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Ores in Sediments

Edited by G. C. Amstutz and A. J. Bernard

Reprint of the First Edition

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With 184 Figures

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Preface

In 1963 the first Symposium on "Ores in Sediments" took place as part of an International Sedimentological Congress. At the end of that first Symposium, the group then assembled adopted a resolution printed in the book which resulted from it (AMSTUTZ, 1964, p. 7), and points (3), (4) and (5) read as follows:

(3) The group considers the integration of sedimentology in any study of ore deposits in sediments essential to a correct interpretation. A study of the role of sedimentary processes, including diagenesis, is an important field in pure as well as in applied research on the genesis of mineral deposits.

(4) In particular, the group also considers the knowledge of sedimentary rocks and processes (in regard to both, the fabric and the geochemical detail) a prerequisite for the understanding of subsequent metamorphic processes and their possible role in the deformation and reconstitution of mineral deposits and host rocks.

(5) The group suggests that similar symposia could with advantage be held at future Congresses of the International Association of Sedimentologists.

The Editors wish to thank the International Association of Sedimentology for including another Symposium on ore minerals in its Congress program.

Considerable progress has been made since 1963, as the reader will see from the following pages. A few instances only can be mentioned here. On a small scale, still more details on the diagenetic crystallization differentiation are now available. The recognition of its existence has gained much ground and slowly the simple explanation which it offers for accumulations of certain late diagenetic sulfides (e. g. galena) in late diagenetic spaces such as compaction fissures and intraformational breccias, is accepted and the assumptions of epigenetic mimetic replacements are gradually recognized to be untenable.

Almost all papers of this Symposium refer, in one way or another, to the diagenetic behaviour or role of ore minerals. Most papers also refer to the facies and paleogeographic relations of ore mineral formation. This facet of the Symposium should be of specific interest to those active in exploration.

An additional type of stratabound deposits has been brought into the limelight and provides an answer to very magny enigmatic deposits at or below erosional unconformities: the karst deposits (BERNARD; PADALINO et al.).

Observations on recent deposits, many still in the process of formation, provide first-hand, direct proof of the formation of ore deposits in sediments. The number of recent deposits known is increasing fast, and more and more ore genetic interpretations can be based also on actualistic analogies (HONNOREZ et al. ; LEMOALLE and DUPONT; PUCHELT; VALETTE).

These are only a few of the new results presented in this Symposium.

If one now looks at the content and tries to classify the papers, various ways of grouping them would appear to be useful. As just mentioned, certain aspects are common to almost all papers. The strongest differences exist with regard to the age of the deposits, the facies and the nature of the ore minerals. The common facets being preponderant, it was decided to arrange the papers alphabetically, except for the introductory paper of the Symposium.

For those interested in a subdivision according to topics, the previous comments plus the following list will help. This list attempts a subdivision of the papers according to the classification given in the first Symposium volume of 1963/64, plus a class of papers on more general principles.

A) Reduzate deposits:

ARNOLD, MAUCHER and SAUPE
BARTHOLOME et al.
BERNARD
BOGDANOV and KUTYREV
BRONDI, CARRARA and POLIZZANO
COLLINS and SMITH
GELDSETZER
HONNOREZ et al.
MONSEUR and PEL
PADALINO et al.
PUCHELT
SAMAMA
SCHADLUN
VALETTE
ZIMMERMANN and AMSTUTZ

B) Oxidate deposits:

BERNARD
BRONDI, CARRARA and POLIZZANO
DOYEN
EARGLE and WEEKS
GERMANN
LEMOALLE and DUPONT
MENGEL
PADALINO et al.
PUCHELT
SAMAMA

C) Sulphate and phosphate deposits:

BERNARD
SAMAMA

D) Detrital deposits (placers, sands etc.)

ARNOLD, MAUCHER and SAUPE
MENGEL
MONSEUR and PEL
SESTINI
TOURTELOT and RILEY

E) Papers on general principles (not pertaining necessarily only to A, B, C or D):

BERNARD (Introduction)
BERNARD
MONSEUR and PEL
POPOV
SAMAMA
VALETTE

Last but not least, I wish to thank the Springer-Verlag for the interest in this book and the effort put into its proper presentation. The informed reader will realize that the fast and simplified offset printing method implies some sacrifice regarding the quality of the figures - which depends largely on the quality of the material received.

Thanks are also due to those staff members in the Mineralogical Institute of Heidelberg who contributed freely of their time for editorial reading, especially Dr. R.A. Zimmermann, Dr. R. Saager and Mr. E. Schot. Mrs. W. Ackermann accomplished not only a masterpiece of typing for offset printing, but also contributed much to the editorial detail work, and Mr. E. Gerike upgraded a good number of imperfect drawings.

Heidelberg, November 1972

G. C. AMSTUTZ

Reference

AMSTUTZ, G.C.: Introduction, In: Developments in Sedimentology, Volume 2: Sedimentology and Ore Genesis (ed. AMSTUTZ, G.C.), p. 1-7. Amsterdam: Elsevier 1963/64.

Contents

A Review of Processes Leading to the Formation of Mineral Deposits in Sediments

A. J. Bernard

A few years ago, eminent scientists still postulated seriously a deep seated, magmatic origin of petroleum. These scientists even maintained that the accumulation of petroleum in sedimentary host rocks after long and intricate migration did not speak against its fundamentally plutonic origin.

This was a typical example of a dogmatic way of thinking or behaviour. It allowed the theorists to cling to their ideas, whereas the prospectors - the practical men - were expected to restrict their interest to oil reservoirs and traps. The factual knowledge of oil deposits consequently still progressed, even though the genetic concept evolved only slowly or not at all. Historically, the work of the prospecting geologist must, therefore, be considered as unstrumental for the present state of our understanding of petroleum as a sediment.

The statistical evaluation of the significance of a certain number of oil-forming environments and the fundamental research on the genesis of sedimentary rocks were efforts which are entirely justified by their economic importance. Thus, it is safe to say that the beginning of sedimentology,or at least its rapid development during the last 25 years, was mainly invoked by the stimulations of research on oil.

Oil-forming environments are characterized by the occurrence of a certain subsidence which not only caused the burial and thus preservation of organic, mostly marine matter, but which transformed them also diagenetically into oil. At the same time, the concept of migration yielded progressively to a concept which assigns more importance to synsedimentary traps, i. e. traps which were at least partially closed by sedimentary processes.

The process of oil formation and accumulation represents thus quite an elementary genetic model. Sedimentation and burial of ultrafine, detritic organic material was followed by a diagenetic evolution in situ under the effects of low pressure and temperature conditions. An additional sine qua non condition which is quite specific for hydrocarbons is the fact that the accumulated oil is fossilized almost in situ together with its connate waters. Furthermore, the fluid nature of oil imposes specific conditions on the existence of the deposits.

Having discussed the economically most important sedimentary "mineral", i. e. oil, whose prospection and genesis had so far-reaching sedimentological implications, I shall proceed with a few thoughts on "solid fuels" which were in earlier times as important as oil today.

The abundance of vegetal remnants which are present in coal saved it from "the honour" of a magmatic origin. This is the reason why paleontological and petrological studies since a long time enabled detailed paleogeographic reconstructions. The environments of epeirogenetic intra-cratonic and coastal basins led to successful regional prospecting. Locally, however, the sequential positions (cyclothems) of coal beds still leave unanswered questions concerning their description and interpretation.

If the paleoclimatology of coal deposits, the biological and the Eh-pH conditions of the ultra-detrital accumulation of vegetal matter, the diagenesis or even the epimetamorphism of these materials and other questions were answered, coal producing environments could be much better understood and thus much better prospected. On the whole, there is still much to be learned from these questions and many more observations need to be made.

With the exception of the chronology problems and the questions which exist on the processes closing oil traps, the conceptual models of fuel deposits are relatively simple. In contrast, economic geologists presently studying metallic ore deposits are confronted with more involved problems which are in the following discussed in the order of their growing complexity.

The problems posed by the heavy mineral placers are best solved by studying the sedimentation processes of detrital rocks. Hydroclassification (based on similarity of properties) apparently answers most of the questions pertaining to the petrography and especially to the grain-size of these deposits. In fluviatile environments, however, the natural jigging of heavy minerals within their associated alluvium often destroys the expected simple grain-size relationships. In spite of our far-reaching knowledge of heavy mineral placers, it is still a hazardous operation to reconstruct the ancient river systems, to localize rapids, and to assess their evolutions, which are responsible for the formation of paystreaks. Very often a prospector has more confidence in a systematic drilling campaign than in a difficult paleogeographical reconstitution.

Finally, a strange theory, which will be discussed during this congress, maintained that there were no pre-Tertiary placers. This, of course, is wrong, but the odd reason of such a tale needs to be mentioned. Economically most placers are workable only if not completely indurated. Once lithified, their grade is usually too low to warrant mining which, in hard rock, would be too costly. The theory mentioned was born by the fact that most pre-Tertiary placers are lithified, which makes their mining uneconomic. For instance, in the discussions on the genesis of the Precambrian uranium and gold conglomerates of the Witwatersrand (South Africa), the old theory was the reason for a lot of misconceptions. The final argument for the sedimentary explanation of this deposit was brought out by sedimentological studies. It was the determination of reworking of daltaic accumulations by coastal currents and their redistribution in bankets, which gave the key to the distribution of workable reefs. To be more exact, the uranium and gold mineralizations are border facies of basins, located less than 60 km from the deltaic zones. Knowing this crucial observation, the prospectors stopped paying attention to the theories of hydrothermal impregnation which were defended by certain authorities, as was the case with the magmatic origin of petroleum.

As simple as it may look, the sedimentation of heavy detrital minerals still leaves some difficult problems. This is for instance the case, when several phases of reworking occurred or when the off-shore prospecting of placers on present-day shelves is considered.

To explain the oolitic iron ores - at least those of the Lorraine - deltaic and detrital sedimentation processes have to be used. In the case of the Lorraine deposits, the sedimentological studies enabled, almost layer by layer, to reconstruct the paleogeography of the deltaic estuary which occupied the Gulf of Luxembourg in Upper Toarcian times. The remarkably detailed maps resulting from this work indicate the zones of oolite formation and localize the spreading zones of granular iron oolites amidst coastal muddy grounds. The paper of LEMOALLE and DUPONT corroborates this statement on the basis of a study of recent oolites in the Lake Chad.

This model, however, is rendered more complicated by the question of the source and nature of the extraordinary iron supply which led to the Lorraine deposits. A formation by the emersion and erosion of bituminous and pyrite-bearing shales of the Lower Toarcian offers a particularly elegant explanation. Elsewhere, i.e. in the Peine and Salzgitter deposits of Germany, the erosion of a lateritic soil-cover and the near-shore distribution of the iron concentrations is a similarly elegant explanation for a high metal supply.

The localization of marine, epicontinental manganese deposits along ancient shorelines, be they oolitic or not, may be explained by similar processes. Therefore, the question can be asked, whether the main stage of concentration did not occur before the detrital sedimentation and whether it consisted of chemical precipitation (or flocculation) of metal-rich terrigenous and fluviatile solutions (or suspensions). The zone of mixing of continental acid waters poor in dissolved salts with basic seawaters of high ionic strength is usually a very efficient geochemical trap.

On the whole, terrigenous sources are responsible for the supply of exceptional amounts of metals, the marine and litoral environments providing only the trapping medium. We are approaching now the important problem concerning the nature of these exceptional supplies of metals. The biological Eh-pH theory (and its heterostasic variant) with the aid of the soil science and of climatology considers only terrigenous aspects; however, the pure marine as well as the exhalative contributions (so spectacular when sub-marine) must also be considered. In the order of growing complexity of the problem, the marine, the exhalative and finally the terrigenous supplies or sources are discussed; the latter leads again back to the difficult and important problem of continental ore genesis.

The Marine Sources

Pure marine sources are best illustrated by phosphate sedimentation which can be explained by the classical theory of upwelling cold streams. Seawater has its highest P_2O_5-content at a depth of 350 to 1000 m. Cold currents rising up to the water surface, for instance along continental slopes, penetrate zones where photo-synthesis takes place. In these zones, large portions of the phosphorus are consumed by plankton which in turn gives rise to a particularly rich "biocenosis". A second phosphorus concentration takes place within living organisms. But even the two concentration effects put together can only form rich phosphate deposits, if the corresponding sedimentary environment is free of or at least depleted in phosphorus-free terrigenous material. Upwelling cold currents, without doubt, can inhibit the terrigenous supply and sedimentation in the shelf zones affected by them. By creating an arid microclimate in the continental hinterland adjacent to the zones of upraise, the presence of upwelling cold currents can perhaps even explain the peculiarities of the terrigenous sediments in phosphatic environments (cherts, Mg-clays).

It is easy to drive the structural and paleogeographic consequences of such a model (epochs of phosphate-genesis, e.g.) which may be used either for regional or local prospecting.

Marine evaporites are a good example for a pure marine source of material. The evaporation of seawater leads to successive precipitations of salts which have been studied in great detail. The explanation of very thick salt accumulations by rhythmical layering led very early to the research of the structures which were responsible for the observed sequences, i.e. coastal lagoons, large closed bays, border areas of epicontinental basins etc. Subsidence rhythms, nature and periodicity of seawater inbreaks, importance of the continental water inlets with respect to the basin size, and climatic conditions were, among others, the main factors used to explain the large mineralogical, petrographic and sequential diversity of old evaporite series. Only recently interaction pehnomena were noticed between brines (evolving through periodical additons of saline or fresh waters) and already deposited salts. Similar processes (sometimes called "metamorphism") occur during the diagenesis of evaporites, for instance in the case of potassic salts.

As simple as the case of the evaporites may look, the number and the diversity of the parameters which can influence the deposition is so complex that each study of a deposit is always a difficult task. Being aware of their scarcity in ancient series, I shall just mention the extreme diversity of continental evaporites. The complexity of marine evaporite resulting from the evaporation of a unique and well known solution, i.e. seawater, is in the case of continental evaporite amplified by the variability of the original waters. Their composition depends largely on the hydrogeology of the different evaporating lakes.

Incidentally, the very special chemistry of evaporitic and pre-evaporitic environments leads to warranted models for:
- sedimentary deposits of native sulfur in reducing environments with high anaerobic bacterial activities;
- barite related to cherty strata;
- siderite and magnesite deposits which are well explained by the arrival of iron and calcium rich continental waters in penesaline lagoons possessing a syngenetic dolomite sedimentation.

However, in the last three cases (barite, siderite and magnesite), the contribution is terrigenous, whereas the chemical trap belongs to the evaporitic environment.

The Exhalative Source

I shall be brief about exhalative-sedimentary sources. The submarine environment only provides the adequate conditions for trapping and fossilizing the concentrations of iron, manganese, pyrite and associated chalcophile metals. Quartz-keratophyric and spilitic volcanism of the pre-orogenic troughs, tholeiitic volcanism of the oceanic ridges, and perhaps alcaline volcanism of the submarine seamounts are potential environments for the exhalation of metal concentrations. In these cases, the problem lies more in the nature of the exhalations and in the mode of their formation than in the sedimentary processes which trap the metals. Incidentally, we may recall the difficulties of mining geologists confronted with the petrological problems of submarine lavas or with the problems of pyroclastic accumulations and their volcano-sedimentary reworking. In many respects this is a sedimentological field which justifies further thorough investigations.

I shall not mention aerial exhalations since they rarely give rise to deposits. They provide, however, together with the associated lavas, the elements of exceptional terrigenous sources which are now discussed in more detail.

The Terrigenous Sources

In addition to the stratabound iron and manganese deposits which were discussed previously, the shelf harbours some further stratabound sulfide concentrations, the genesis of which is still controversial. For some investigators they are the results of telethermal circulations; for others they are the results of syn- or diagenetic sedimentary processes. As in the case of petroleum, it was here, too, the initiative of mining geologists which led to the sedimentological examination of mineralized environments. The results of these studies in turn permitted to define the rules of localization of these deposits.

The main process is the fixation of heavy chalcophile metals in reducing H_2S-generating environments. The "Kupferschiefer" are their best known example, even though perhaps somewhat exceptional, as also the Zechstein evaporites. Despite of a very coherent set of arguments, taking into account the possible diagenetic recrystallizations of primary precipitates, some workers are still in doubt of the syngenetic origin of such sulfide concentrations.

Similar environments exist in areas which were more restricted and thus more active than the one of the Kupferschiefer. The most frequent occurrence is probably that of sea bottom heights influencing the synchronous sedimentation of oscillating shales and carbonate series (those of evaporitic environments included). This reminds us of a trap well known to petroleum geologists, i. e. that of the "buried-hills" which often occurs in a less subsiding and more litoral environment. Reducing environments producing syn- and/or diagenetic H_2S exist selectively on the slopes or on the top of these structures which are well known to sedimentologists (lateral pinching, slumping, "rolls", etc.). Similar to the Kupferschiefer, the mineralizations are pyritic or cupriferous in pelitic host rocks, whereas in carbonate host rocks the mineralizations are lead- and zinc-bearing. The height of the structures is not of importance, be it an epeirogenic horst, a reef bioherm or a diapiric upraise of the bottom, provided that the geometry of the trap creates a slowed down sedimentation of adsorbing material and an H_2S-generating environment at the time of an exceptional terrigenous influx of heavy metals.

Tracing this conspicuous terrigenous metal-influx towards the continent, along the sulfide-bearing horizons which are characterized by a distinct geochemical anomaly ("source beds") one encounters the marine, then lagoonal and finally continental red-bed impregnations. No matter whether they are uranium, lead-zinc or copper mineralizations, it is known that the circulation of ground water bodies, through reducing portions of large piedmont flood-plains, is responsible for the formation of metal impregnations. This circulation occurs obviously during the cementation of detritic sediments, i. e. during diagenesis of the host sandstones. But there, too, it is a prerequisite that the circulating waters bear metals!

With this, we reach the problem of the geochemical behaviour of heavy metals on the continents. The study of paleo-alteration profiles discloses that, depending on the parent rocks and climate, leaching of pedological concentrations may occur. Fast and probably instant reworking of soil concentrations seems to be the most general cause of conspicuous terrigenous sources. Volcanic ashes are, indeed, another possibility for such a source, but a very strong argument against this source is the rather strict correlation which seems to exist between the occurrences of the deposits and paleoclimatic zones. This climatological dependance of terrigenous contributions confirms, well enough, that their nature lies mainly in processes related to soil formation.

Let us have a brief insight into the apparent variability of these pedological processes; it is known that nickel is leached together with magnesium from ferralitic profiles situated on ultrabasic rocks. If the drainage of the altered zone is poor (flat topography), nickel and magnesium are stored and concentrated at the basis of the profiles as montmorillonite or garnierite ... Conclusion: look for ferralites developed on ultrabasic rocks in equatorial paleozones, but look on massives which are levelled by erosion! Should such paleo-surfaces be raised by epeirogenesis, a series of reworking may occur about which I do not want to say more, at least with reference to nickel.

The geology of bauxites provides us with much better known examples of alteration successions and of detrital reworkings of profiles, followed by new alterations on differenciated parts. The simple allitization of a nepheline-syenite is a model which has been complicated by the Fe-Al separation of the ferralites. I shall briefly mention the evolution of a ferralitic material sedimented on karst which easily explains the separation between iron and aluminium, and also the bauxite deposits of the Provence, France; at the same time it introduces the new problem of traps related to the pedological alteration.

We are dealing, of course, with concentrations located below unconformity surfaces. At first, the cementation of sulfide ore bodies demonstrates undoubtedly that the residual concentration of copper and silver occurs per descensum. To what extent will the karstic reworking of stratabound pre-concentrations in a carbonate environment not lead to cross-cutting sulfide bodies below the paleo-emersion surface? To what extent are certain uranium, barite and fluorite veins which are, geometrically speaking, strictly linked to unconformity surfaces not caused by per descensum processes, as proposed up to now? I shall close this short review with these two questions which lead away from purely sedimentary phenomena.

In conclusion I would like to emphasize the following thought: It is logical and "cartesian" in scientific research to go from the known towards the unknown and, in geology, from the surface towards the depth. As a paradox, economic geology is a field which has been dominated in its concept as well as in its methods by a theory related to deep seated and, so to say, to magmatic phenomena. I believe, it is about time in 1971 to go back to Descartes and to ask if many of the deposits which occur in sedimentary rocks are not the results of exogenous processes. Sedimentology gave the start, and economic geology follows its example in a way which now appears irreversible.

Diagenetic Pyrite and Associated Sulphides at the Almadén Mercury Mine, Spain

M. Arnold, A. Maucher, and F. Saupe

Abstract

The pyrite of Almadén provides an excellent record of the early history of the sediments. It is especially important as it appears on a regional scale as a constituent feature of the "Criadero Quartzite". The pyrite crystals are built up of a macromosaic nucleus surrounded by a diagenetic cortex. Framboids of the nucleus display frequently a mutual orientation, a structure which is unusual in "Rogenpyrit". The cortices display different growth types (zonal, fibrous and sectorial).

Cinnabar and pyrrhotite appear only within the nucleus and never in the cortex. Cinnabar thus precipitated under equilibrium conditions between pyrite and pyrrhotite. Mercury was present before the addition of the diagenetic pyrite cortices, since it is trapped in the nucleus.

A - Introduction

1. The Problem

Due to its low mobility and its mechanical strength, pyrite is an excellent recorder of the early history of the sediments, and the contained mineralizations. Cinnabar displays opposite features. Therefore, the first mentioned mineral was selected as the object of a microscopic study of the ore at Almadén.

The Almadén pyrite was first studied by MAUCHER and SAUPE (1967) and was interpreted by them as syngenetic (in the meaning of economic geology and not of sedimentology). The new technique of epitaxic oxidation developed by one of us (ARNOLD, 1969 and in preparation) led us to take the problem up again, in order to delimit the conditions of pyrite formation and to know by these means those of cinnabar. The employed techniques aim to recognize the variation of different parameters within a given crystal. For this reason, phase contrast microscopy, after epitaxic oxidation, and microprobe analysis were used.

2. Regional Geological Setting

Almadén is located in the Paleozoic block forming the Iberian Meseta, exactly between the Sierra Morena to the south and the Montes de Toledo to the north (Fig. 1). Above several thousand meters of schists and greywackes belonging probably to the Upper Precambrian and the Lower Cambrian, lies unconformably (Sardic phase) a Paleozoic sequence, extending from Ordovician to Carboniferous. From the Arenig to Siegenian stages inclusive, this series consists of about 2000 m of sedimentary rocks. It is framed in by two quartzite levels, corresponding to these two stages, and is composed of a monotonous sequence of shales, alternating shales and sandstones, and two other quartzite levels belonging to the Caradoc and the Llandovery[1]. The latter supports the mercury mineralization and its pyrite is described in the following lines.

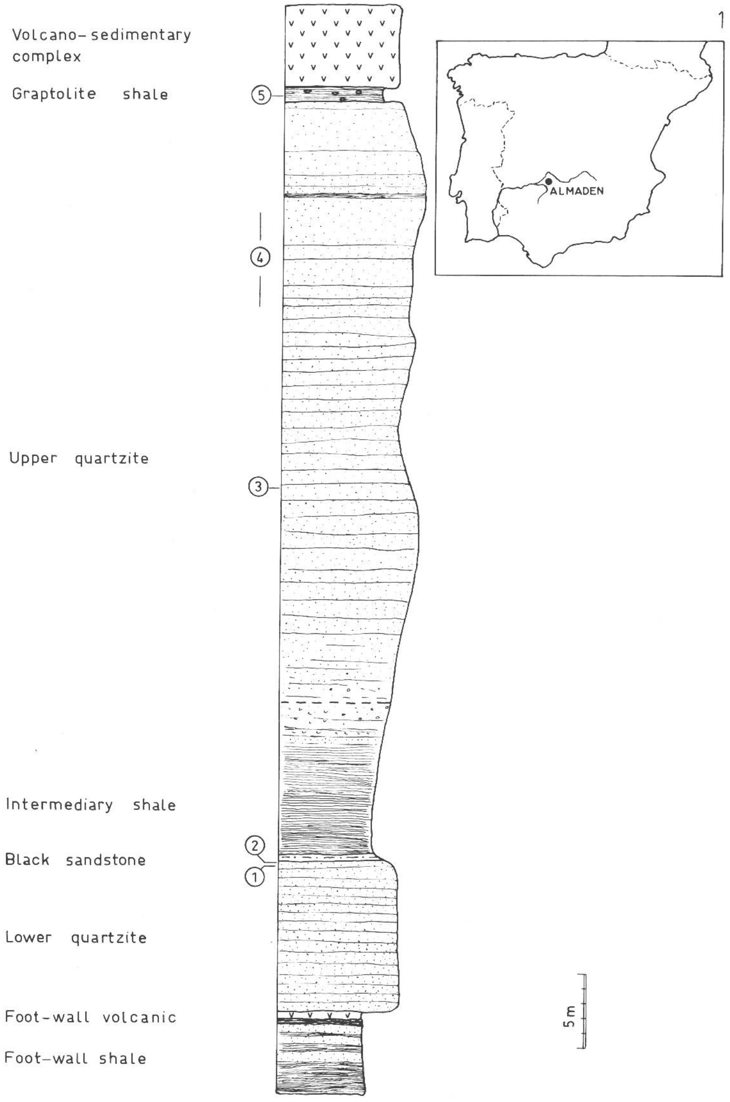


Fig. 1. Stratigraphic profile of the "Criadero Quartzite", with the five sample locations. Location map of Almadén

1) A detailed description with a bibliography is given by SAUPE (1971a).

3. Local Geological Setting

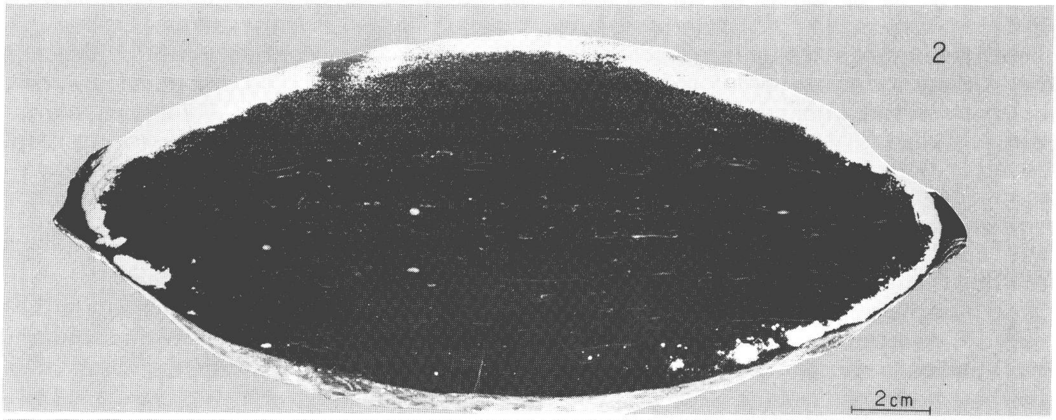
The following stratigraphic summary is based on a recent publication (SAUPE, 1971b). The "Criadero Quartzite" is built up of two members, framed in and separated by shales. Its total thickness is about 50 m at Almadén, but it gradually decreases in all directions. The constituent quartzite is remarkably pure and of diagenetic origin, the latter being a consequence of the former. The lower member (13 to 15 m) consists at its base of a sandstone, losing progressively upwards its argilo-carbonaceous cement, thus changing into a quartzite. Its lower and upper limits are sharp; the footwall is formed by the already mentioned shale, and the hanging wall by a black sandstone bed, overlain by black shales. About 10 m higher in the section, these rocks grade into the second quartzite member which has an approximate thickness of 30 m. Fig. 1 shows the location of the three ore horizons and the position of the five samples studied in the present paper. Table I contains short descriptions of them (see also fig. 2 to 5).

Table I - Description of the studied samples

Sample Number	Description of pyrite	Description of host-rock
Top of stratigraphic column		
5	Pyrite corona of 0.5 to 1 cm thickness	Ellipsoidal dolomite nodules containing organic matter. Fine and plane internal stratification. Occur within Graptolite shales.
4	Thin pyrite seams (a few mm)	Black quartzite on top of the S. Nicolas ore zone. Fine plane internal stratification.
3	Pyrite nodules, with a faint concentric zoning	Gray quartzite in the footwall of S. Francisco ore zone.
2	Pyrite bed of 2 to 5 cm	Top of a light gray quartzite bed, overlain by black sandstone.
1	Pyrite seam of 0.5 to 1 cm	Upper bed of the S. Pedro ore horizon.
Bottom of the stratigraphic column		

Samples 1, 2 and 5 are well located stratigraphically and their lateral equivalents may easily be found in the lower levels of the mine. Sample 3 is also stratigraphically well defined, but similar material is rare. Sample 4 is not characteristic for a given horizon and may be found anywhere in the upper half of the second quartzite member, though not abundantly. The five selected samples cover all the distinct diagenetic pyrite forms. Remobilized pyrites are encountered in fissures, but are not described here.

The presence of pyrite in the "Criadero Quartzite" is a regional feature. It was found by one of us (F. S.) in the town of Almadén, where the quartzite is barren of ore and it is limonitic in many places in the concession (cubic relicts are frequent). Thus the pyrite appears as a constituent feature of the "Criadero Quartzite".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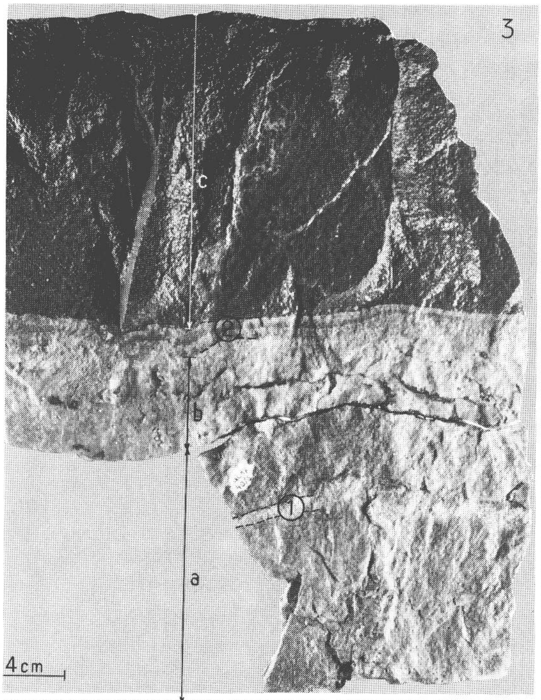
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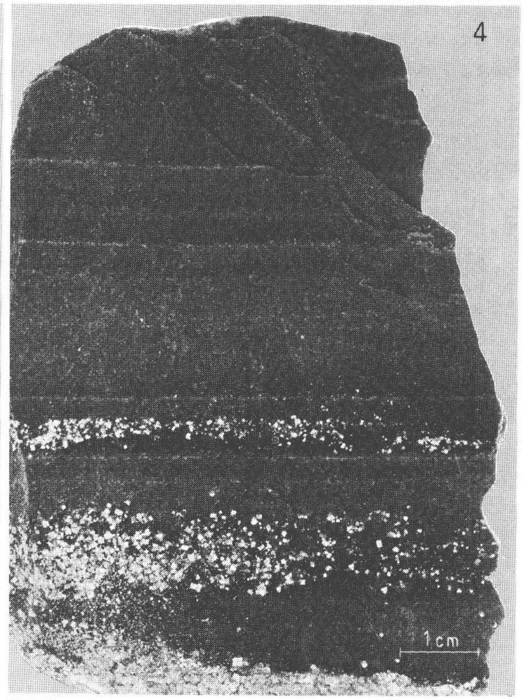
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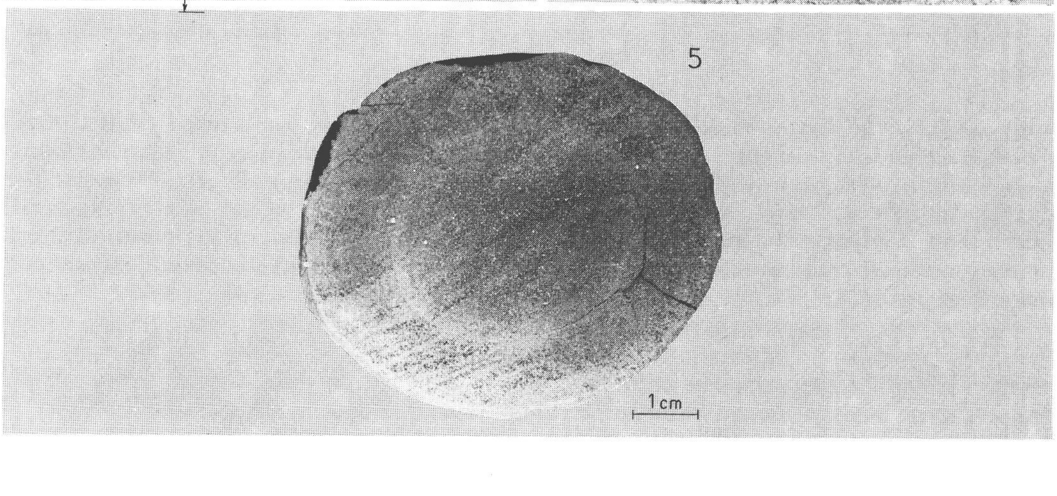
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