Conference Report

Low-temperature mineralization

P. R. Ineson


The Conference, ably organized by Dr R. A. Ixer with the co-operation of the University and the Department of Geological Sciences, to whom the Mineral Deposits Studies Group extend their thanks, was subdivided into 3 sections. The first day was devoted to a number of papers which covered varied aspects. Isotopic studies on the mineralization of the Ophir Valley, Colorado (Jackson), and the Ba-Zn deposit at Aberfeldy (Willan) were presented together with 2 papers on U mineralization in Namibia (Marlow and Clemmy). Ineson and Walters indicated the problems of correlating horizons and interpreting the attendant alteration associated with the igneous rocks in the South Pennine Orefield, while Alabaster & Pearce described the geological setting of the sulphide deposits in the Oman ophiolite complex. For this type of meeting, an unusual but interesting contribution by Broadbent et al. reviewed European Pb-Zn production and indicated recent research into new recovery processes for Pb, Zn and Cu as well as improving hydrometallurgical techniques.

Well over 100 people attended the second day, and were no doubt attracted by a number of papers related to Permo-Triassic mineralization. A review of the Permo-Triassic rocks and related mineralization was given by Clarke who, in proposing new genetic models, caused some disquiet amongst the audience. On a more localized scale, isotopic evidence indicating possible inter-relationships was presented by Harwood & Coleman, while Turner & Margaritz argued that the Marl Slate/Kupferschiefer metal sulphides were related to early diagenesis under anoxic conditions.

Considering the proximity of the conference venue to the Cheshire Basin it was not surprising that a number of papers discussed this area. A general review by Carlon & Thompson described detailed mineral occurrences in the Cheshire Basin, while Vaughan & Ixer presented recent studies on the mineralogy of the Alderley Edge area and the genetic models the investigations had supported.

Clemmy described Cu mineralization in the Andes, and hypothesized that they may represent the first stages in the formation of a stratiform ore deposit. A related topic, in which Surman had undertaken a stable isotopic study of the Mufulira Cu deposit, likewise enabled genetic models to be evoked. Remaining in the field of ‘red-bed’ palaeo-environments, Ruxton proposed a syngenetic origin for the late Proterozoic deposits in Namibia and Botswana.

The residential part of the conference was terminated by a paper by Suttill et al. on Mössbauer spectral studies in elucidating the formation of iron sulphides in recent tidal-flat sediments.

The third and final part of the meeting was devoted to field excursions. Carlon led a visit to Wood Mine in the Alderley Edge area and Harker (standing in at the last moment owing to the unfortunate illness of King) conducted a party around the small, but interesting, mineral occurrences in Leicestershire.

P. R. INESON, Department of Geology, University of Sheffield, Mappin Street, Sheffield, S1 3JD.

A geochemical, geochronological and stable isotope study of porphyry-style mineralization in the Ophir Valley, Colorado

S. E. Jackson

The study area extends from the Ophir mining district (Au, Pb–Ag) eastwards to the Silverton Caldera. The Sultan and Ophir monzonite stocks lie at either end of this area and are localized respectively by a caldera-related ring fracture system and an E-W trending fracture zone. Numerous differentiated pluggs and some small intrusive breccias occur between these stocks. The dominant country rocks are mid-Tertiary volcanics, which overlie early Tertiary and Mesozoic sedimentary rocks. Of recent economic interest are 2 areas of strong, pervasive, argillic to sericitic hydrothermal alteration. Various differentiated pluggs and some small intrusive breccias occur between these stocks. The dominant country rocks are mid-Tertiary volcanics, which overlie early Tertiary and Mesozoic sedimentary rocks. Of recent economic interest are 2 areas of strong, pervasive, argillic to sericitic hydrothermal alteration superimposed on a regional propylitization. Biotite pairs from the Sultan and Ophir stocks give average K-Ar ages of 25.8–27.9 Ma respectively. Similarity in age and petrology suggests that the stocks may be surface expressions of a deep pluton. Five K-Ar dates on coarse hydrothermal sericites range from 24.1 to 24.7 Ma (±1 = 24.4 Ma). Two distinct areas of 18O enrichment (max. = +9.2%o) relative to the regionally 18O-depleted country rocks (min. = −1.3%o) are associated with positive (Mo, W, Pb, Rb) and negative (Zn, Sr) geochemical anomalies within the two areas of strong hydrothermal alteration. A corresponding high in δD (−30–−100%o) relative to the region at depletion (−120–−140%o) is associated with one δ18O high. The data suggests: (1) intrusion of a major igneous body at 25.9 Ma, (2) the concomitant development of a meteoric hydrothermal system which caused regional propylitic alteration, (3) a localized hydrothermal event with a significant magmatic component associated with the emplacement of late-stage plugs and breccias producing areas of strong hydrothermal alteration and metal enrichments and depletions, and (4) a duration for the total hydrothermal system of the order of 1.5 Ma.
Stratabound Ba-Zn mineralization in Dalradian schist near Aberfeldy, Scotland  J. S. Coates

A stratabound zone of Ba, Zn and Pb mineralization occurs in Middle Dalradian metasedimentary rocks near Aberfeldy. The mineralization is contained in graphitic schist of the Ben Easach Formation. Initially located by a reconnaissance geochemical drainage survey, it has a general thickness of c. 100 m and is present over a strike length of 7 km. Shallow boreholes indicate that it extends to at least 100 m below surface and consists of interbedded baryte-rock and quartz-celsian rock, together with sulphide-bearing carbonate rock, muscovite-schist and graphitic mica-schist. Individual baryte bands are up to 15.5 m thick and Ba-rich rocks, probably deposited in a direct result of deuteric alteration.

Geological setting of massive sulphide deposits in the Oman ophiolite complex  T. Alabaster & J. A. Pearce

The volcanic stratigraphy of the Oman ophiolite complex is made up of 3 distinct mappable units termed (in order of eruption) the Geotimes, Lasail and Alley Units. The Geotimes Unit is dominantly basaltic pillow lavas, whereas the Lasail and Alley Units comprise basalt-andesite-rhyolite fractionation series. Field observations and geochemistry indicate that each formation erupted in a different local tectonic environment: the Geotimes Unit as a fast-spreading ridge crest; the Lasail Unit as a series of discrete volcanic seamounts; and the Alley Unit in a submarine graben setting. Almost all significant massive sulphide deposits formed on the Geotimes pillow lavas just prior to eruption of the basalt pillow lavas of the Lasail Unit and all are located within the seamount areas. The pre-forming hydrothermal activity took place within a geologically short period of time above a subduction zone, possibly at the margins of magma chambers feeding island arc volcanoes.

The igneous horizons of the South Pennine orefield—A review of the Matlock-Wirksworth area  P. R. Ineson

Exploration boreholes, underground investigations and mineral operations, together with historical records and field mapping, have resulted in the elucidation of the numerous lavas, tuffs and vents in the area. Apart from the work of Arnold-Bemrose no systematic survey of all the various rock types has been forthcoming. It is anticipated that the present reappraisal will clarify these units and assist in the overall stratigraphical, structural and mineralogical aspects of the orefield.

Substantial deposits of low-grade Pb, Zn and Cu ores have been identified in Europe and the EEC has initiated a research programme, the aim of which is to develop and define processes which will facilitate recovery of such metals. Self-sufficiency in non-ferrous metals is not, at present, either possible or economic, but the formation of cartels, similar to the bauxite producers, is a distinct possibility and could result in escalating metal prices. Such action could render indigenous deposits attractive.

Palaeoclimatic control on U mineralization in Namibian calcrete  H. Clemmy

Following the discovery in the early 1970's of Yeelirrie in Western Australia, calcrete of groundwater origin became recognized as a potential host for U mineralization. Genetic models are now well established and involve 3 major steps: (1) the supergene oxidation of primary U minerals in 'fertile' source rocks; (2) the formation of soluble uranyl carbonate complexes and their eluviation of groundwaters; (3) precipitation of the uranium, usually in the form of carnotite (K₂(UO₂)₂[V₂O₇]:3H₂O) within the calcrete forming from the same groundwater. Precipitation follows decomplexing induced by excessive evaporation (CO₂ loss) following ponding, concretion and forced upwelling of groundwater.

These models are first approximations and need refinement.

Primary U mineralization in granites and alaskites, Namibia  A. G. Marlow

Economic and sub-economic primary U deposits occur over a large part of the high temperature zone of the Damara Orogenic belt between Swakopmund and Usakos. The deposits occur as granites, pegmatites and alaskites which intruded during the late Pan African.

The alaskites are characterized by high K-feldspar, thorium and rare early minerals, and contain a variety of U phases in the form of oxides, silicates and carbonates. These U phases may have a simple chemistry or they may be complexly zoned probably as a direct result of deuteric alteration.

The significance of indigenous low grade non-ferrous metal deposits to the European Economic Community  C. Broadway, S. Guy & D. Jackson

Western Europe produces substantially more Pb and Zn metal than is mined as ore, e.g. the estimated quantity of Pb ore mined in 1979 contained 540,000 tonnes of metal whilst 1,527,000 tonnes of refined Pb was produced: equivalent tonnages for Zn are 1,226,000 and 1,881,000.

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The Department of Minerals Engineering at the University of Birmingham has formed a small group which is researching new recovery processes for Pb, Zn and Cu in conjunction with the EEC Primary Raw Materials Programme. Existing hydrometallurgical processes involving leaching and solvent extraction separation are being modified and additional data are being generated in the laboratory. In order to assess the more important experimental parameters, ores from the British Isles, especially Eire, and from the Cayeli district of Turkey are being characterized and tested.
Marine transgression, basin wide stagnation and consequent mineralization of the Marl Slate/Kupferschiefer  P. Turner & M. Magaritz

The Marl Slate/Kupferschiefer is a sapropelic dolomitic laminate rich in metal sulphides. Textural studies indicate that the sulphides are closely associated with replaced evaporites and abundant organic material; mineralization took place during early diagenesis under anoxic conditions; calcium sulphate being reduced to form metal sulphides (pyrite, chalcopyrite, galena, sphalerite). The implication is that metals were present in Zechstein connate waters.

The source of these Zechstein metals has been investigated by comparing secular trends in base metal concentration and stable carbon and oxygen isotope ratios for a number of complete Marl Slate/Kupferschiefer sections. The zones of higher metal concentrations are markedly depleted in $^{18}O$ and followed by a marked enrichment in $^{13}C$. These data are remarkably similar to those obtained from Pleistocene and Recent sapropels which have been deposited as a result of the influx of fresh water into a marine basin causing stagnation and anoxic bottom conditions.

By analogy the Zechstein marine transgression is thought to have resulted from the influx of fresh or brackish water from the Boreal Ocean. Such influxes may have enriched in base metals, which were precipitated following the resultant basin-wide stagnation.

Isotopic evidence from mineralization in the Permian Lower Magnesian Limestone  G. M. Harwood & M. L. Coleman

Isotopic analyses of S, C, O and Pb from mineralization occurrences in the Lower Magnesian Limestone have given further evidence on their relationships. $^34S$ sulphate values show both metasomatic and displacive anhydrite within the Lower Magnesian Limestone to be of Upper Permian age. In sites of former displacive anhydrite nodules $^34S$ analyses of sulphides show these to be a product of bacterial reduction of sulphate, and bacterial reduction is further demonstrated by C-O values with the possible influence of meteoric waters and/or a small temperature increase. Analyses of galena leads throughout the Lower Magnesian Limestone produce a large spread of values, whereas Kupferschiefer/Marl Slate galena leads give a distinct, and different, cluster.

Ore mineralogy and ore genesis of the Alderley Edge deposit, Cheshire  D. J. Vaughan & R. A. Ixer

The Alderley Edge deposit, which has been mined for Cu, Pb and Ag, occurs as veins and disseminations in Keuper Sandstones. Previous mineralogical investigations have concentrated on the identification of the large number of secondary Cu, Pb, Zn, Ni, V and Co minerals; however, little systematic work has been done on the primary ore-mineralogy, and its contribution to the understanding of the genesis of the deposit has been neglected.

Examination of material in polished sections accompanied by X-ray powder diffraction and electron microprobe analysis has provided the following information on the assemblages present and their parageneses. The earliest opaque phases are associated with the earliest diagenesis of the sandstones and include authigenic anatase, and bravoite, pyrite and chalcopyrite within quartz overgrowths. This stage of mineralization was followed by the formation of intergrown bravoite, galena, sphalerite and chalcopyrite cementing the

in order to increase the predictive capability. Outstanding problems of critical economic importance concern the origin and movement history of the V needed to fix the uranyl ion; explanations for the time stratigraphic control on ‘economic’ mineralization; and the establishment of guidelines for prospecting beneath younger gravel cover.

Sedimentological work on the Namib Desert, a major U province under the influence of a hyper-arid climatic regime, suggests possible approaches to some of the problems. Mineralization is intimately related to cycles of sedimentation documenting pluvial-arid-hyperarid climatic transitions. U mineralization develops towards the end of the cycles under the influence of falling and fluctuating water tables, and the potency of the mineralizing fluid is controlled by the duration of priming and flushing periods. However, the early part of the cycle is critical for V behaviour. The lacustrine greywackes formed during the pluvial period may be the key to supplying the bulk of the V and an answer to the thorny problem of transporting V and uranyl ions in the same solution. The observation that the highest grades of ore are found not in the calcrite but in the gravels overlying lacustrine greywacke provides some confirmation for the hypothesis.

Comparison between the sedimentological record and the palaeoclimatic record as deduced from palynology, geomorphology and palaeocurrent analysis provides some confirmation for the hypothesis. The lacustrine greywackes of the Zechstein more massive base metal-rich and the disseminated base metal-poor mineralization ($^34S = -2.5\%$ and +6.4\% respectively) possibly indicating a dual source of sulphur.

**Sulphur isotope study on stratabound baryte and sulphide from the Dalradian metamorphic terrain, Scotland**  R. C. R. Willan

Sulphur isotope data from the Aberfeldy Ba-Zn-Pb mineralization do not support re-equilibration of the sulphur isotope contents during lower amphibolite facies metamorphism. The $^34S_{Sba}$ (+26.7 to +36\%) indicates derivation of sulphate from Lower Cambrian seawater sulphate and the variation of $^34S_{Sba}$ is controlled, on the small scale, by the host lithology (base metal content) and by the amount of mixing of the mineralizing brines with seawater ($^18O$ and $^34S$). On the large scale, the $^34S_{Sba}$ increases along strike from the Eastern Sector (+31.6\%) to the Western Sector (+35.7\%) and in the E the $^34S_{Sba}$ ‘lightens’ upwards, whereas in the W the values are similar. These data suggest that the Western Sector brine was more restricted to mixing with seawater sulphate, perhaps due to greater water depth.

The large and variable $^34S$ between sulphide pairs ($-5$ to +6.3\%) is evidence of gross disequilibrium below 200°C. The $^34S_{sulphide}$ (+18 to +28\%), $^34S_{pyro}$ = +23.6\% and $^34S_{sp}$ = +22.2\% suggests that this occurred within warm (c. 45°C) anoxic and toxic brines. The $^34S$ is lowest in the mineralized MnO-rich carbonates (8\%) and increases to 15\% from bacteriogenically reduced seawater sulphate, and the $^34S_{sulphate-py}$ of 11\% suggests that this occurred within warm (c. 45°C) anoxic and toxic brines. The $^34S$ is lowest in the mineralized MnO-rich carbonates (8\%) and increases to 15\% in graphic schist away from the mineralized horizon, the latter suggesting greater bacterial fractionation of sulphur under cooler, less toxic and higher $^18O$ conditions.

The $^34S_{sulphide}$ from 11 other localities of stratabound sulphide mineralization near Loch Tay, Tyndrum and Loch Pynne range from $-5$ to 11\%, also suggesting a seawater sulphate source, but there is a marked contrast between the more massive base metal-rich and the disseminated base metal-poor mineralization ($^34S = -2.5\%$ and +6.4\% respectively) possibly indicating a dual source of sulphur.

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elastic grains. This primary assemblage has undergone extensive alteration resulting in the formation of a variety of copper sulphides including covellite, blauhnakeite, covellite, and djurleite accompanied by lead and zinc carbonates and sulphates. Later, extensive shattering of the cemented elastic grains has been infilled by supergene copper and lead carbonates and sulphates, limonite and exotic secondary minerals. Formation conditions of the ore mineral assemblages were considered in the light of experimental data.

Aspects of mineralization within the Cheshire Basin  
C. J. Carlon & D. Thompson

The Triassic rocks of the Cheshire Basin contain a widespread, chiefly disseminated, mineralization, whose limits are not clearly defined, marked chiefly by mottling effects, barite and 'wad' and local concentrations of Pb-Cu-Co minerals with As, Ni, Ag and other elements. Taking examples throughout the basin, including the 3 former mining areas of Alderley Edge, Bickerton and North Shropshire, the nature and distribution of the mineralization was described and possible hypotheses for its genesis discussed.

Genesis of the mineral deposits in the Permo-Triassic rocks of Britain  
A. M. Clarke

The Permo-Triassic rocks of Britain were deposited in arid continental conditions, and may be termed 'Red Beds'. The varied clastic and carbonate lithologies provide host rocks for metallic and non-metallic mineralization, which is evident at various stratigraphic levels throughout Britain. The metallic mineralization is dominated by Pb-Cu-Fe and Mn, while the non-metallic mineralization is dominated by Ba-Sr-Ca and F.

The distribution of mineralization in the Permo-Triassic rocks was outlined, and the characteristics of the deposits noted. A series of regional 'mineral provinces' were defined and discussed in relation to the mineral deposits in the Palaeozoic rocks of Britain. The main emphasis was placed on the regional and local controls of the mineralization. Several genetic models were compared and a new model presented.

Cu mineralization in Andean gravels: first stage in stratiform ore formation?  
H. Clemmy

Erosion of lower/middle Tertiary porphry Cu deposits in Northern Chile has exposed them to late Tertiary/Recent arid weathering producing supergene enrichment and extensive gravel aprons: the so-called 'unroofing molasse'. In some instances supergene solution has moved laterally, resulting in cupric sulphate and silicate mineralization in the surrounding sediment. The Caleta Coloso Group in Antofagasta represents an unroofing molasse from the Jurassic synprophyritic deposits and contains similar ores to the ones described above. However, the Coloso ores have undergone marked diagenetic evolution and provide the missing link between Recent processes and ancient, often metamorphosed ore. Comparison with ancient provinces serves to emphasize the links between present day processes in the Atacama desert and early stages in the formation of stratiform Cu provinces.

Weathering is suggested as the dominant factor in ore formation, with sedimentation, geomorphological evolution and diagenetic ageing controlling the number, type and size of ore-bodies.

Models were presented to characterize stages in the evolution of the Cu province from 'Juvenile' (when most of the Cu is retained in the primary host), to 'Mature' (when most of the Cu is in sediments deposited during events at the mature end of the first geomorphological cycle, i.e. extensive lowland playa development and/or marine or lacustrine transgression).

Major priming and flushing events provide the key to economic ore formation and account for the remarkable time control on mineralization so evident in many Cu provinces.

A stable isotope study of the Mufulira Cu deposits, Zambia  
J. Surman

A major stable isotope study has been carried out on the Mufulira Cu deposit as part of a wider field of research into the litho-geochemistry of stratiform basement deposits in arenites. Samples collected from all horizons across the strike length of the deposit, from more localized mineralization in the hanging-wall formations, and from vein occurrences in the basement and Lower Roan sediments, have been analysed for isotopic ratios of sulphide sulphur, sulphate sulphur, graphitic carbon, and carbonate carbon and oxygen. Each sample has also been studied petrologically in transmitted and reflected light. Study of coexisting chalcopyrite and bornite has resulted in some geothermometric conclusions, as well as giving information on the chemical conditions of the mineralization, vital in any genetic consideration. Results were presented and discussed, with particular reference to the genetic theories applied to Mufulira and other similar deposits.

Copper/lithofacies relationships in late Proterozoic red bed deposits in Namibia and Botswana  
P. A. Ruxton

Stratabound Cu/Ag deposits occur within a late Proterozoic, molassic sedimentary sequence on the southern margin of the Damara Orogenic Belt, Southern Africa. A series of 'red bed' alluvial fans prograde into a tidal sea. Mineralization occurs within reduced playa lake and initial shallow marine sediments. A syngenetic origin for the ore is proposed, involving release of Cu, by weathering of a Cu-rich basement; its transport in particulate or fluid form through groundwaters; and sedimentological plus chemical control during deposition.

Mössbauer spectral studies of the formation of iron sulphides in Recent tidal-flat sediments  
R. J. Suttill, D. J. Vaughan & P. Turner

The iron-bearing mineralogy of a 9 m core of sediment through a Recent tidal-flat sequence has been studied using X-ray diffraction, SEM, and Mössbauer spectroscopy. Geochemical analysis of whole sediment samples showed little variation in the total iron content throughout the core. However, Mössbauer spectra show increasing concentrations of pyrite with depth. It thus appears that the source of iron involved in the formation of iron sulphides is from the breakdown of some other iron-bearing phase in the sediment at its time of deposition, and evidence for this was presented. The possibility of using palaeomagnetic dating of the sediments to date such diagenetic processes as the formation of iron sulphides was illustrated.