball coals; all the other forms are ellipsoid.

Objaśnienia: * — forma cylindryczna; pozostałe formy elipsoidalne.

The analysis of ash obtained from burning of coal seems to confirm the presence of some of the above-mentioned minerals. A high content of SiO_2 — 51.20%, Al_2O_3 — 38.67%, K_2O — 3.28% may be suggestive of the presence of silicates, whereas Fe_2O_3 — 4.15% and SO_3 — 0.10% may evidence the occurrence of minerals containing iron and sulphur. The content of other components is: 1.27% CaO, 0.78% MgO, 0.38% Na_2O. The examined sample has been found to contain about 2% of ash. It appears, therefore, that the ash content in the sample is lower than in the coal seams. This is due to the fact that in the coal seams, apart from the matter disseminated in coal, there occurs matter forming thicker layers.

DISCUSSION

A comparison of the data obtained for the ball coals from Alto Chicama with those reported for ball coals from other parts of the world shows that they are in good agreement. The external features (shape, spheroidal jointing, slickensided surface) of the ball coals from Alto Chicama are very similar to those of ball coals from, e.g. the Jharia and Raniganj coalfields in India (Chandra, Chatterjee, 1969), although the coal making up ball coals in those areas differs in age, petrography and the degree of coalification. It appears, therefore, that those parameters play a subordinate role in the formation of ball coals. In the area under study, as well as in other regions from which ball coals have been reported, intrusive rocks have been noted. There is a growing body of opinion among the geologists that their presence is responsible for the formation of ball coals. It was presumably the amount of heat supplied when coal was still weakly coalified (brown coal stage) rather than high temperature in the contact zone of coal with the intrusion that played a significant role in the formation of ball coals. There is evidence (Chandra, Chatterjee, 1971) to suggest that ball coals formed in situ from coal blocks by gradual rounding-off of their corners and edges, since jointing in a coal seam and the formation of regular blocks occur most frequently at the stage when weakly consolidated coal dries out rapidly. The rounding of the cornes of blocks was probably due to weathering processes. The slickensided and smooth surface of the ball coals in question indicates that both the static pressure of rocks and the dynamic pressure played a significant role in their formation.

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REFERENCES
WYKAZ LITERATURY

Chandra D., Chatterjee K. K. (1969), Petrology of Permian ball coals from the Raniganj and Jharia coalfields, India. *Neues Jrh. Geol. Paläont. Monatsh.* 10, p. 577—593.

Chandra D., Chatterjee K. K. (1971), On the origin of ball coals. *J. of Sediment. Petrol.* 41, 3, p. 770—779.

Chandra D., Hodge B. L. (1962), Niggerhead coal structure from county Durham, U. K. (unpublished report).

Masterson J. (1920), Coal apples. Edinbourgh Geol. Soc. Trans. 11, p. 58—60.

Moore E. S. (1922), Coal. New York.

Piddington H. (1848), Examination and analysis of the ball coal of the Burdwan Mines. *J. Asiat. Soc. Beng.* 17, p. 59—61.

Potonié R. (1924), Einführung in die allgemeine Kohlen Petrographie. Berlin.

Smith J. (1900). Coal apples from Lughton water. *Glasgow Geol. Soc. Trans.* 11, p. 130.
Stutzer O. (1923), Kohle (allgemeine Kohlengeologie). Berlin.
Stutzer O., Noé A. (1940), Geology of coal. *University of Chicago*, Chicago.
Types of hard coal, PN-68/G-97002 (1970).
Zincken C. (1877), Aphorismen über Fossile Kohlen. *Berg u. Hüttenm. Monatsh.* p. 272.

STRESZCZENIE

W latach 1973-1974 polsko-peruwiańska grupa geologów prowadziła badania geologiczne w północnej części Andów Peruwiańskich (Cordillera Occidental). Celem tych badań było udokumentowanie złoża węgla antracytowego i antracytu Alto Chicama (fig. 1). W pokładach węgla zostały stwierdzone kuliste utwory zbudowane z węgla, które w literaturze są często nazywane ball coals. Pokłady węgla są zlokalizowane w formacji Chimu (dolny walanżyn). Utwory kredy są zaburzone tektonicznie. Dyslokacjom tektonicznym towarzyszą intruzje skał magmowych. W węglonośnej serii złożowej, o grubości około 500 m, która stanowi część formacji Chimu, stwierdzono 10 pokładów węgla oznaczonych numerami od 1 do 10 (licząc od stropu serii do spągu). Pokłady 4 i 5 posiadają większą od przeciętnej dla pozostałych pokładów węgla grubość. W pokładach tych stwierdzono węgle kuliste. Zanotowano elipsolidalny, kulisty i cylindryczny kształt węgli kulistych, których powierzchnia jest gładka i błyszcząca (tabl. I, II). Przeciętna długość najdłuższej z trzech osi, wśród pomierzonych węgli kulistych, wynosi kilka do kilkunastu cm; maksymalnie do 40 cm. Najdłuższa oś węgli kulistych jest na ogół prostopadła do warstwowania pokładu węgla (tabl. 1, fig. 2).

W węglach kulistych megaskopowo można zaobserwować dwie odmiany węgla. Jedna wykazuje cechy witrynu, a druga, która w węglu przeważa, najbardziej przypomina duryn. Witryn występuje w formie nieregularnych na ogół soczewek w durynie (fig .2). Grubość większych soczewek witrynu waha się od 2 do 5 mm; maksymalnie do 10 mm.

Węgiel badany w spolaryzowanym świetle odbitym przy nikolach skrzyżowanych wykazuje silną anizotropię optyczną. W węglu wyróżniono macerały: kolinit i fuzynit oraz materię mineralną: ił i piryt.

Porównując wyniki badań przeprowadzonych nad węglami kulistymi z Alto Chicama z wynikami uzyskanymi w innych rejonach na kuli ziemskiej można stwierdzić, że istnieje duża ich zbieżność. Wygląd zewnętrzny (kształt, sferyczna oddzielność, rodzaj powierzchni i jej zlustrowanie) węgli kulistych z Alto Chicama jest bardzo podobny do węgli kulistych np. z Jharia i Raniganj w Indiach (Chandra, Chatterjee, 1969) a także innych rejonów, mimo że węgiel, z jakiego są zbudowane węgle kuliste w obu rejonach, różni się między innymi wiekiem, skła-

dem petrograficznym oraz stopniem uwęglenia. Wymienione zatem parametry odgrywają, jak się wydaje, podrzędną rolę w powstawaniu węgli kulistych. W badanym rejonie, podobnie jak w innych rejonach, gdzie stwierdzono węgle kuliste, występują skały intruzywne. Ich obecność, jak stwierdza większość autorów, jest czynnikiem decydującym w tworzeniu się węgli kulistych. Można przypuszczać, że w powstaniu węgli kulistych odegrała rolę nie tyle wysoka temperatura, ile odpowiednia ilość ciepła dostarczona w czasie, gdy węgiel był jeszcze słabo uwęglony (przypuszczalnie w stadium węgla brunatnego). Istnieją dowody (Chandra, Chatterjee, 1971), że węgle kuliste powstały in situ, oraz że formowały się z bloków węgla, przez stopniowe zaokrąglanie ich naroży. Tworzenie się spękań w pokładzie węgla i formowanie się tą drogą bloków zachodzi bowiem najczęściej wówczas, gdy mało jeszcze zdiagenezowany węgiel szybko wysycha. Zaokrąglenie naroży jest zapewne wynikiem procesów późniejszych, między innymi wietrzeniowych.

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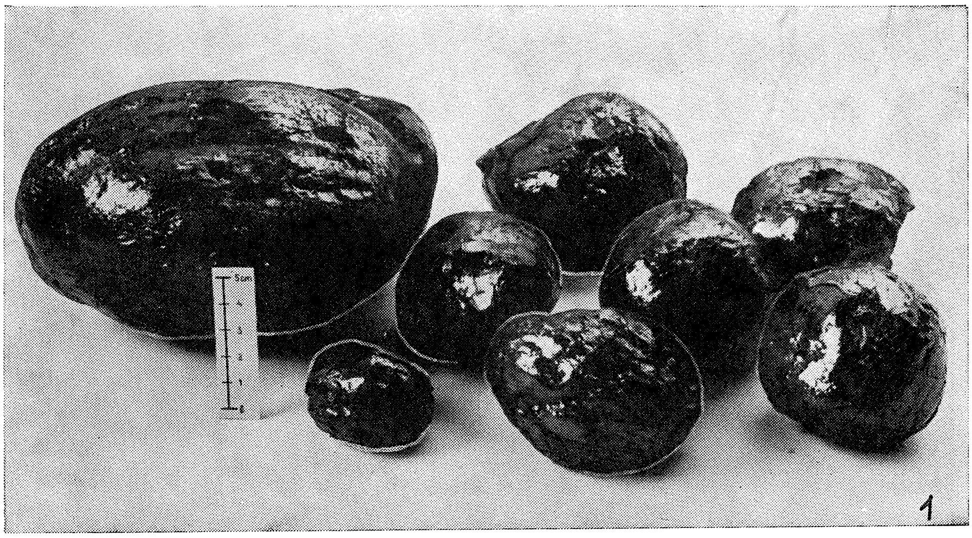
EXPLANATION OF PLATES
OBJAŚNIENIA TABLIC

Plate — Tablica 1

Fig. 1. Ball coals from Alto Chicama
Fig. 1. Węgle kuliste z Alto Chicama
Fig. 2. Ball coals from Alto Chicama (three photographs of the same specimen). Spheroidal jointing visible in figs. 1 and 2
Fig. 2. Węgle kuliste z Alto Chicama (trzy fotografie tego samego okazu). Sferoidalna oddzielność jest widoczna na fig. 1 i 2

Plate — Tablica 2

Figs. 1, 2. Different photographs of the specimen shown in Plate 1, fig. 2
Fig. 1, 2. Dwa ujęcia fotograficzne okazu pokazanego na tabl. 1, fig. 1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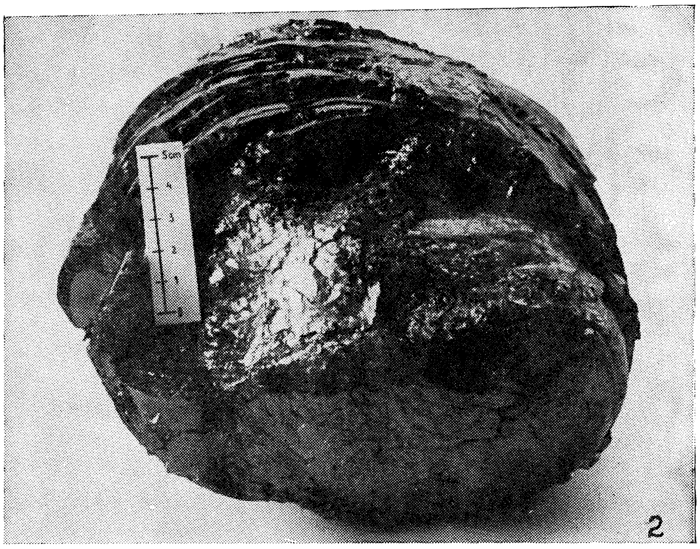
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