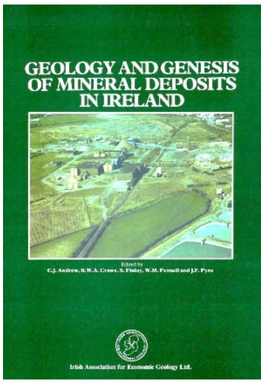

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The geology of the Navan Zn-Pb orebody.

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Abstract

The Navan Zn-Pb orebody, with initial reserves of 69.9Mt grading, 10.1% Zn and 2.6% Pb, occurs within Lower Carboniferous limestones on the northern flank of a strongly faulted, NE trending anticlinal structure which defines the SW margin of the Longford-Down Lower Palaeozoic inlier.

The bulk of the ore occurs as a series of superimposed, generally stratiform lenses which dip at gentle angles to the SW and are hosted within a shallow-water carbonate succession of Courceyan age termed the Pale Beds. Ore within the Pale Beds is characterized by a low Fe content, a generally fine grain size and a large variety of mineral textures. Evidence for sulphide sedimentation, soft-sediment deformation, replacement of host rock and episodic sulphide precipitation within both cross-cutting and bedding parallel veins is present. Consequently, the mineralization is regarded as the result of superimposition of subsurface solution growth, replacement and fracture-fill sulphide precipitation on earlier, essentially synsedimentary sulphides. These processes spanned a large time interval in the diagenetic history of the host rocks, and were the result of sustained passage of mineralizing fluids through the Pale Beds, facilitated by the development of early cross-cutting fractures inter-connecting permeable layers in the succession.

A primary structural control on the mineralization is evident in the form of ENE- to NE-trending mineralized fractures, centred on similarly orientated but more widespread and irregular areas of Zn+Pb enhancement. This vein-style mineralization pre-dates several major, unmineralized, ENE-trending faults, which clearly cut and displace ore. Maximum development of the Pale Beds ore lenses occurs in the south-central area of the orebody, where vertically continuous mineralization exceeds 80m in thickness and a clear vertical metal zonation pattern is developed, characterized by an upwards increase in Fe and in the Zn/Pb ratio. The more distal ore, however, occurs entirely in the thinner, laterally extensive, lowest lens. Widespread trace element haloes of Zn, Mn and As have been identified in the Pale Beds surrounding the orebody.

A pre-Arundian submarine erosion surface truncates large sections of the Courceyan and Chadian succession, clearly post-dates movement on the major ENE-trending faults and contains fragments of Pale Beds ore, together with other lithologies, in a chaotic debris-flow style breccia termed the Boulder Conglomerate. Localized areas of strongly pyritic, massive sulphide ore, which constitute only a small proportion of reserves (< 3%), occur within the conglomerate, and are generally located immediately above and down-slope from the truncated Pale Beds ore. This Conglomerate Group ore is regarded as a product of the final phase of Zn-Pb mineralization and may relate to unroofing of the Pale Beds mineralizing system by the erosion event.

The deposit is overlain, and masked, by a thick sequence of Arundian Upper Dark Limestones which locally contain pyritic laminae but no Zn-Pb mineralization. Trace element values for Mn, As, Zn and Pb in the Upper Dark Limestones form an irregular but extensive halo over the orebody, which may indicate that the mineralizing event continued, at a greatly reduced level, for some time after the cessation of ore formation.

NE-trending, dextral wrench-style faults of Hercynian age dislocate both the orebody and earlier faulting, and are locally accompanied by the development of intense folding within the Upper Dark Limestones. The entire succession is cut by several thin Tertiary dolerite dykes.

The Navan orebody occurs close to where the major faults intersect a late Caledonian syenite intrusion, and this coincidence is likely to have caused the high permeabilities necessary for localized large scale hydrothermal fluid flow upwards through the underlying Lower Palaeozoic basement.

Introduction

The Navan orebody is located 1km west of Navan town, in an area initially investigated because of its proximity to the faulted southwestern periphery of the Longford-Down Lower Palaeozoic inlier (Fig. 1). It was discovered by Tara Exploration and Development Company Ltd. in 1970 as a result of regional, shallow soil geochemical sampling. Detailed soil geochemistry, the discovery of mineralized float and of trace mineralization in a small outcrop, followed by Induced Polarization surveying, led to the siting of the initial drill holes (OBrien and Romer, 1971; Byrne et al., 1971; Brown, 1979). Drilling immediately intersected ore grade mineralization and the fourth and fifth holes contained 37m of 13.8% Zn+Pb and 32m of 30.1% Zn+Pb respectively.

An initial phase of surface diamond drilling outlined geological reserves of 69.9Mt grading 10.09% Zn and 2.63% Pb, at 4% combined Zn + Pb cut-off (Tara Exploration and Development Co. Ltd. Annual Report 1972). Acquisition of mineral rights by third parties led to ore north of the River Blackwater becoming unavailable to

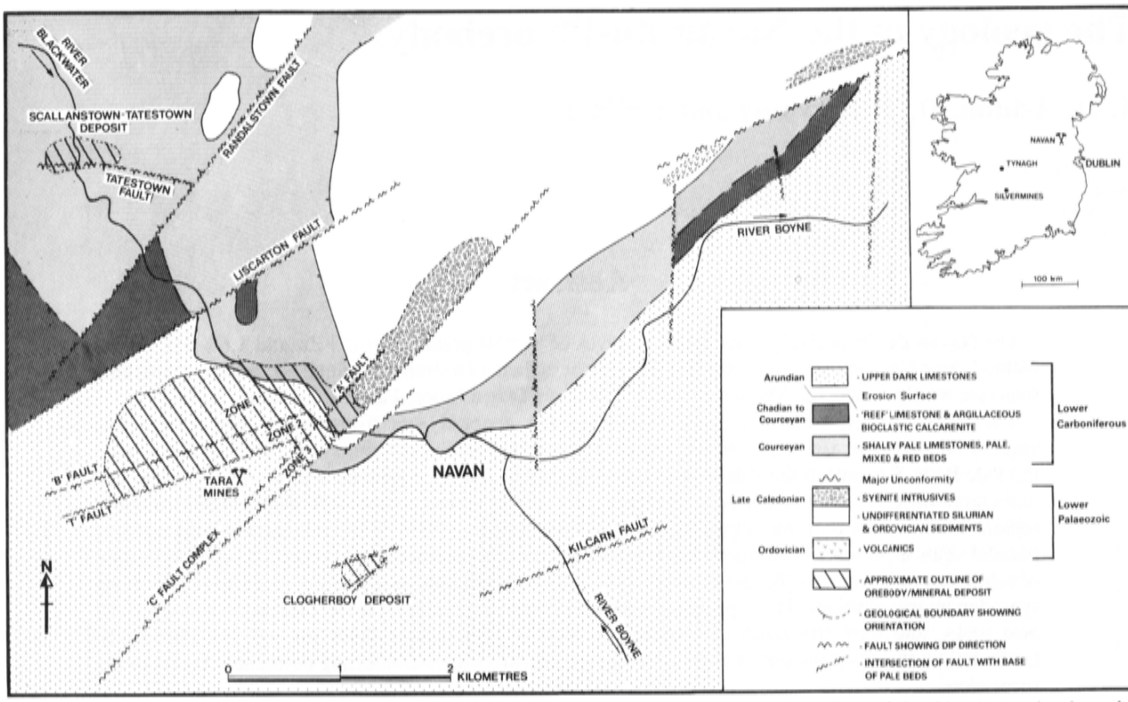

Figure 1. Plan showing the surface geology of the Navan area and the location of the Navan orebody, with Zones 1, 2 and 3.

Tara Mines Ltd, leaving 60.9Mt at 10.07% Zn and 2.73% Pb available for extraction south of the river. Underground development commenced in 1973 and led to initial production in 1977 (Libby et al., 1985; Hoppe, 1977). Surface and underground drilling has been in progress on an almost continuous basis since the discovery, and has confirmed that the orebody extends as far as 2km down dip (west) from the discovery site. Total reserves south of the Blackwater, at the end of 1983, amounted to 53.5Mt grading 9.32% Zn and 2.60%Pb, at 5% combined Zn + Pb cut-off, the mine having produced some 10.6Mt up to that time.

Tara Mines Ltd., operate a trackless underground mine, currently the largest zinc producer in Europe and rated fifth largest world-wide, with annual production scheduled at 2.3Mt. The development of gently dipping, vertically superimposed ore lenses necessitates complex mining methods. Consequently, detailed geological, planning and rock mechanics studies are required prior to finalization of mining schemes in order to optimize metal recovery, to maintain ground stability and to ensure that ore in vertically adjacent lenses is not rendered unmineable (Libby et al., 1985). In the area of thickest ore, mining methods include multiple topslice bench and fill (in vertical lifts of 15m) and drawpoint extraction in open stopes reaching 80m in height. Stopes are hydraulically backfilled with cemented tailings prior to pillar recovery. Pillars are mined by a variety of methods, including the use of large diameter blastholes, drilled from above the hanging-wall, with broken ore removed from original stope drawpoints. In areas of ore up to 20m thick, undercut open stoping is employed, with room and pillar extraction methods used for particularly thin layers (< 5m). Ore is transported to the surface, via a production shaft, prior to milling in a modern largely automated concentrator, from where concentrates are railed and shipped to several European smelters. The mine operates under strict environmental controls which involve close monitoring and control of blast vibrations, noise, dust and trace element levels in air, water, soil and vegetation.

Stratigraphy

Lower Palaeozoic rocks in the vicinity of the orebody (Fig. 2) consist of Ordovician siltstones, sandstones and mudstones, with intercalated tuffs and volcanic breccias of diverse composition, intruded by syenites and lamprophyres of probable late Caledonian age (Harper, 1952; Phillips et al., 1976; Romano, 1980; Morris, 1984).

The Lower Palaeozoic rocks are unconformably overlain by up to 45m of dark red interbedded polymict conglomerates and sandstones termed the Red Beds, which are of Lower Carboniferous age (MacDermot and Sevastopulo, 1972; Clayton and Higgs, 1978). These pass transitionally into a varied suite of rocks termed the Laminated Beds, which consist of dark laminated siltstones, mudstones and shales with local pale sandstones and calcarenites. These rocks are frequently bioturbated but are only weakly fossiliferous, containing rare layers of shell and crinoid debris. Plant fossils are present at some horizons. A thin (< 30cm) horizon of nodular chalcedonic silica containing rare gypsum, occurs within the Laminated Beds and is thought to be a replaced evaporite horizon (Gustafson, 1981). The upper part of the Laminated Beds is particularly variable and is characterized by local fine calcareous sandstones and dark mudstones. The overlying Muddy Limestone represents a rapid transition from periodically siliciclastic to dominantly carbonate sedimentation, and consists of generally dark, well bedded, argillaceous and crinoidal limestones with local, strongly bioclastic, coarser sections of microconglomeratic nature. Corals, particularly *Syringopora,* are common along some horizons. The Laminated Beds and Muddy Limestone are collectively known as the Mixed Beds in other parts of the east Midlands where the Muddy Limestone lithology is either absent or poorly developed (Philcox, 1984).

The Muddy Limestone passes through a variably thick transition zone, possibly of diachronous nature (Philcox, 1980), into the Pale Beds which comprise a varied suite of

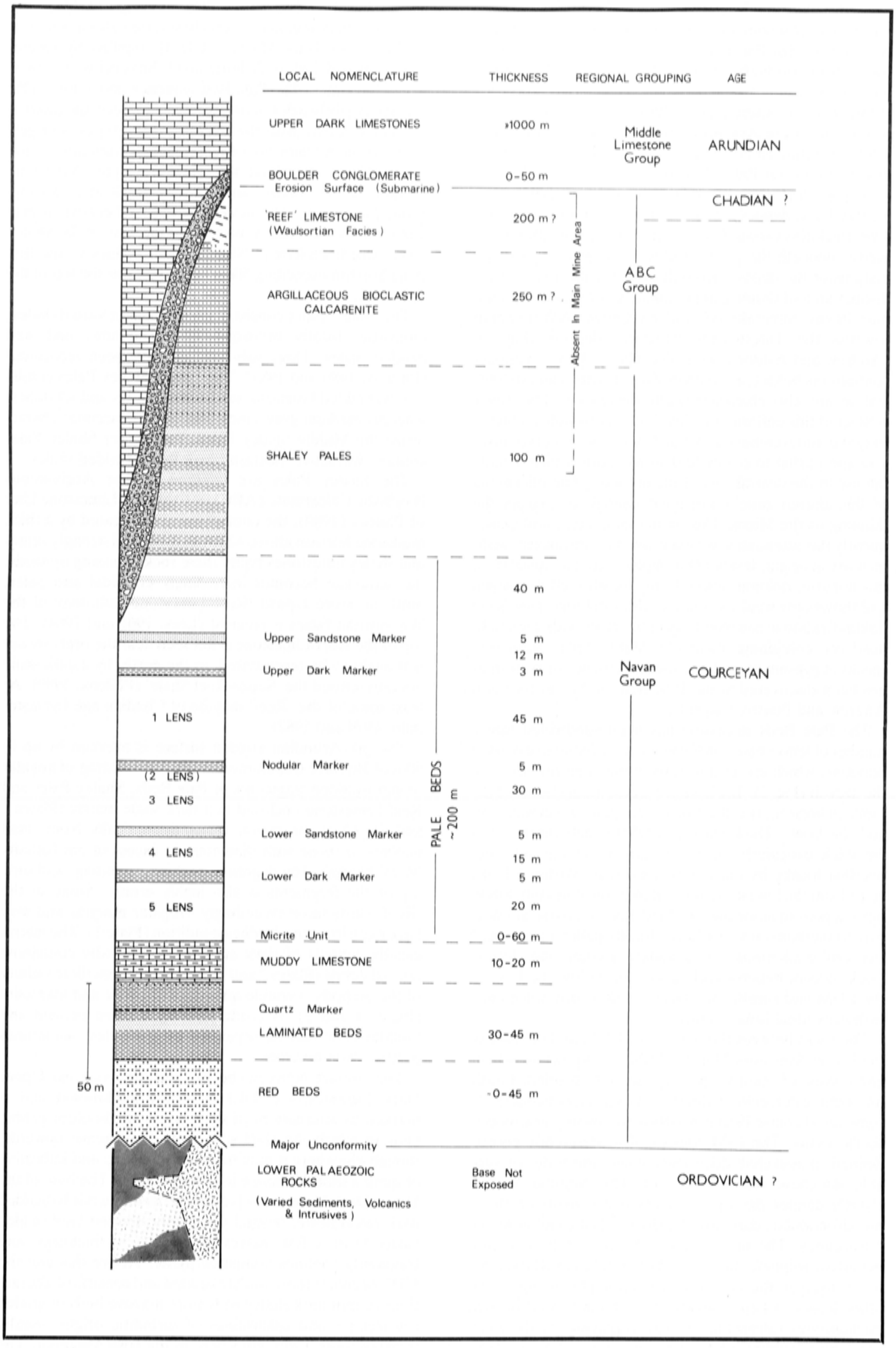

Figure 2. Diagrammatic representation of the Lower Carboniferous stratigraphy in the vicinity of the orebody.

pelletal, oolitic and bioclastic calcarenites, locally containing significant quantities of quartz sand and darker argillaceous layers. The Pale Beds, which constitute the main host rocks to the orebody, are over 200m thick at Navan but tend to be thinner in other parts of the east Midlands (Philcox, 1984; Andrew and Ashton, 1985). In the vicinity of the mine a pre-Arundian erosion surface (Sevastopulo, 1979) has removed large sections of the succession and lies directly on Lower Palaeozoic rocks to the south of Navan.

A pale fine-grained micritic limestone, termed the Micrite Unit, defines the base of the Pale Beds and shows large thickness variations in the mine area, from only a few metres beneath the thicker ore to over 60m towards the margins of the deposit. Isopach plots for this unit show a distinct area of thinning approximately coincident with the most intense mineralization and trending in a NW direction towards the Tatestown-Scallanstown deposit (Fig. 3) (Andrew and Ashton, 1985). The Micrite Unit commonly contains oncholites, and both birdseye textures and stylolitization are also characteristically developed. The upper contact of this unit with the Pale Beds calcarenites is highly irregular and is commonly defined by a zone of recrystallization and partial to complete dolomitization which is most intense in the central area of the orebody. The thickening of this altered zone is not great enough to explain the thinning of the Micrite Unit in the mine area, and consequently this attenuation is believed to be substantially sedimentary in origin. It should be emphasized that, apart from this horizon, dolomitization is only locally well developed and shows only weak correlation with sulphides. Low-level dolomitization is common in the Pale Beds with Tara millhead ore containing about 6% MgO. Apart from rare specks of gypsum no evidence for the presence of evaporites has been discovered in the Pale Beds at Navan (see also Andrew and Poustie, this vol.).

The Pale Beds succession has been subdivided into a number of lenses based on the position of distinctive marker horizons, which are used to classify the main ore layers in the deposit (Fig. 2). The lowest, 5-Lens, occurs between the footwall horizon, (i.e. the base of ore-grade mineralization) and the Lower Dark Marker (LDM) which consists of a 5m thick irregularly-laminated dark micaceous siltstone, overlain locally by calcareous sandstone. Within 5-Lens, apart from the lowest micritic material, the dominant lithology is a poor to moderately bedded, fine- to coarse-grained, pale to medium grey, bioclastic, locally pelletal and oolitic calcarenite/calcirudite. A subsidiary marker, the Bottom Dark, occurs impersistently about 8m below the base of the LDM and consists of 1 to 2m of dark silty calcarenite with occasional isolate corals.

The rocks between the base of the LDM and the base of the Lower Sandstone Marker (LSM) are known as 4-Lens and consist of medium grey, moderately bedded, locally quartzitic calcarenites exhibiting minor cross-bedding. In some areas coarse bioclastic debris comprising brachiopod shells occurs. The LSM consists of a, frequently poorly-defined, massively-bedded calcareous sandstone, of variable thickness and development. The Nodular Marker (NOD) defines the top of 3-Lens and consists of 5m of pseudo-nodular, dark silty, locally bioclastic and crinoidal calcarenites. The term 2-Lens is used to denote a thin, persistent sulphide band beneath the Nodular Marker but is not used in the same broad stratigraphic sense as the other lenses. 3-Lens consists of moderately well bedded medium-grey calcarenites, locally displaying poorly developed cross-bedding, sometimes containing dark silty horizons or coarser intraclast-bearing calcirudite layers. In 1-Lens, locally oolitic calcarenites, showing variable development of bedding, occur. This lens terminates at the base of the Upper Dark Marker (UDM), typified by several closely-spaced dark shale horizons (1-3m) enclosed by massive calcarenites. The Pale Bed sequence above the UDM becomes slightly paler, more massively-bedded and quartzitic, and together with the overlying rock types is largely absent from the mine area due to the pre-Arundian erosion event. About 12m above the UDM the Upper Sandstone Marker (USM) occurs and consists of clean massively-bedded sandstone. The succeeding material persists as pale quartzitic, oolitic, calcarenites up to the base of the Shaley Pales, which Philcox (1980 and 1984) defines as the first shale horizon exceeding 50cm in thickness at the top of the Pale Beds.

The Shaley Pales consist of about 100m of varied shaley, bioclastic, locally bryozoan-rich calcarenites and well bedded shales. Three sub-divisions have been recognised (Philcox, 1980 and 1984). The Lower Shaley Pales consist of interbedded bioclastic sandstones, shales and siltstones, whereas medium grey sandstones and calcarenites characterize the Middle Shaley Pales. The Upper Shaley Pales contain distinctive bioclastic dark thinly-bedded shales.

The Shaley Pales are overlain by the Argillaceous Bioclastic Calcarenite (ABC) or Crinoidal Limestone Unit of Philcox (1980), the contact being delineated by a thick mudstone horizon above which well-bedded strongly-crinoidal shaley limestones typify these rocks. Passing upwards, the sequence becomes increasingly crinoidal and paler, until the more typical 'Reef Limestone' lithology of the Waulsortian facies is reached (Lees, 1961 and 1964). The top of the Reef Limestone is not seen near the orebody but is thought to be represented, to the north, by a dark shale horizon termed the 'Supra-Reef Shale' (Philcox, 1980). At least some of the 'Reef' may be of Chadian age (Sevastopulo, 1979 and 1982).

The pre-Arundian erosion surface is overlain by up to 50m of Boulder Conglomerate (BC), consisting of angular to sub-rounded fragments of Pale Beds, Shaley Pales and Reef Limestone enclosed in a dark shale matrix (Plates 1 and 2). Clast dimension varies dramatically from small pebbles to those with diameters in excess of 5m (usually 'Reef' blocks). The degree of packing, rounding, and sorting of the fragments is also highly erratic. Some of the 'Reef' clasts have exceedingly irregular margins and may have been in a semi-lithified condition (Plate 1). The matrix usually consists of dark argillite, occasionally containing crinoid debris (Plates 2 and 3), and in the immediate vicinity of the orebody, variable quantities of pyrite and marcasite (Plates 4 and 5). A crude layering is often present and boulder beds may be separated by laminated, sometimes pyritic, shale horizons.

The contact between the BC and the overlying Upper Dark Limestones (UDL) is locally gradational and is marked by alternations of shale layers and boulder-pebble beds in which the clast size tends to decrease upwards, though elsewhere it may be relatively sharp and indicative of quite a sudden change in sedimentation. The base of the Upper Dark Limestones is characterized by a thinly-bedded dark calcargillite, termed the Thinly Bedded Unit, which varies from a few metres up to 20m in thickness, and frequently contains laminated pyrite. Above this unit the UDL becomes more thickly bedded and consists of alternations of thin dark shales with more massive beds of graded calcarenites and calcirudites of turbiditic origin, usually referred to as 'Calp' elsewhere in the Irish Midlands. The top of the UDL has not been intersected in the Navan area.

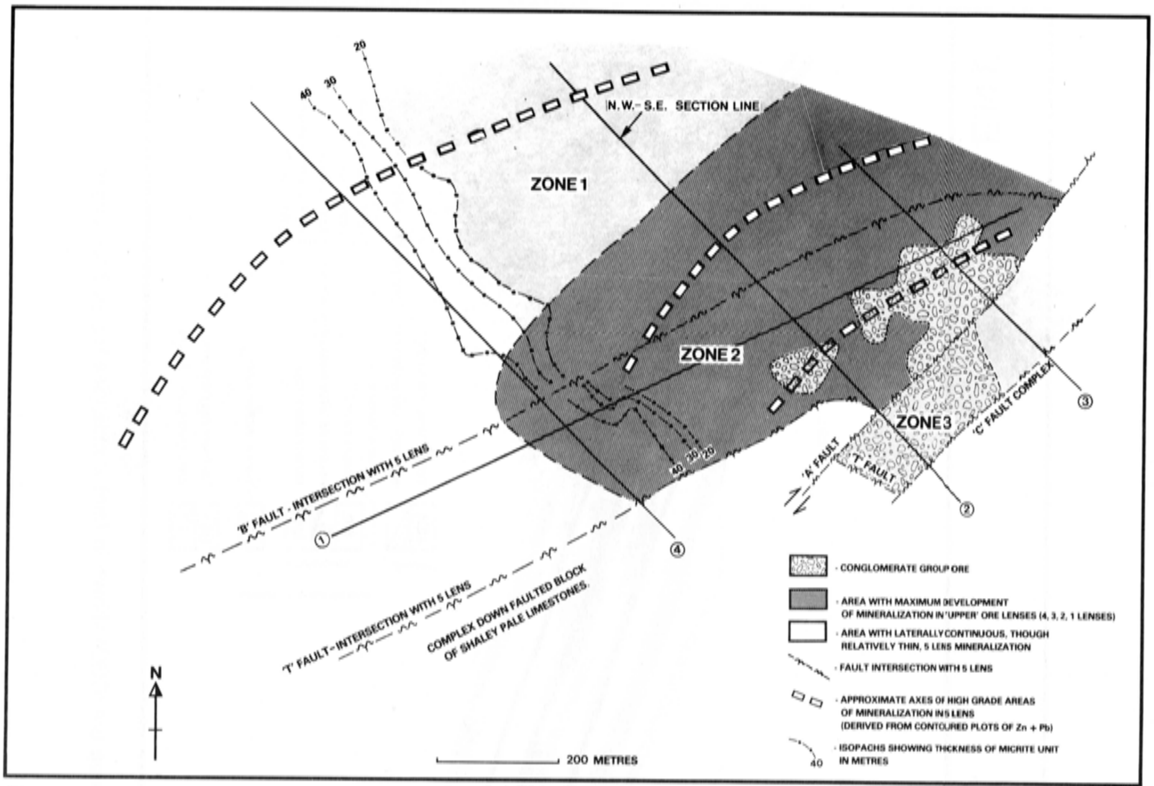

Figure 3. Summary plan showing location of Zones 1, 2 and 3, extent of Pale Beds and Conglomerate Group ore, location of high grade mineralized belts in 5-Lens and location of section lines.

Structure

The Navan orebody occurs on the NW flank of a complex anticlinal structure which delineates the SW margin of the Longford-Down Lower Palaeozoic inlier (Fig. 1). This structure plunges gently SW and is severely dislocated by a major NE-trending fault system, termed the 'A-C-D' Fault Complex. (Figs. 1 and 3). Although this Fault Complex has clear post-ore movement of presumed Hercynian age, the NE elongation of a pre-Carboniferous syenite intrusion and, to the east, the broad separation of Silurian from Ordovician successions by the so called 'Navan Fault' (Romano, 1980) suggest that the Fault Complex was active during pre-Carboniferous times. Furthermore, Phillips et al., (1976) consider that this faulting represents the former position of a major Caledonian plate collision zone, termed the Iapetus Suture, separating differing structural and faunal regimes (e.g. Anderton et al., 1979). However, aeromagnetic data and recent drilling suggests that the main basement dislocation may lie to the north of the deposit, possibly below the position of the Liscarton Fault (Fig. 1).

The Carboniferous succession at the mine generally dips at angles of around 20° to the SW (Fig. 4), and folding in the pre-Arundian rocks is either absent or characterized by low-amplitude gentle structures orientated parallel to the major faults (ie. ENE and NE). A large variety of fractures with variable attitudes and displacements are developed, and five major sets can be recognized:

(i) Mineralized fractures with little throw, striking between NNE and E, and usually displaying steep dips, frequently southwards. They are most common in the Pale Beds but also occur in the Laminated Beds and Muddy Limestone. These fractures are of earlier age than the larger structures described below, and are interpreted as the initial structural response of the Lower Carboniferous rocks to reactivation of a major underlying Lower Palaeozoic fault system (Andrew and Ashton, 1982 and 1985). They frequently display evidence of later reactivation in the form of oblique or strike-slip post-sulphide shears (Plate 6).

(ii) ENE-striking faults with moderate to steep dips (40-70°) to the south (Figs. 1, 3, 5, 6 and 7). These include the 'B'and 'T' Faults in addition to other smaller structures. The 'B' Fault displaces Micrite Unit isopachs (Fig. 3) normally, and downthrows southwards by 60m, increasing to 80m in the western part of the deposit. The 'T' Fault is a larger structure and downthrows Shaley Pales against Pale Beds with a throw of around 200m. These faults are sub-parallel and exhibit a listric profile with curvature of adjacent beds indicative of growth faulting (eg. Jackson and McKenzie, 1983). They are regarded as normal faults developed in an extensional regime. However, both structures display a clockwise rotation at their eastern ends on approaching the 'A' Fault, and minor structures suggest a wrench (dextral) component of movement (Phillips et al., 1983). Hence it is conceivable that they formed in response to localized extension resulting from regional right lateral wrench movements, influenced by curvature of the main basement structures in this area and/or deflection against the Navan syenite (Sevastopulo and Phillips, this vol.).

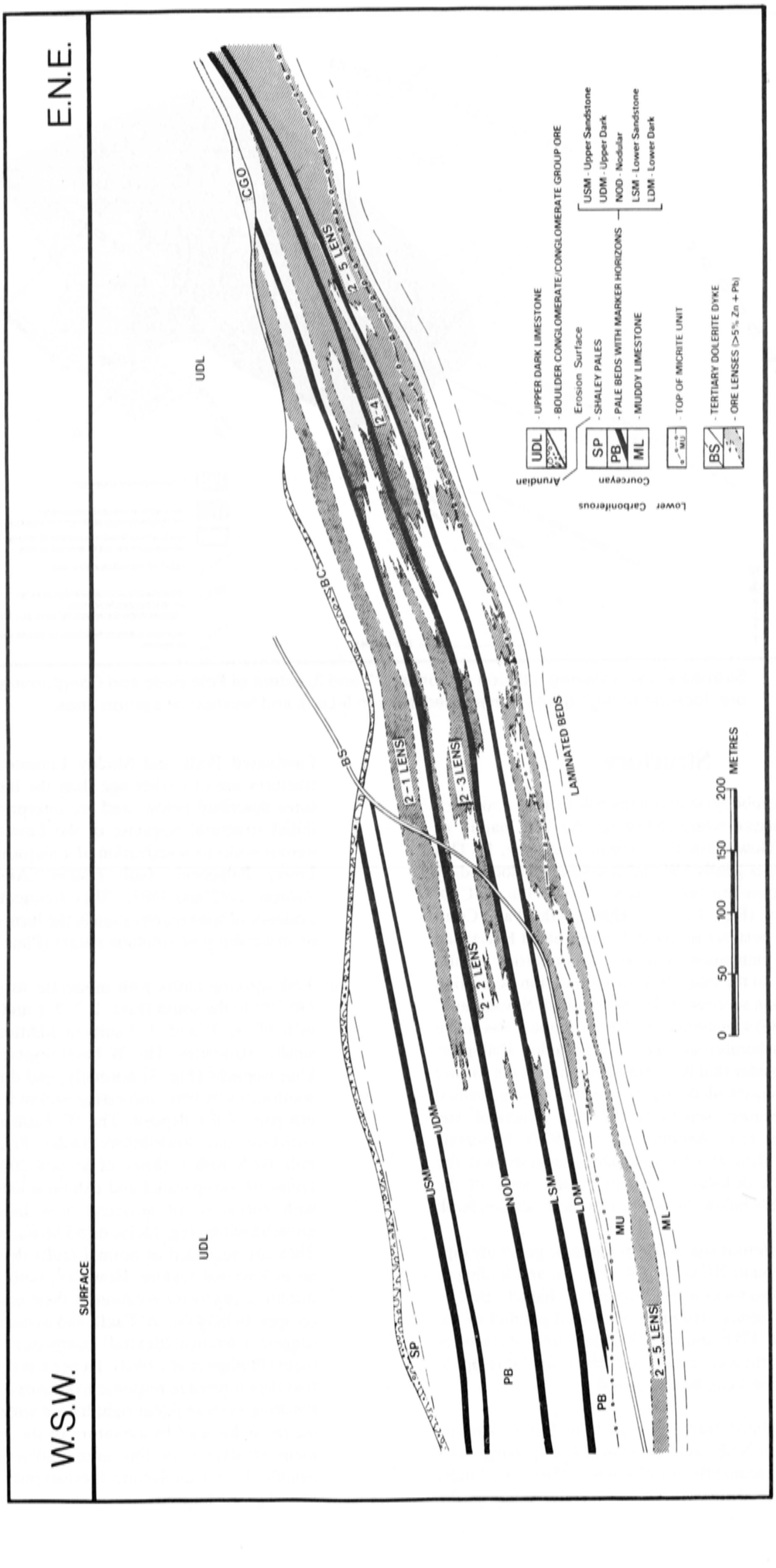

Figure 4. Section line 1. ENE-WSW dip section through Zone 2, Conglomerate Group ore (CGO) shown in faint stipple. See Figure 3 for location.

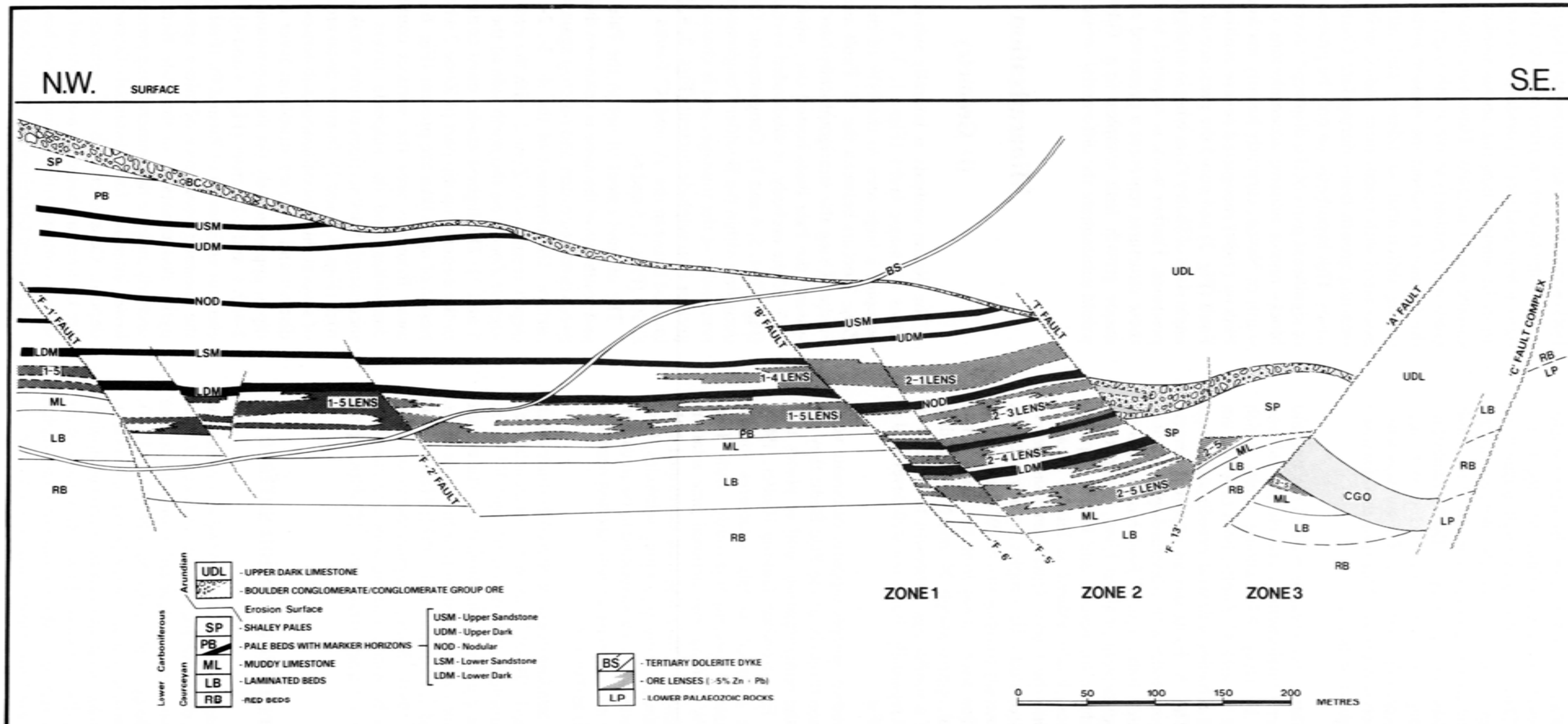

Figure 5. Section line 2. NW-SE strike section through central part of the deposit showing the location of Zones and Lenses. See Figure 3 for location.

The 'T' Fault shows clear reactivation in that it locally displaces the base of the Boulder Conglomerate by over 50m and continues into the overlying Upper Dark Limestones as a tight gouge-filled shear (Figs. 5 and 7). The BC thickens in the central mine area immediately south of the Fault and the base of the Upper Dark Limestone becomes conglomeratic in this area (Fig. 5). Consequently it is considered that the 'T' Fault was active during the erosion event. (This is further discussed in a subsequent section.)

(iii) The preceding structures, as well as the ore and the Boulder Conglomerate, are clearly cut and dislocated by steep NE-trending faults which include the 'A' and 'C' Faults, both of which are interpreted as having a dextral wrench component (Fig. 3). The 'A' Fault has an apparent reverse throw of around 60m with a dextral displacement of approximately 100m. The 'C' Fault has an apparent normal displacement of about 150m, though there is also evidence for reverse and lateral displacements. These Faults extend as intense areas of shearing into the Upper Dark Limestone where they are associated with complex, locally isoclinal, folding, generally trending in a NNW direction and becoming less intense away from the Faults (Plate 7). Sinistral, approximately N- and NW- trending faulting of a similar age is present to the east of Navan and regionally, but is not well developed at the mine (Fig. 1).

(iv) NNW-trending, steeply dipping, carbonate veins are common throughout the Pale Beds; they clearly cut the mineralization, and in places they cross the ENE-trending faulting (Coller, 1984). They are regarded as late structures formed approximately contemporaneously with Hercynian NW faulting, but detailed time relations are ambiguous. Other less well developed NW-trending faults, some containing sulphides, have been recorded, but are suspected to be an earlier, relatively minor, phase of deformation occurring around (i) and/or (ii).

(v) Northerly trending dykes of altered Tertiary dolerite, (termed "Basalt" in mine nomenclature), display variable dips between 10° and 70° to the W, cut the previously mentioned structures, and cause minor contact metamorphism of ore (Figs. 4, 5, 6 and 7) (Turner et al., 1972; Halliday and Mitchell, 1983). Minor displacements of these dykes have been noted at the mine and elsewhere along pre-existing structures, (Phillips, pers. comm.).

The nature of the erosion surface

The Boulder Conglomerate is interpreted as a submarine debris-flow which, due to the inclusion of a variety of older Carboniferous clasts, may be regarded as an olistostrome (Reading, 1978; Boyce et al., 1983; Scholle et al., 1983). The origin of the erosion surface itself however is less clear. A sub-aerial origin has been invoked by several geologists, including Philcox (1980 and 1984), primarily because of the absence of a thick section of the Courceyan stratigraphy, more than 800m south of Navan, where UDL rests on Lower Palaeozoic rocks. An alternative view (Boyce et al., 1983) is that the surface represents a large submarine slump-scar, on the basis of a marine origin for the BC and because there is little evidence for oxidation or karstification. Derivation by simple slumping seems unlikely as the erosion surface is quite irregular. However, since the 'T' and similar faults were probably active at this stage, it is suggested that the feature is a submarine erosion surface resulting from strong differential subsidence and attendant slumping, associated with reactivation and/or development of ENE trending growth faults during late Courceyan to Chadian times. This hypothesis can only be proved by the discovery of significant parts of the displaced succession as low angle blocks and/or massive accumulations of BC in the area south of Navan, currently heavily masked by thick UDL. Philcox (1980) recognized severe faulting south of the 'T' Fault (Fig. 3) and noted the presence of several large low-angle slabs of Shaley Pales lying in stratigraphically inverted positions. Further work is required to establish whether these structures represent a preserved root/sole zone of a major growth fault complex (e.g. Gibbs, 1984), which would substantiate the differential subsidence model.

Mineralization

(i) Geometry

The Navan orebody is laterally sub-divided into three zones by major faults (Figs. 1, 3, 5, 6 and 7). Zone 1 occupies a large area to the NW of the 'B' Fault, while Zone 2 occurs between the 'B' Fault and the 'T' and 'A' Faults. Using the stratigraphically-based lens numbering system, the Pale Beds-hosted ore, which comprises over 97% of the orebody, is subdivided vertically into 5 lenses (Figs. 2, 4, 5, 6 and 7). Conglomerate Group ore (CGO), occurring within the Boulder Conglomerate, makes up the remainder of the tonnage, and is characterized by a much greater iron sulphide content (Figs. 3, 4, 5 and 6). Zone 3, located between the 'A' and 'C' Faults, mostly consists of CGO (Figs. 3, 5 and 6).

The original extent of ore in the Pale Beds to the east and southeast of the mine is unknown due to truncation by pre-Arundian erosion and outcrop against the present land surface. Development of the 4-, 3-, 2-, and 1-Lenses is largely restricted to Zone 2, with the exception of a narrow area in Zone 1 on the north side of the 'B' Fault (Figs. 3, 5 and 7). The highest grade, most continuous ore occurs in the eastern, up-dip part of Zone 2 where vertical thicknesses of up to 80m are present (Fig. 6). Passing laterally away from this area the vertical continuity of the ore diminishes, and the sulphide layers are separated by increasingly thick sections of more weakly mineralized host rock (Figs. 4, 5 and 7). In more distal areas the ore consists of several thin discontinuous sub-lenses. 2-1 Lens forms a distinct and separate stratiform layer and dies-off down dip at approximately the same position as the underlying 2-4, 2-3, and 2-2 Lenses (Figs. 3 and 4). Widespread trace element enrichment of Zn and Pb (Finlay et al., 1984) and the common occurrence of minor sphalerite, galena and pyrite disseminations in the Pale Beds surrounding the orebody indicate that mineralizing processes continued, at lower intensity, for substantial distances away from the deposit. Consequently it is emphasized that interpreted ore outlines are based on assay cut-off and are not usually simple contacts with unmineralized host rock.

Maximum lateral development of ore occurs in 5 Lens in

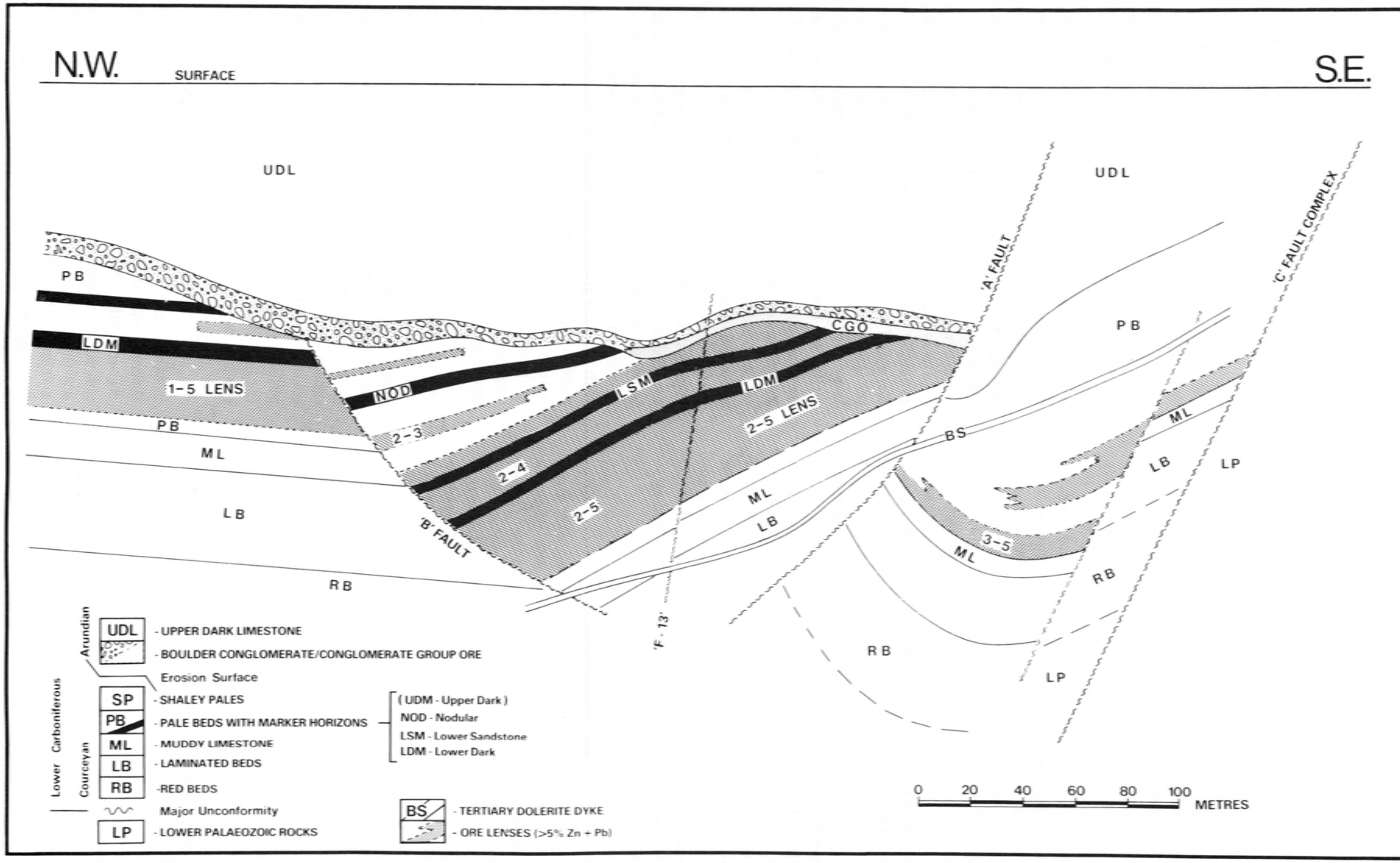

Figure 6. Section line 3. NW-SE strike section through the eastern, up-dip part of the orebody showing thick development of ore in Zone 2. See Figure 3 for location.

or immediately above the Micrite Unit, and the westwards down-dip termination of this mineralization has not yet been delineated (Figs. 1 and 3). To the north, ore grade mineralization becomes impersistent and finally absent at this horizon, but near the Liscarton and Tatestown — Scallanstown Faults small tonnages have been defined by neighbouring prospecting licence holders (Fig. 1) (Andrew and Poustie, this vol.). To the south, ore-grade mineralization (0.34Mt at 7% Zn+Pb) has been discovered at Clogherboy, again mostly at this stratigraphic horizon (Tara Mines Ltd, unpublished data) (Fig. 1). The Micrite Unit exhibits weak mineralization on a regional basis with further significant Zn-Pb concentrations at Oldcastle, Clonabreany, Sion Hill, Moyvoughly and Ballinalack. (Brand and Emo; Poustie and Kucha; Jones and Brand; all this vol.).

The Conglomerate Group ore is located immediately above and down-slope on the erosion surface from the truncated Pale Beds mineralization and hence tends to occur where the Lower Carboniferous succession has been deeply incised in the up-dip part of Zone 2 and in Zone 3 (Figs. 3, 4, 5 and 6). Virtually no mineralization has been seen in the Upper Dark Limestones above the orebody, though minor sphalerite has been noted in carbonate veins in other parts of the area, and chalcopyrite/carbonate veins were mined on a small scale in the 19th century at Beauparc, Brownstown and Walterstown a few kilometres east of Navan.

Ore-grade mineralization has been locally intersected in the upper Pale Beds above the UDM and within the Shaley Pales. In addition minor fracture-fill style mineralization is present within the Muddy Limestone and Laminated Beds. Rare disseminated chalcopyrite occurs within the Red Beds and within the syenite intrusives, together with minor barite, galena, sphalerite and specularite. Minor disseminations and veinlets of galena, chalcopyrite and sphalerite have also been noted in Ordovician(?) siltstones and greywackes beneath the orebody.

(ii) Mineralogy

Fine grained, pale brown-yellow sphalerite with lesser galena comprise the chief minerals with iron sulphides locally becoming the dominant phase within the Conglomerate Group ore and in localized parts of the Pale Beds. Barite and carbonates make up the chief gangue minerals. Microscopic quantities of semseyite, bournonite, freibergite, pyrargyrite (Steed, 1981), boulangerite and cylindrite (Andrew, pers. comm.) have been identified in the ore and single grains of frankeite, argyrodite (Halls, Russell, pers. comm.) and jordanite (Boast, 1978) have been reported.

(iii) Ore textures

The Pale Beds ore is defined as stratiform lens-shaped layers from sectional interpretation of diamond drill data. When examined underground the ore outlines vary from simple sharp stratiform contacts, to highly irregular or diffuse boundaries (Plates 8, 9 and 10). These complex outlines indicate that ore emplacement involved several differing processes, as does the very large range in textures, which can broadly be subdivided into bedding-parallel and cross-cutting styles. The relation between the two types is best displayed in areas where mineralization is not pervasive, since in high grade areas the two styles are difficult to distinguish in complex layers of massive sulphides.

Bedding-parallel styles

The simplest fabric consists of locally well-laminated layers of fine-grained pale brownish-yellow sphalerite, inter-layered with smaller quantities of usually slightly coarser galena and, occasionally in 5-Lens, thin bands of white barite (Plate 11). These layers display evidence of strong disruption in the form of contortions and pull-apart structures with dislocation and rotation of broken fragments. The upper contacts of these layers with the host rock are frequently sharp breaks, or are marked by a gradual decrease in the proportion of fine-grained sphalerite into the host rock, with no evidence of cavity-top textures (Plates 8, 9, 10 and 11). Locally, pull-apart structures are developed where simple bands of fine sphalerite have been dislocated and are surrounded by homogeneous calcarenites (Plates 12 and 13). The combination of well-developed laminated sulphides with soft-sediment deformation is interpreted as evidence for deformation of synsedimentary sulphide layers and/or selective replacement of unlithified sediments. More detailed definition of the mechanism of emplacement of these layers awaits comprehensive thin section petrography. To date, no evidence for the presence of precursor material amenable to selective replacement by sulphides, such as evaporite, has been found.

Particularly complex relations occur in the lowest part of 5-Lens in brecciated micrites where locally undolomitized, generally boulder-sized clasts are enclosed in a matrix of disrupted layered sulphides and/or barite with dark argillites and minor marcasite (Plates 14 and 15). Due to their large lateral extent, relative uniformity and absence of cavity-top textures they could be mineralized sedimentary breccias possibly resulting from development of irregular palaeotopography.

The widespread development of disruption textures has obscured original fabrics, and fragments of earlier sulphides are commonly enclosed by microcrystalline sphalerite rhythmites, with lesser galena, indicating that several episodes of disruption and sulphide crystallization occurred. The location of former cavities is marked by patches of coarse-grained white barite and carbonate, sometimes rimmed with medium-grained pale yellow 'honeyblende'. Bedding-parallel veins are developed beneath dominant bedding units such as the LDM, and are characterized by an infill of barite/carbonate, but more significantly by stalactitic sulphide growths composed of variable quantities of pyrite/marcasite, sphalerite and galena (Plates 16, 17a and 17b). These features are approximately perpendicular to bedding and were therefore formed before the tilting of the Pale Beds. They are interpreted as solution overgrowths of gravity controlled crystalline growth structures in hydraulically dilated cavities (I. K. Anderson, pers. comm.). The floors of the cavities locally display laminated internal sediments containing sphalerite (Plates 17a and 17b). Some cavity-fill textures are suspected in sulphide bands showing pull-apart textures in otherwise homogeneous Pale Beds (i.e. not internal sediments) and these must have formed prior to host rock lithification (Plate 13).

Cross-cutting styles

Mineralization crossing the stratification occurs in discrete veins and breccia zones which predominantly strike NE to ENE. The smaller structures contain fine-grained sphalerite, normally with subordinate amounts of galena and pyrite. They locally display strongly contorted outlines, and are bordered by disseminations of fine-grained sphalerite, suggesting that they formed prior to complete lithification and compaction (Plate 18). The larger veins frequently display banding of fine-grained sulphides and are locally filled with coarser grained crustified layers of galena and

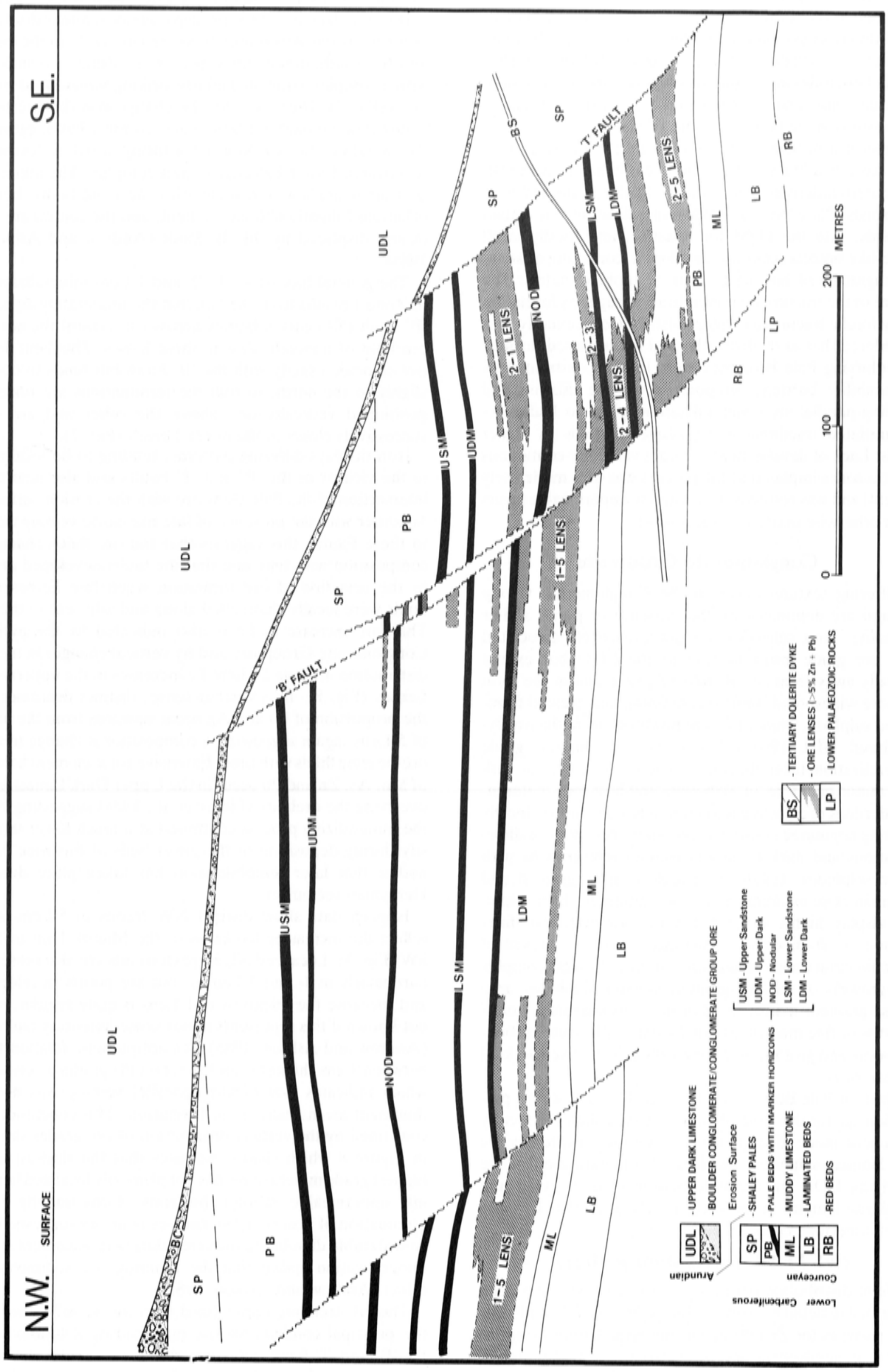

Figure 7. Section line 4. NW-SE strike section through the southwestern, down dip part of orebody. See Figure 3 for location.

finer sphalerite (Plates 19 and 20). Post-sulphide shearing is frequently present (Plate 6). Some veins, particularly those containing pyrite or marcasite, post-date nearby bedding-parallel sulphides but, more commonly, cross-cutting sulphides pass without obvious disruption into bedding parallel layers (Plate 16). Increased thicknesses of bedding-parallel sulphides are frequently observed above, even thin, sulphide veins, and sometimes take the form of irregular depressions in the base of the ore (Plate 8).

Impermeable beds acted as local traps for the mineralization, since bedding-parallel veins occur beneath them with associated underlying cross-cutting 'feeder' veins and fracture zones (Plate 16). Vein-style mineralization may extend upwards, into the LDM for instance, and locally small flame-like breccia zones are developed, consisting of angular fragments of host rock set in a sulphide matrix. The nature of the fracture-fill mineralization suggests formation by hydraulic fracturing (Phillips, 1971). Consequently, it is considered that as the hydrothermal fluids passed through the lithifying Pale Beds they were locally constrained by permeability barriers, temporarily causing dilation and bedding-parallel style mineralization, prior to hydraulically-initiated fracturing and passage of fluids to higher levels. Lack of development of large, vertically-continuous breccia zones implies that the process was only moderately forceful and was restricted to relatively impermeable layers in an otherwise permeable succession.

Conglomerate Group ore

Differing textures occur in the Conglomerate Group ore and are dominated by the presence of pyrite and/or marcasite. Iron sulphides are not exclusively associated with ore grade mineralization in the CGO but extend laterally away from ore as massive pyrite and in the form of more widespread laminae containing fine-grained framboidal sulphide, which also commonly occurs in the overlying basal UDL (Plates 4 and 5). The highest grade mineralization takes the form of massive sulphides with only minor quantities of carbonate and host rock material. Sphalerite is present as irregular patches and layers, locally showing laminated fabrics but elsewhere occurring as disseminations and darker, slightly coarser intergrowths with other sulphides. Galena is usually coarser grained and occurs in close association with the sphalerite. Iron sulphides display highly variable textures varying from fine-grained framboidal laminae of presumed synsedimentary/early diagenetic origin, through complex intergrowths of medium-grained massive sulphides, into coarse-grained marcasite. Locally, even-grained intergrowths of fine/medium-grained pyrite with white carbonate occur and give rise to a rock with a distinctive speckled appearance.

Clasts of Pale Beds ore occur in the BC indicating a pre-erosion age for this mineralization. A synsedimentary/early diagenetic mode of origin for the CGO is indicated by the fine laminar sulphides, the lack of mineralization in the overlying UDL and the deformation of both pyrite and sphalerite laminae in the shale matrix of the BC by large 'Reef' limestone clasts (Plates 1 and 3).

(iv) Metal distribution patterns

Metal distribution patterns for the orebody have been described in detail by Andrew and Ashton (1982 and 1985). The patterns for Zn+Pb define the large lateral extent of 5-Lens mineralization and the relatively restricted extent of the 4-, 3-, 2-, and 1-Lens ore layers, these being largely localized between the 'B' and 'T' Faults (Fig. 3). Within all Lenses there is a strong trend for metal enrichment along elongate irregular areas trending in a NE direction with subordinate ENE trends developing towards the eastern part of the deposit. Three principal areas of mineralization occur in 5-Lens which tend to swing clockwise to the east, and the southernmost area, present in Zone 2, coincides with a complex array of similarly striking mineralized fractures (Fig. 3). The reason for this change in strike direction is not clear, though Phillips (pers. comm.) has suggested that it relates to extensional fracturing above a dextrally reactivated Lower Palaeozoic fault complex. The mineralized areas are not coincident with the main faults, being orientated slightly oblique to them, and the central area is clearly displaced by the 'B' Fault (Andrew and Ashton, 1985).

The general lack of 4-, 3-, 2- and 1-Lens mineralization in Zone 1 results from the fact that the moderately dipping 'B' Fault (50°) cuts obliquely across (in section) the northern limit of mineralization in these lenses. This limit does not coincide exactly with the 'B' Fault but tends to occur slighly to the north, so that the terminations are roughly positioned vertically one above the other and are cut successively closer in the upper Lenses (Fig. 7).

Iron displays differing patterns, tending to be localized to the vicinity of the 'B' and 'T' Faults and also near the intersection of the Pale Beds ore with the erosion surface. Together with the presence of late marcasite veining close to these Faults, this suggests that the ore fluids changed composition with time and that the faults developed prior to the cessation of ore formation when late Fe-bearing fluids were locally channelled along and adjacent to them. This late increase in Fe is also indicated by the pyritic Conglomerate Group ore and by vertical changes in metal distribution in Zone 2 where Fe increases in the uppermost Lenses (Fig. 8). In a vertical sense, distinct decreases in the proportion of Pb and Ag occur upwards from the base of 5-Lens, again suggesting a compositional change in the ore-bearing fluids with time. Extensive trace element haloes of Mn, As, Zn and Pb occur in the Upper Dark Limestones overlying the orebody (Finlay et al., 1984) suggesting that the mineralizing process continued at a much lower intensity during deposition of the lower beds of this rock type and/or that later remobilization has taken place during Hercynian tectonism.

Isopach data show distinct NW trends in 5-Lens and reflect the increasing thickness of the Micrite Unit to the SW (Fig. 3). Localized NE isopach trends are also present, particularly in 4- and 3-Lenses, but are poorly developed and, because the thickness of 1-Lens is quite regular, it is not known if this represents minor synsedimentary faulting (Andrew and Ashton, 1985). An antipathetic relationship between Lens thickness and the Zn+Pb grades is evident which indicates that bedding-parallel veining was not a dominant mechanism in ore formation. This conclusion is confirmed by the vertical distribution of ore grades shown in Figure 8 which clearly indicates that the thickest and highest grade mineralization is not primarily localized beneath impermeable marker horizons. Consequently this attenuation of host rock thicknesses near ore suggests that considerable dissolution occurred during replacement style mineralization and/or that the thinning is a sedimentary effect (Andrew and Ashton, 1985).

The NE-trending mineralized fractures clearly acted as the principal conduits for the mineralizing solutions and the 'B' and 'T' Faults are somewhat later structures which were initiated during the period that the mineralizing fluids became enriched in Fe. The only approximate correlation

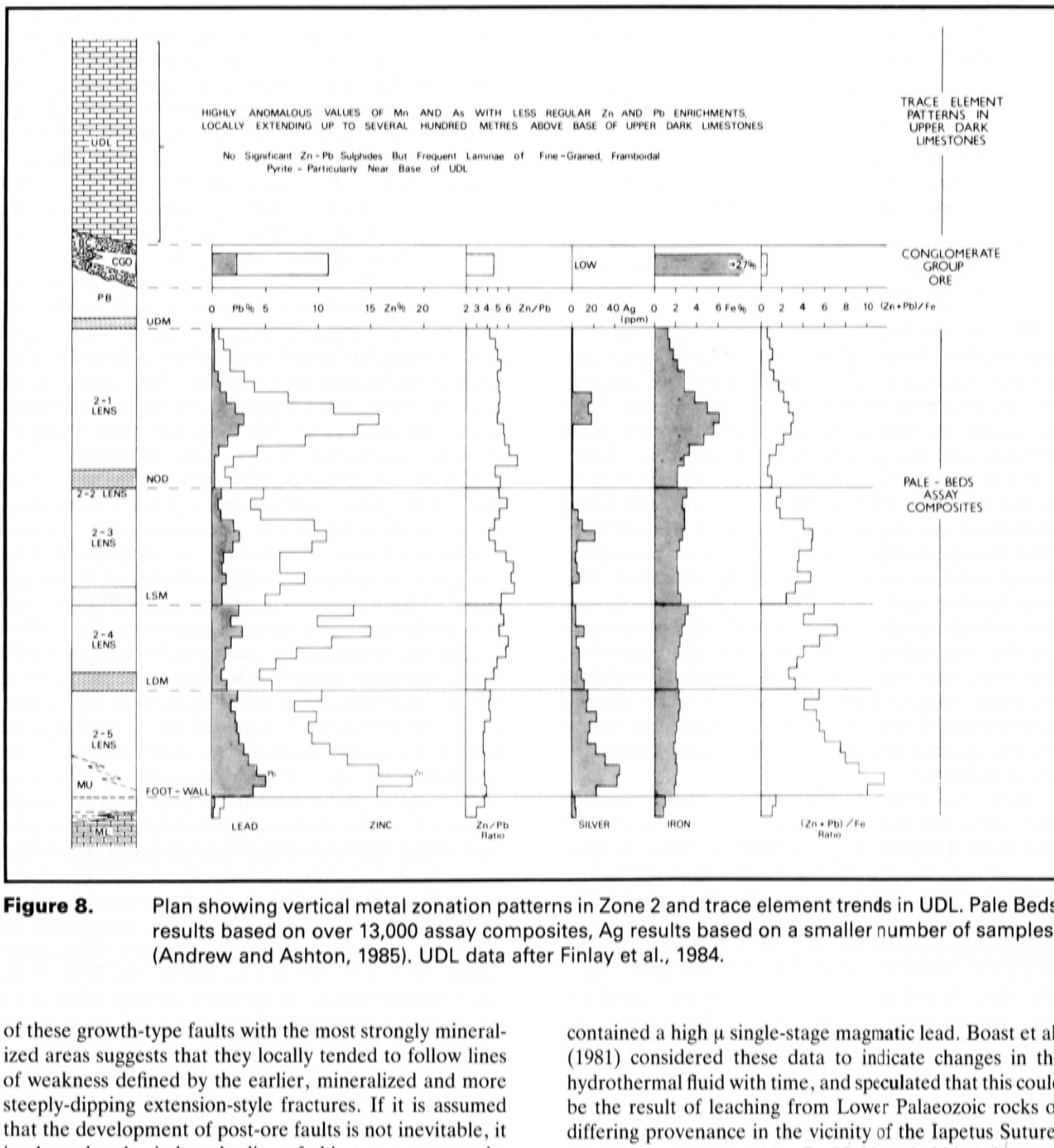

Figure 8. Plan showing vertical metal zonation patterns in Zone 2 and trace element trends in UDL. Pale Beds results based on over 13,000 assay composites, Ag results based on a smaller number of samples. (Andrew and Ashton, 1985). UDL data after Finlay et al., 1984.

of these growth-type faults with the most strongly mineralized areas suggests that they locally tended to follow lines of weakness defined by the earlier, mineralized and more steeply-dipping extension-style fractures. If it is assumed that the development of post-ore faults is not inevitable, it is clear that buried orebodies of this type may not be marked by major faulting in cover rocks (Andrew and Ashton, 1985).

(v) Isotope data

No comprehensive study of the isotopic composition of the Navan ore has yet been undertaken although a few results, based on very sparse sample data, are available. Boast (1978) reported sulphur isotope results of $\delta^{34}S$ = +19.63 to +22.56‰ in barite, compatible with Carboniferous sea-water sulphate and values of +2.93 to −23.75‰ for sulphides. Caulfield et al. (this vol.) quote $\delta^{34}S$ values for two galenas of +8.92 and −11.93‰ and conclude, on the basis that Tatestown sulphur isotopes display heavy values, that sulphur was partly derived from a basement source and partly from the host sediments by biogenic reduction of sea-water sulphate and, possibly, evaporites.

Boast (1978) investigated the Pb isotope content of the ore and concluded that the 5-Lens galena contained radiogenically anomalous Pb whereas that from the upper Lenses contained a high μ single-stage magmatic lead. Boast et al. (1981) considered these data to indicate changes in the hydrothermal fluid with time, and speculated that this could be the result of leaching from Lower Palaeozoic rocks of differing provenance in the vicinity of the Iapetus Suture, a conclusion supported by Caulfield et al. (this vol.).

Genetic synthesis

The early age of mineralization at Navan is indicated by the lack of Zn-Pb sulphides in the Upper Dark Limestone. The presence of synsedimentary pyrite layers in the basal UDL also indicates pre-Arundian emplacement of the Conglomerate Group ore. Numerous lines of evidence suggest that the Pale Beds ore largely formed prior to this event. These include:

(i) The gross difference in nature, particularly Fe content, between Pale Beds- and Conglomerate-hosted mineralization.

(ii) The presence of clasts of Pale Beds ore within the BC and deformation of layered sulphides in the BC by large blocks of 'Reef'.

(iii) The presence of sedimentary laminations and soft sediment deformation fabrics in Pale Beds-hosted sulphides.

(iv) Late pyrite-rich mineralization cross-cutting Pale Beds sulphides, particularly in 2-1 Lens and near the 'T' Fault.

(v) Displacement of the ore lenses by the largely pre-erosion 'B' and 'T' Faults.

(vi) The pre-tilting age of sulphide stalactites in bedding-parallel veins, themselves thought to be relatively late in the ore forming sequence.

(vii) A K/Ar age of 366 ± 11 Ma which has been reported for a sample of ore from 2-1 Lens. (Halliday and Mitchell, 1983).

Thus it seems clear that mineralization in the Pale Beds could not have formed below sediment depths greater than around 700m, and a significant proportion of this is thought to have formed at substantially shallower depths. More specifically, ore textures strongly suggest that some of the mineralization occurred contemporaneously with sedimentation and continued as shallow subsurface replacements of soft sediments. Further mineralization occurred during lithification and diagenesis as a result of channelling of fluids along permeable layers and upwards along numerous, though generally small, fractures in the Pale Beds. This stage involved hydraulic brecciation, dilation and dissolution with subsequent formation of cavity fill, and replacement-style mineralization. The mineralization appears to have been a semi-continuous event, the hydrothermal fluids becoming enriched in Fe with time and finally exhaling from unroofed Pale Beds to form the Conglomerate Group ore during early Carboniferous faulting, erosion and differential subsidence.

The source of the mineralizing fluids is unknown; however, derivation from Lower Palaeozoic rocks is favoured due to the shallow depth to basement (c. 100m), the presence of vein mineralization in the Muddy Limestone — Laminated Beds, and the isotope data (Boast et al., 1981; Caulfield et al., this vol.). Bischoff et al. (1981) have demonstrated how the metals could have been leached by brines from these basement rocks and it should be noted that since these locally contain pyrite, sulphur could also have been derived from this source. Furthermore, the intersection of NE and ENE faulting (possibly also the NW lineament defined by Micrite Unit isopachs) with the Lower Palaeozoic syenite intrusion provides an obvious locus of enhanced permeability cross-cutting the basement which could have channelled fluids from below (Evans and Maroof, 1976). Russell (this vol.) has argued for a Lower Carboniferous sea-water source for the ore-forming brines which would have circulated through the basement by convective mechanisms and the concept of the Navan syenite acting as localized control on the site of upwelling would clearly fit this model (see also Russell, 1978 and 1983; Russell et al., 1981). Alternatively, the hydrothermal fluids would need to be modified formational water (Badham, 1981) and/or metamorphically-derived solutions retained in the Lower Palaeozoic rocks and released during the extensional movements involved in early Carboniferous faulting.

The principal criticism of the synsedimentary-syndiagenetic model is the lack of evidence for oxidation of sulphides forming in and above shallow-water sediments. Muir (1983) has argued that since reducing conditions exist just beneath the surface of shallow water sediments, sulphides in the northern Australian sediment-hosted deposits grew and persisted in such environments. The large volumes of fluid required to form the Navan deposit must have escaped on to the sea floor and would have caused local changes in the prevailing redox conditions, especially in an area with irregular topography such as the top of the Micrite Unit, conditions that were sufficient to precipitate and preserve sulphides. Kucha and Wieczorek (1984) have suggested, on the basis of studies of carbonate grains in the Micrite Unit, that the sulphides at Navan are the result of massive sulphidization of Zn-bearing dolomite. We believe that insufficient evidence has been presented to support this hypothesis, and no significant unreplaced Zn carbonates have been found by Tara metallurgists.

A less plausible genetic model is one where ore formation was also early but where sedimentary sulphide and deformation textures formed by extremely selective replacement of pre-existing fabrics and by infill of early dilational and/or dissolutional bedding-parallel cavities. This 'variant' model requires considerable retention and/or creation of porosity and permeability in the Pale Beds and needs testing by detailed petrographic studies. One attraction of this hypothesis is that substantial lateral flow of the ore-forming fluids would have occurred and a basal Carboniferous source for the metals then becomes a possibility. (Williams and Brown; Lydon; both this vol.) An alternative hypothesis involves a comparison with the Mississippi Valley-type model of ore formation whereby the mineralization would be regarded as infilling karstic cavities in Pale Beds below a subaerial erosion surface and carried by brines expelled from a thickened basinal Carboniferous succession SW of Navan. Although open-space filling textures are present, there is little evidence of karstification. In particular the tops of the sulphide layers do not show remnant cavities or infilled vugs, apart from very localized circumstances; coarse vuggy crystal growths are virtually unknown and the amount of layered, disseminated and fracture-fill mineralization within otherwise normal host rock unequivocally rules out cave-fill precipitation for significant amounts of ore. Furthermore, the Pale Beds marker horizons can be traced, with no evidence of collapse structures, right across the orebody. A particularly specialized karst development would need to be invoked to explain the form of the superimposed lenses, the presence of large areas of (in terms of this hypothesis) unsupported ground in 5-Lens and the lack of 'cave' development between the lenses.

Mineralization in the Pale Beds bears certain resemblances to the Alpine, Silesian and Sardinian Zn-Pb ores (Maucher and Sneider, 1967; Bechstadt, 1979; Sass-Gustkiewicz et al., 1982; Scholle et al., 1983; Klau and Mostler; Boni; both this vol.) and, in terms of host rock, the sediment-hosted deposits of Northern Australia (Muir, 1983). Several modes of formation have been proposed for these deposits varying from synsedimentary deposition through diagenetic replacements to open-space filling of hydrothermally dissolved or karst-related solution cavities. At Navan, however, the timing of mineralization in the Pale Beds is uniquely constrained by the presence of the overlying and mostly younger Conglomerate Group ore which bears comparison to a sedimentary exhalative massive sulphide ore (Large, 1980 and 1983; Gustafson and Williams, 1981; Hamilton et al., 1982). The deposit is classified as a variant of the sedimentary exhalative class of orebody in which substantial quantities of sulphides were deposited in the diagenetic environment, due to a combination of a long-lived hydrothermal system, a host rock sequence of rapidly sedimented shallow-water carbonates (Andrew and Ashton, 1985), a high geothermal gradient (Russell, 1983 and this vol.) and a periodically active basement fault zone which promoted localized extension.

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Discussion

MURRAY HITZMAN (Chevron Mineral Corporation of Ireland) asked:

1. Is the mineralogy of the Old Red Sandstone and equivalent coarse basal clastics below the Navan orebody different than seen regionally? Specifically, has K-feldspar destructive alteration occured? 2. What is the extent, style and timing of dolomitization associated with the Navan orebody? 3. What is the stratigraphically highest unit in the Navan ores which shows hydrothermal alteration and mineralization? 4. What is the extent of the Boulder Conglomerate in the Navan ores? Does it show distinct thickness variations and do such troughs parallel structures in the area?

REPLY:

1. The authors have not investigated the mineralogy of the Red Beds but are not aware of any local changes in its composition at Navan. 2 and 3. Since the Shaley Pales, 'ABC' and 'Reef' rock types are absent in the area overlying the thick development of Pale Beds ore, due to erosion, it is not known to what extent they were dolomitized and/or mineralized, although the formation of the Conglomerate Group Ore clearly post-dated deposition of these rocks. Detailed petrographic work is lacking for the Navan orebody, so the timing of dolomitization is unclear, since its development is usually incomplete (see paper) and is not clearly correlated with mineralization. (See also Andrew and Poustie, this vol.) 4. The Boulder Conglomerate occurs throughout the Navan area, but in the immediate vicinity of the orebody it thickens southwards and is clearly influenced by the 'T' Fault (see paper). In other areas there are similar relatively thick developments of the Boulder Conglomerate, but these infill depressions in the erosion surface which are not directly related to fault development.

GEOFF STEED (University College Cardiff) asked:

1. Could the authors describe the form and composition of mineralization in the underlying and nearby Lower Palaeozoic rocks? 2. Can they indicate whether there is any

evidence of hydrothermal alteration within Lower Palaeozoic rocks, including the nearby Caledonian syenite body, which are intersected by several faults?

PAUL DULLER (University of Strathclyde) asked:

Do the authors foresee any potential for discoveries of economic mineralization within or associated with the feeder vein system at Navan?

REPLY:

The form of mineralization in the Lower Palaeozoic rocks has been described in the paper and is based on information from isolated surface and underground exposures, and sparse drill data. It is considered likely that undiscovered fracture-fill, disseminated and replacement style mineralization could occur near intersections of faults with competent intrusives and volcanic breccias, particularly where these occur close to pyritic mudstones. Whether such mineralization exists and whether it has any economic potential must await the results of deep drilling beneath the orebody.

The syenite body is conspicuously altered with replacement of original ferromagnesian phases by chlorite and carbonate, and it has even been referred to as a heavily altered granodiorite by some geologists (W.E.A. Phillips, pers. comm.; P. Kennan, pers. comm.). Sericitization has been noted in a few samples. Bleaching and pyritization occur in some Lower Palaeozoic mudstones and siltstones intersected by drilling below the orebody, but these have not been studied in thin section.

FRIEDRICH GUNTHER (Aachen Technical University) asked:

1. Is there any variation in the trace element geochemistry of sphalerite and galena in the two types of mineralization, stratiform and vein-type (e.g. Fe, Cd in ZnS, Ag in PbS)? 2. Do you have sulphur isotope data from sulphides of both types?

REPLY:

Detailed studies of trace element content and sulphur isotope composition of the differing ore textures have not yet been undertaken, although Steed (unpublished report, 1981) noted a tendency for relatively high Ag values to occur in samples associated with coarse-grained growths of galena locally interbanded with sphalerite and surrounding host-rock breccia fragments.

PLATES 1-20 FOLLOW

Plate 1. Boulder Conglomerate in Zone 2, south of the 'T' Fault. Boulder beds with isolate large 'Reef' clasts, are separated by dark pyritic mudstone layers. Note deformation of laminated pyritic mudstones by 'Reef' boulder.

Plate 2. Boulder Conglomerate from Zone 2 showing poorly supported angular 'Reef' clasts enclosed by dark crinoid-bearing mudstones. (Scale=15cm).

Plate 3. Deformed laminated sphalerite-galena layer in crinoid-bearing matrix of Boulder Conglomerate. This occurs directly beneath a large reef clast; Zone 2. (Hammer for scale).

Plate 4. Detail of layered pyrite, associated with dark mudstones in Boulder Conglomerate. Zone 2, near location of Plate 1. (Width of frame=1m).

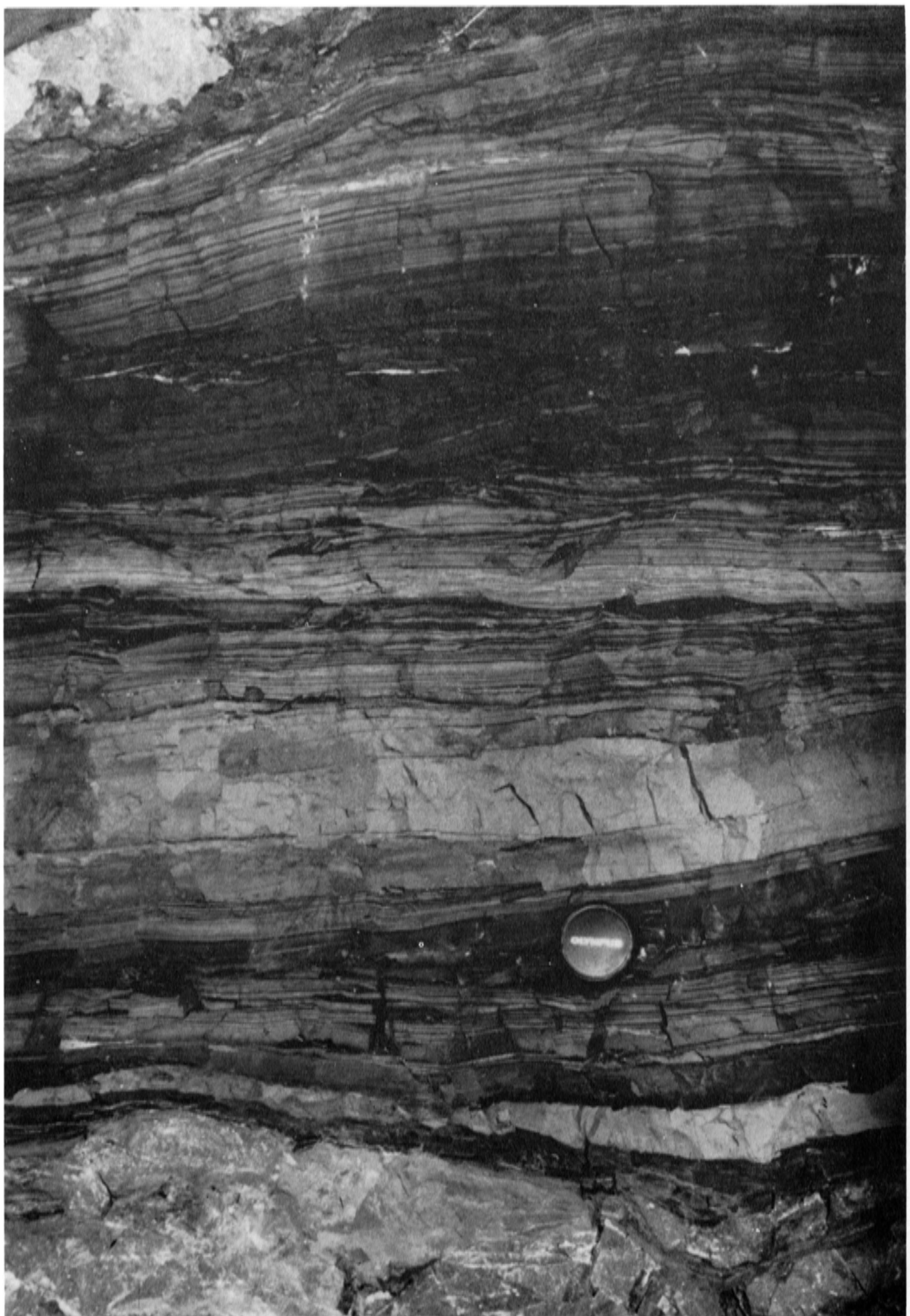

Plate 5. Well-developed laminated pyrite and subsidiary fine-grained sphalerite-galena layer in Boulder Conglomerate. Zone 2. (Width of frame = 0.8m).

Plate 6. Irregular cross-cutting sphalerite vein cutting Muddy Limestone and followed by later shearing and carbonate veining. 10m below base of 1-5 Lens. (Width of frame 0.8m)

Plate 7. Isoclinally folded Upper Dark Limestones near 'A' Fault. (Hammer for scale).

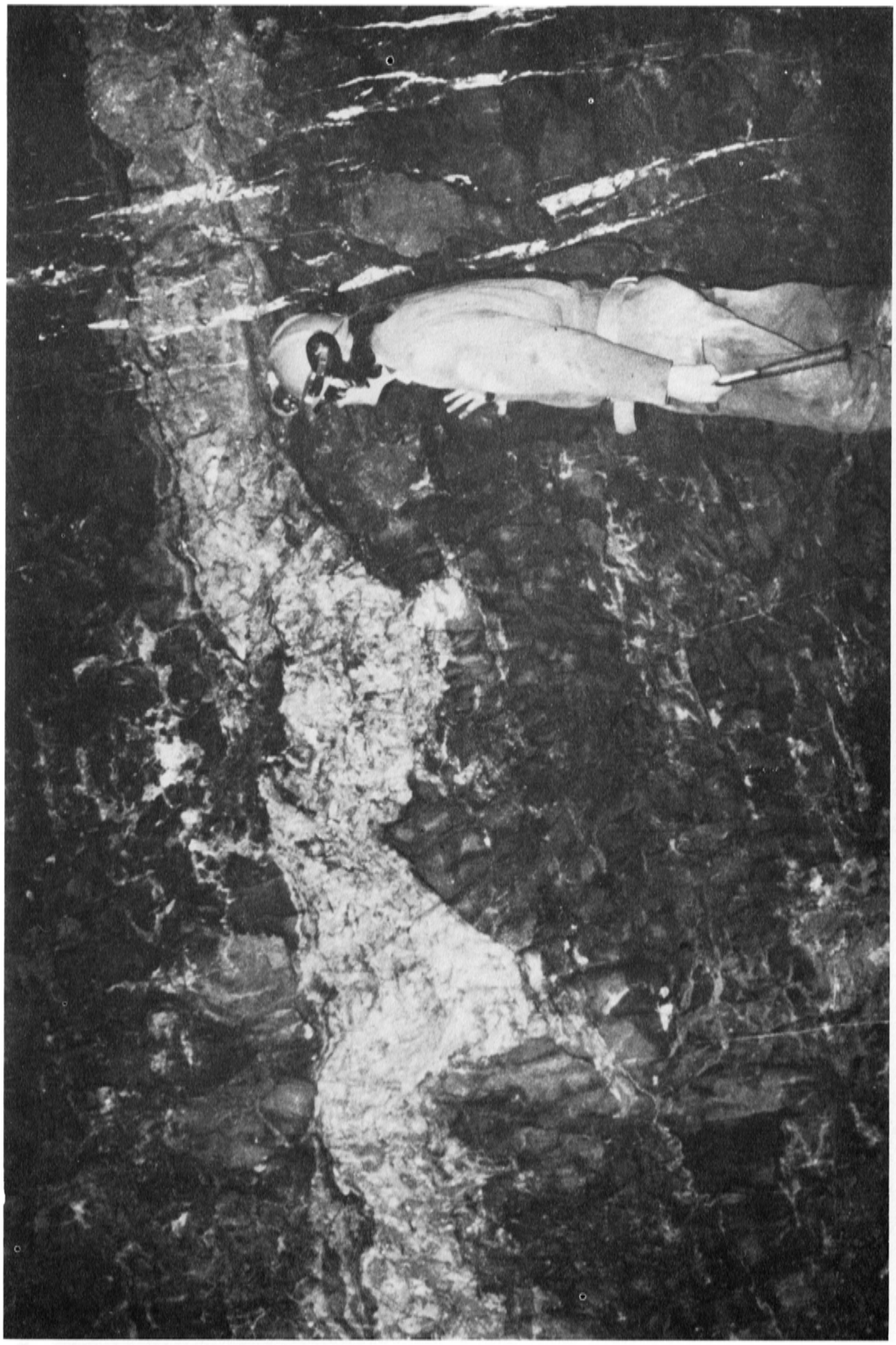

Plate 8. Irregular stratiform sulphide layer in 2-3 Lens showing thickening and depression near minor vein mineralization in foot-wall.

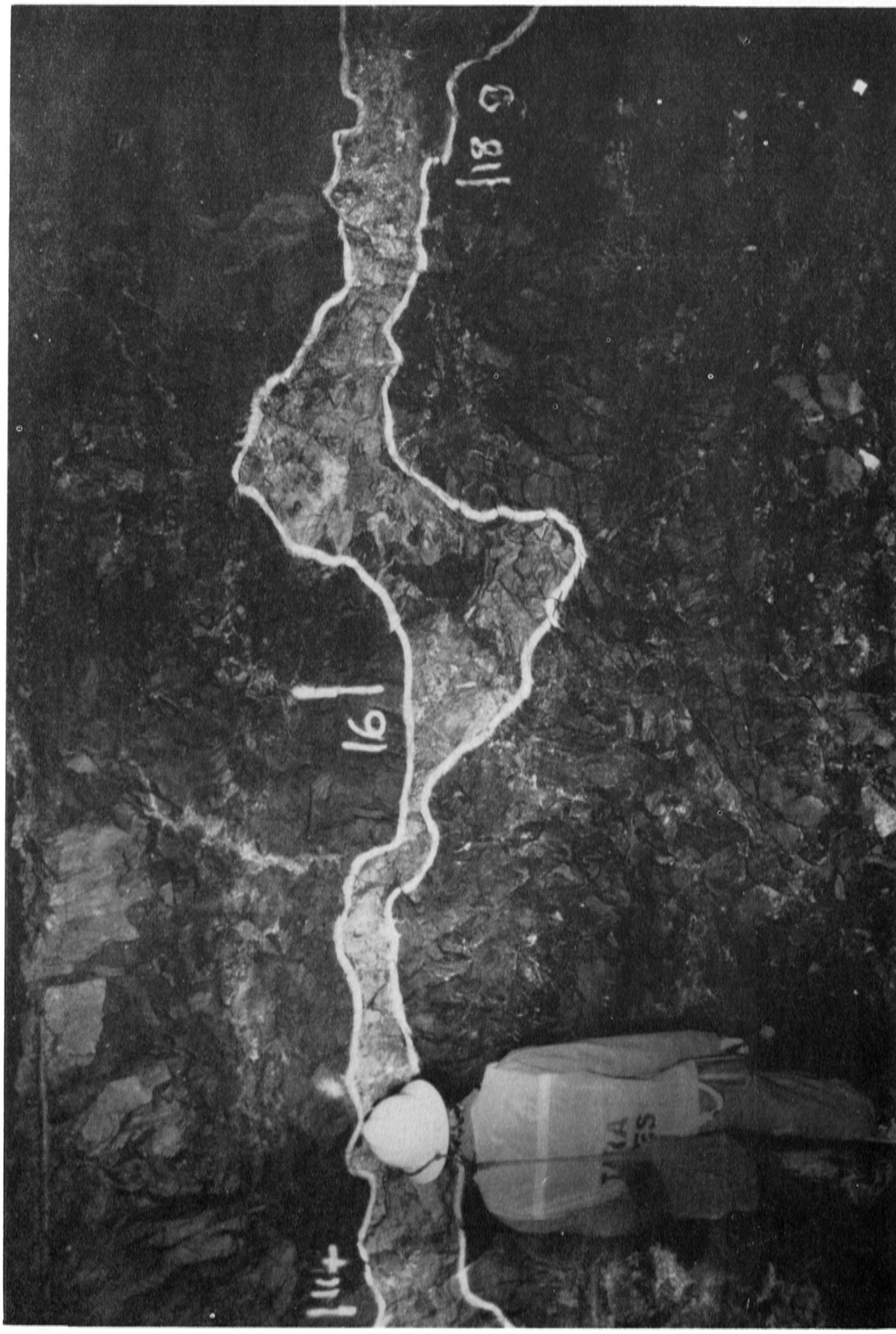

Plate 9. Irregular stratiform sulphide layer, 2-2 Lens showing ore outline in white.

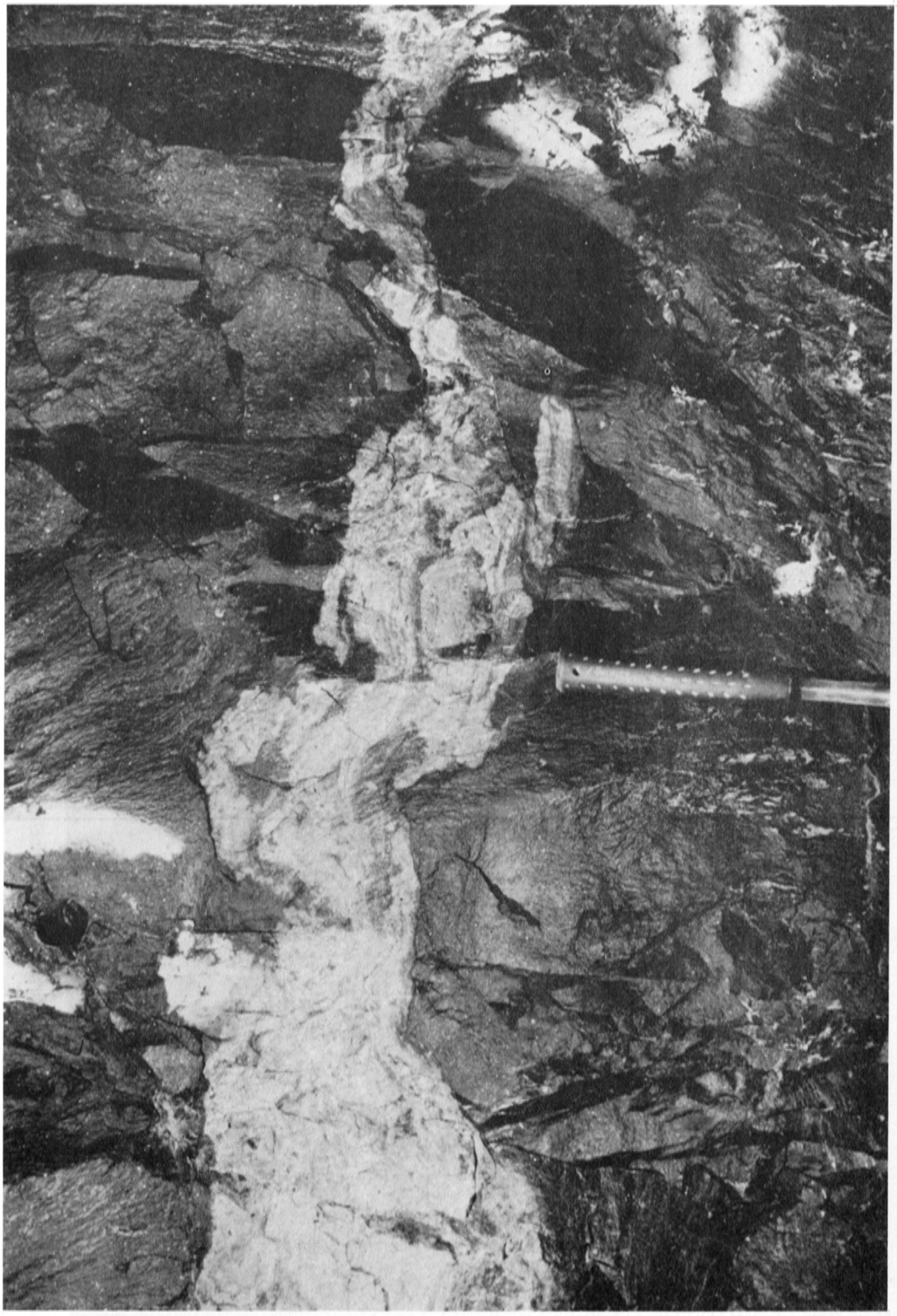

Plate 10. Detail sulphide textures in 2-2 Lens near location of Plate 9. (Hammer handle for scale).

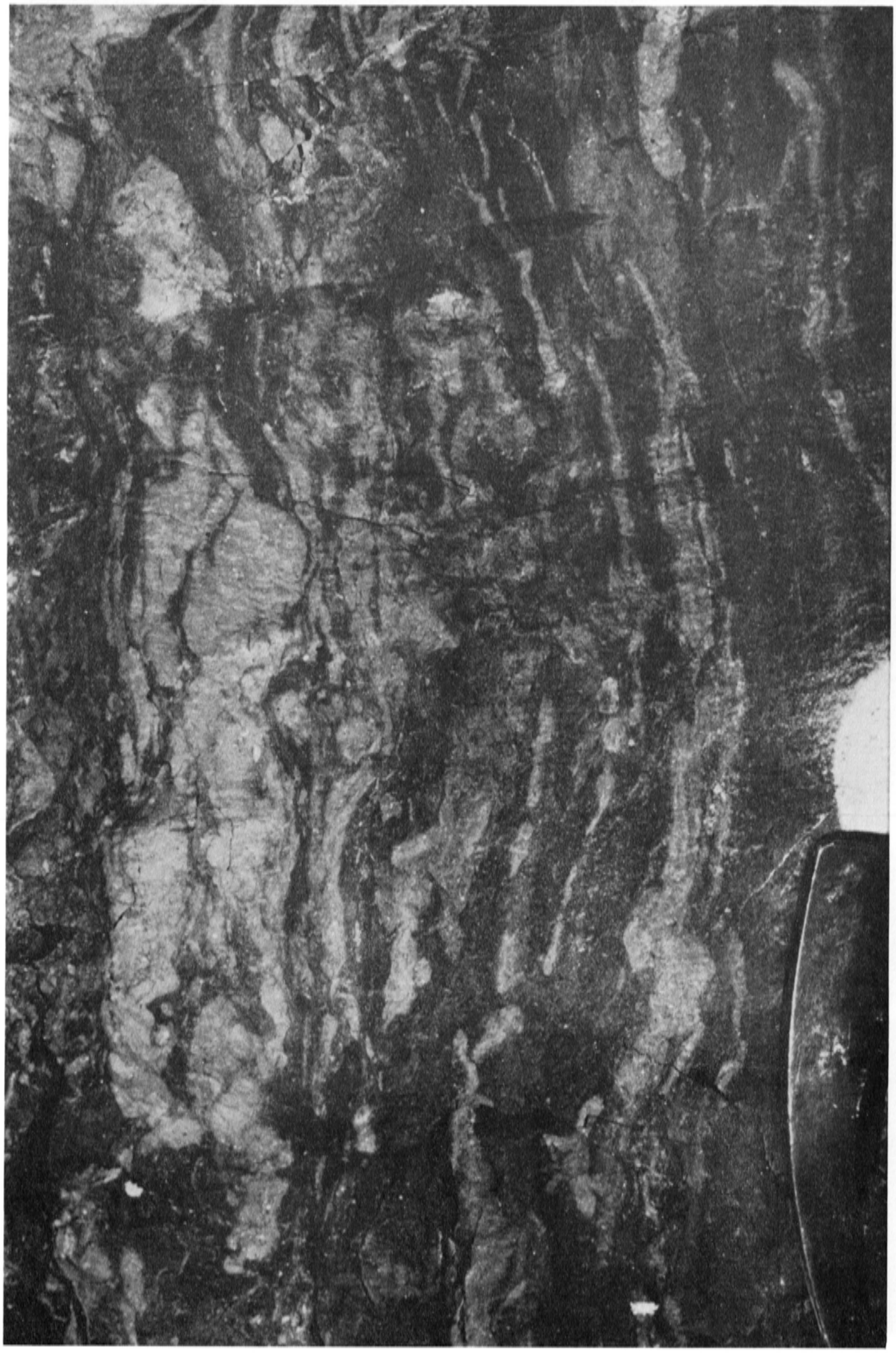

Plate 11. Irregular sphalerite layers in 2-3 Lens calcarenites. (Hammer top for scale). Note absence of cavity textures and strong, soft-sediment style disruption.

Plate 12. Layered sulphides in 2-1 Lens. Disseminated and locally cross-cutting sulphides are present and obscure a central area of closely spaced disrupted sulphide layers showing well-developed pull-apart textures. (Hammer for scale).

Plate 13. Pull-apart textures in sulphide layers enclosed by typical 2-1 Lens calcarenites. The tops of some layers display weak carbonate infills and may indicate bedding-parallel veining in soft sediment. Lens cap (5cm) for scale.

Plate 14. Complex mineralized breccia in 1-5 Lens. Irregular micrite clasts containing oncholites are enclosed by a mineralized matrix, containing dark argillite, laminated and layered sphalerite and minor galena. The micrites are undolomitized. (Hammer for scale).

Plate 15. Irregular, undolomitized micrite boulders enclosed by fine-grained sphalerite, 1-5 Lens. (Hammer for scale).

Plate 16. Cross-cutting breccia zone cemented by fine-grained sphalerite terminating at the base of the Lower Dark Marker, 1-5 Lens, with concomittant development of bedding parallel sulphide veins, containing stalactitic textures. (See plate 17a for close-up).

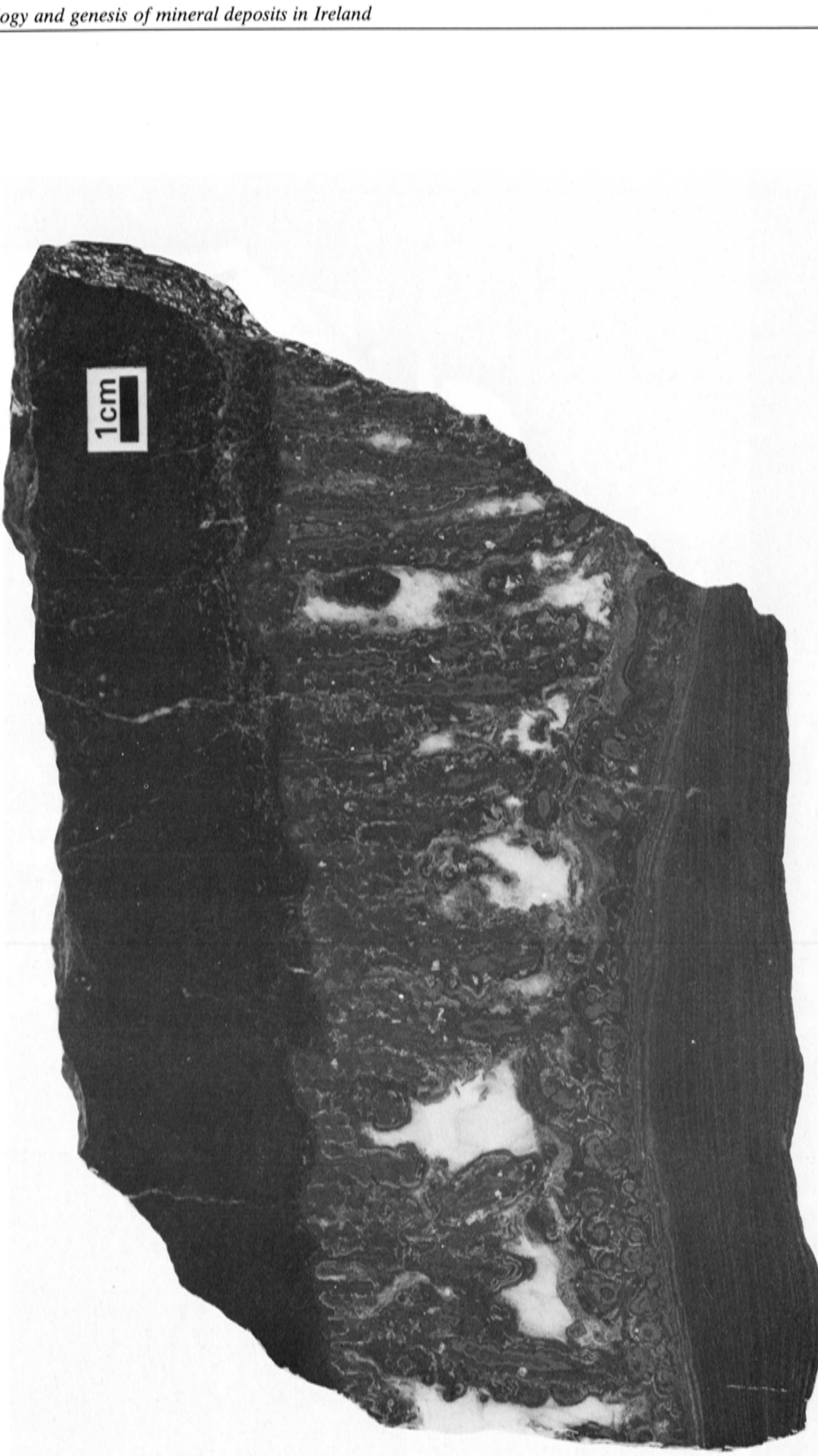

Plate 17a. Close-up of sulphide stalactites from bedding-parallel veins shown in Plate 16. Note internal sediments at base and late stage infill of coarse-grained white barite.

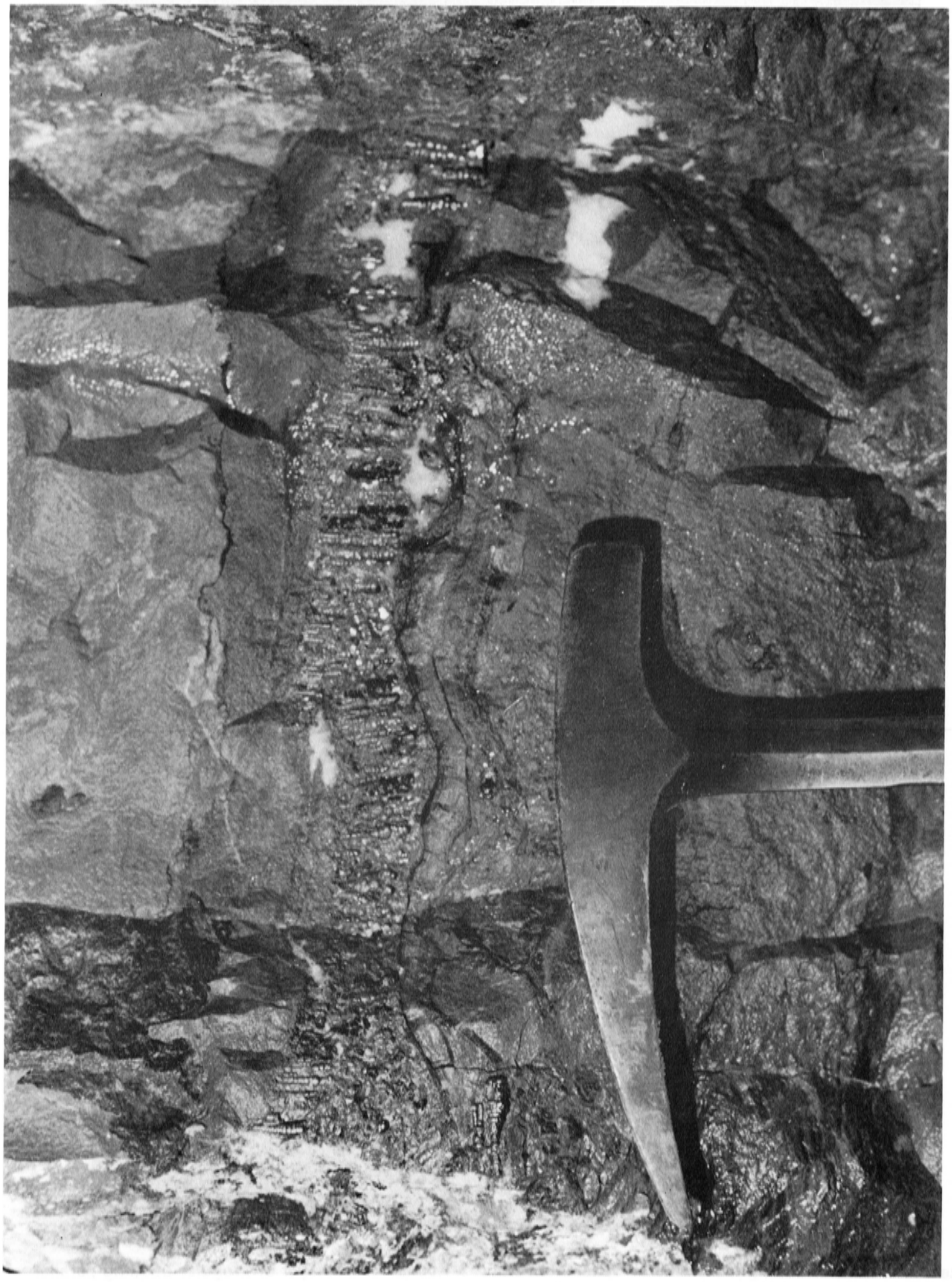

Plate 17b. Well-formed pyrite stalactites from bedding-parallel vein in dolomitized 1-5 Lens micrite. Note internal sediments at base. (Hammer top for scale).

Plate 18. Cross-cutting disseminated sphalerite vein in 2-1 Lens. A thick layer of irregular bedding-parallel sulphides is developed above. (Hammer for scale).

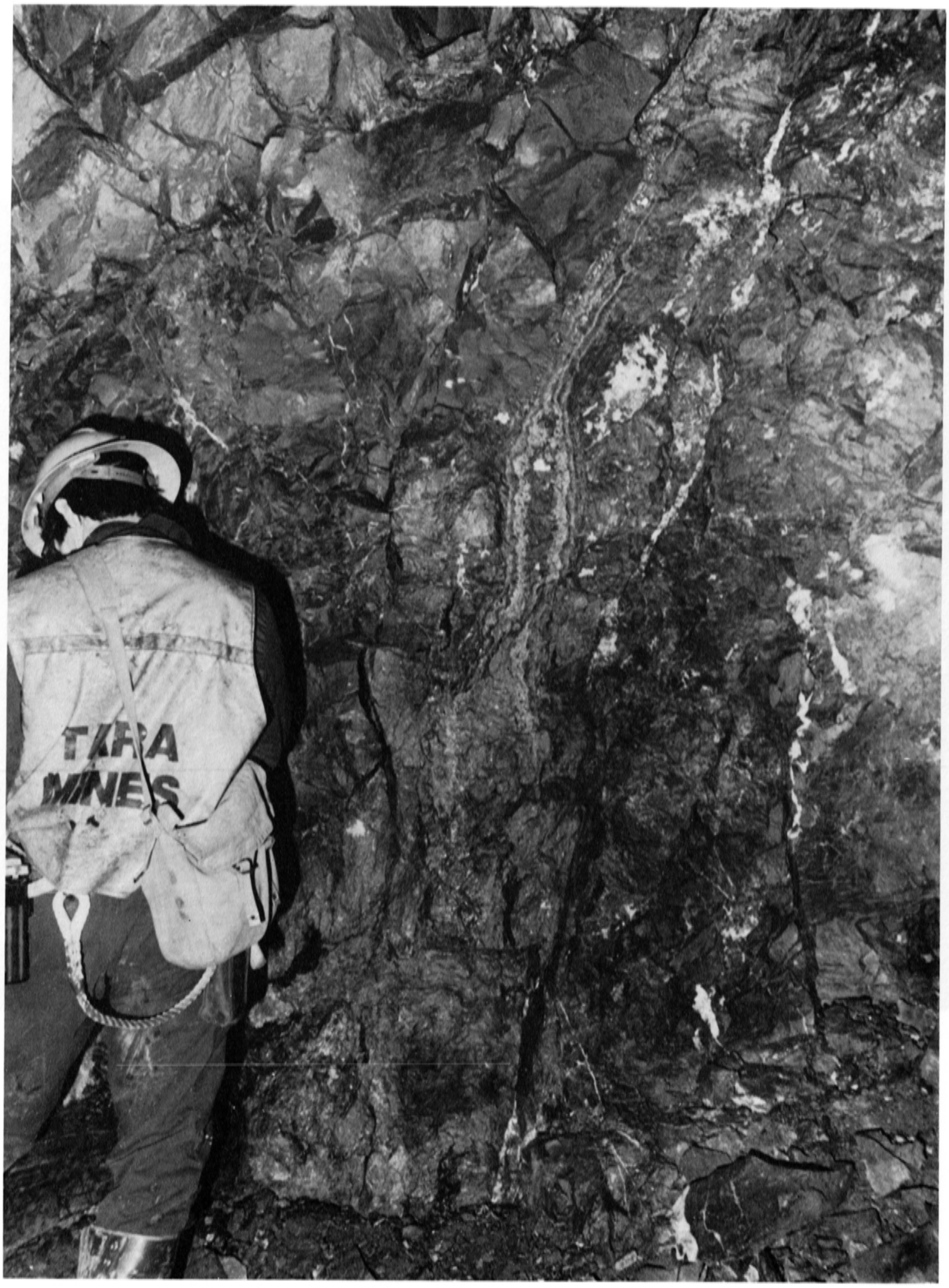

Plate 19. Crustiform galena-sphalerite vein cutting 3-5 Lens.

Plate 20. Close up of crustified galena-sphalerite vein shown in Plate 19.