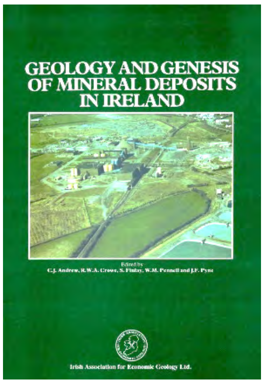

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Syndiagenetic or epigenetic mineralization — the evidence from the Tatestown zinc-lead prospect, Co. Meath.

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Abstract

The Tatestown prospect, containing 1.6Mt grading 6.76% Zn+Pb, is part of the Tatestown-Scallanstown deposit (3.6Mt @ 6.9% Zn+Pb) and is regarded as a satellite to the major Navan orebody 3km to the SSE.

The deposit is hosted within Lower Carboniferous (Courceyan) shallow-water carbonates and is generally stratiform, occurring at two horizons at or near the top of the Micrite Unit. Mineralization is thickened and preferentially enriched in the immediate hangingwall of a northerly dipping E-W normal fault which transects the orebody.

Mineralization of sphalerite, galena, pyrite-marcasite and barite occurs as rhythmic colloform infill to fractures and voids and in interparticle porosity. It is best developed within two horizons of oobioclastic wackestones with abundant calcite allochems, in which the microspar has been dolomitized. These horizons are interbedded with birdseye micrites which suffered early pervasive dolomitization, particularly adjacent to the Tatestown Fault. Within the wackestones permeability and subsequent sulphide deposition was controlled by steeply dipping solution seams, initiated by compaction and hiatically dilated during early movements of the Tatestown Fault.

Detailed petrography has revealed the presence of eight diagenetic stages; the earliest cements, thin vadose and phreatic rims, pass to blocky calcites showing a general increase in Fe content and to later dolomites. These early cements represent initial diagenesis under the action of connate pore waters. Later zoned Fe-calcite, silica and ferroan baroque dolomites accompanying and post-dating mineralization were deposited from hydrothermal fluids. Fluid inclusion studies suggest salinities of 10-12 equivalent wt. % NaCl and temperatures in the range 140-190°C.

The Tatestown deposit was formed during early lithic diagenesis in a closed system, analogous on a smaller scale, and peripheral to, the late stage cross-cutting system active at Navan. It is thus a syndiagenetic deposit.

Introduction

The Tatestown prospect lies on the eastern side of the River Blackwater 3km to the NNW of the major Navan orebody in County Meath. The deposit was discovered by Irish Base Metals Limited (the property is currently operated by Ennex International PLC) by diamond drilling down dip of a shallow soil geochemical anomaly. Subsequent drilling defined a 1.6Mt deposit grading 6.76% Zn+Pb including 0.34Mt at 12.15% Zn+Pb. To the west of the River Blackwater a contiguous deposit of approximately 2.0Mt grading 7.00% Zn+Pb has been drill indicated on a property currently operated by Glencar Explorations PLC (Finlay, 1982).

The deposit has not previously been described although Andrew and Ashton (1985) briefly relate Tatestown to the Navan deposit. Unpublished work by Danielli (1982 and 1983), Catlin (1982), and Catlin and Danielli (1983) on the petrology of the host rocks is summarized herein.

Regional setting

The Tatestown deposit is hosted within Lower Carboniferous carbonate sediments covering the same stratigraphic interval as the lowermost lenses of the Navan deposit (Andrew and Ashton, 1982, 1985; Ashton et al., this vol.). The deposit lies to the SW of the small Randlestown periclinal Lower Palaeozoic inlier situated south of the fault-bounded Longford-Down massif (Fig. 1). Complex polyphase pre-Hercynian and main phase Hercynian faulting transects the ore, resulting in both normal and oblique reverse components of displacement.

Stratigraphy

Drilling in the Tatestown area has defined in detail the local Courceyan lithostratigraphy. The basement to the succession comprises grey-green and reddish-purple fissile shales, siltstones and thin micaceous sandstones of Silurian age. The Silurian passes via a peneplanar angular unconformity into 0-25m of Red Beds (Fig. 2) comprised of sienna red siliciclastics of variable grain size. In general these clastics fine up from coarse grits and polymict pebble conglomerates into sandstones and siltstones with pebble lenses. Displacive calichiferous nodules are commonly developed in the finer lithologies. The Red Beds are overlain by the Mixed Beds (15-20m thick) comprising dark grey fine-grained laminated crossbedded clays, silts and sands exhibiting sedimentary features such as asymmetrical ripple marks, slumps and syndiagenetic micro-faulting. The Muddy Limestone which occurs at the top of the Mixed

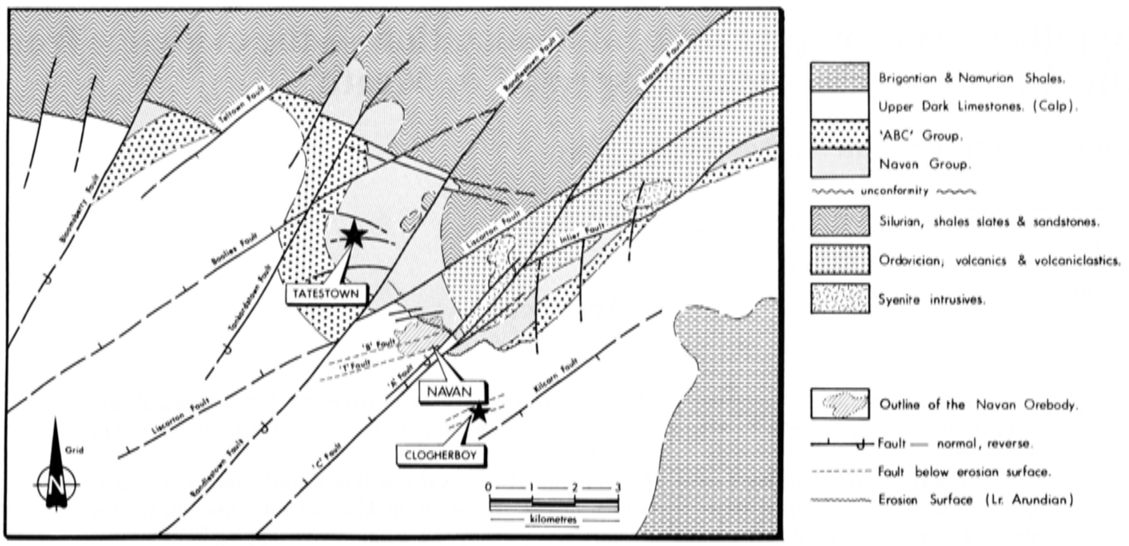

Figure 1. Regional geological map of Tatestown area showing the proximity of the Navan orebody.

Beds at Navan (Andrew and Ashton, 1982 and 1985; Ashton et al., this vol.) is irregularly developed at Tatestown, thinning and wedging out to the west of the area. Where developed it comprises an argillaceous, poorly bedded, dark grey nodular biomicarenite up to 10m thick. The Mixed Beds are superceded by the Micrite Unit (30-50m), the basal unit of the Pale Beds. It comprises pale to dark grey fine-grained, generally massive to thick-bedded micrites with thin interbedded horizons of pelletal bioclastic and sandy calcarenites. Bioturbation is commonplace, as is the development of fenestral or birdseye voids infilled by sparry calcite cements. Algal nodules, gastropods and ostracods occur sparsely. Aeolian terrigenous silt-sized siliciclastics amount to 10-15% of the micritic rock mass, locally forming quartzose sand horizons with bioclastic detritus. These sand horizons become increasingly abundant towards the overlying Lower Pale Beds. The uppermost 0-8m of the Micrite Unit is often dolomitized and recrystallized into an equigranular pale buff-grey lithology known locally as the "MPC". Minor dolomite horizons also occur locally in the uppermost 15m of the Micrite Unit. These "MPC" horizons correlate with the localization of mineralization and will be discussed later.

The boundary between the Micrite Unit and the overlying Lower Pale Beds is a normal sedimentary transition, but the presence of micritic microconglomerates with a concentration of quartz silt and organic (? algal) material suggests a minor non-sequence or hiatus. This is supported by evidence of different compaction and cementation histories above and below the contact (Danielli and Catlin, 1983).

Above the Micrite Unit the Lower Pale Beds (50-60m) consist of pale to medium grey, argillaceous carbonate-cemented sands, silts and thin shales within a package of oolitic, pelletal and bioclastic calcarenites. Quartz sand content increases upwards from about 10 to 25%. Fossil material is clearly bioclastic and is commonly fragmented and abraded. Organisms represented include a variety of foraminifera, crinoids, brachiopods, ostracods, corals, lamellibranchs and phylloid algae. Bioclasts and siliciclastic grains (quartz, feldspars, tourmaline, zircon and micas) form the nuclei for ooliths.

The lower portion of the Upper Pale Beds (30-40m) comprises pale grey sandy oolitic calcarenites, massively bedded and devoid of bioturbation. Upwards, sands and silts become predominant and bioclasts are sparse. The silici-clastic detritus is poorly sorted and angular; abraded and derived ooliths are sparsely present in these rocks. A marker horizon (the Lower Bryozoan Marker), averaging 30cm thick and of a similar lithology but with a distinctive fauna of Polypora bryozoans, occurs 10m above the base of the Upper Pale Beds.

The Upper Pale Beds pass transitionally over 2-5m into the overlying Shaley Pales (60-70m). The Lower Shaley Pales (15-20m) are dominated by medium to dark grey thinly bedded silty calcarenites with black shale partings; bioclasts of small crinoids, fennestellid bryozoans and articulated ostracods are common. The upper contact of the Lower Shaley Pales is defined by a 30cm bed of massive calcisiltite with abundant *Polypora* and fennestellid bryozoans — the Upper Bryozoan Marker.

The overlying Middle Shaley Pales (20-25m) comprise white to pale grey medium- to fine-grained quartzose sajdstones, occasionally with large crinoid bioclasts. The sandstones are interbedded with laminated bioclastic, terrigenous silty mudstones; ripple bedding, compressed mud intraclasts and minor slumping are well developed. The Upper Shaley Pales (~ 25m) are typified by dark grey to black thinly bedded bryozoan and crinoidal argillites and calcisiltites, locally with thin wispy terrigenous silt horizons.

The Red Beds, Mixed Beds, Pale Beds and Shaley Pales together form the Navan Group from which Johnston (1976) has obtained microfaunal assemblages indicative of the *Pseudopolygnathus multistriatus* and lower-middle *Polygnathus mehli mehli* conodont biozones (Courceyan 3). Keegan (1981) obtained miospore assemblages from Tatestown drill core which places the *PC-CM* biozonal boundary in the Lower Pale Beds.

Above the Navan Group lies the Argillaceous Bioclastic Calcarenite Group (ABC Group) which consists of the Argillaceous Bioclastic Limestones (ABL) and the Waulsortian facies. The Shaley Pales pass transitionally over a few metres into the ABL (250-280m) which comprises dark grey silty argillaceous organic-rich matrix-supported

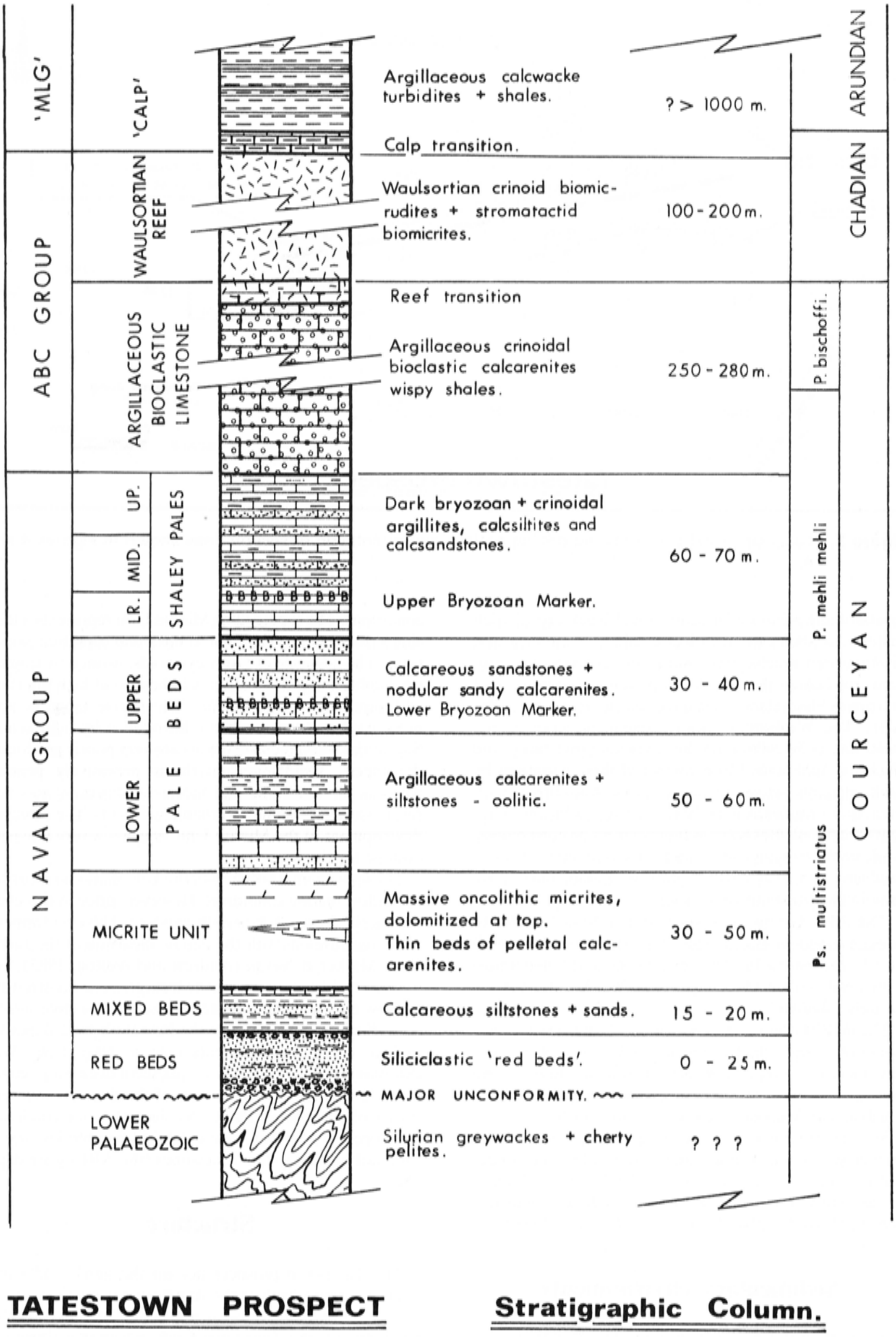

Figure 2. Summary stratigraphic column at Tatestown.

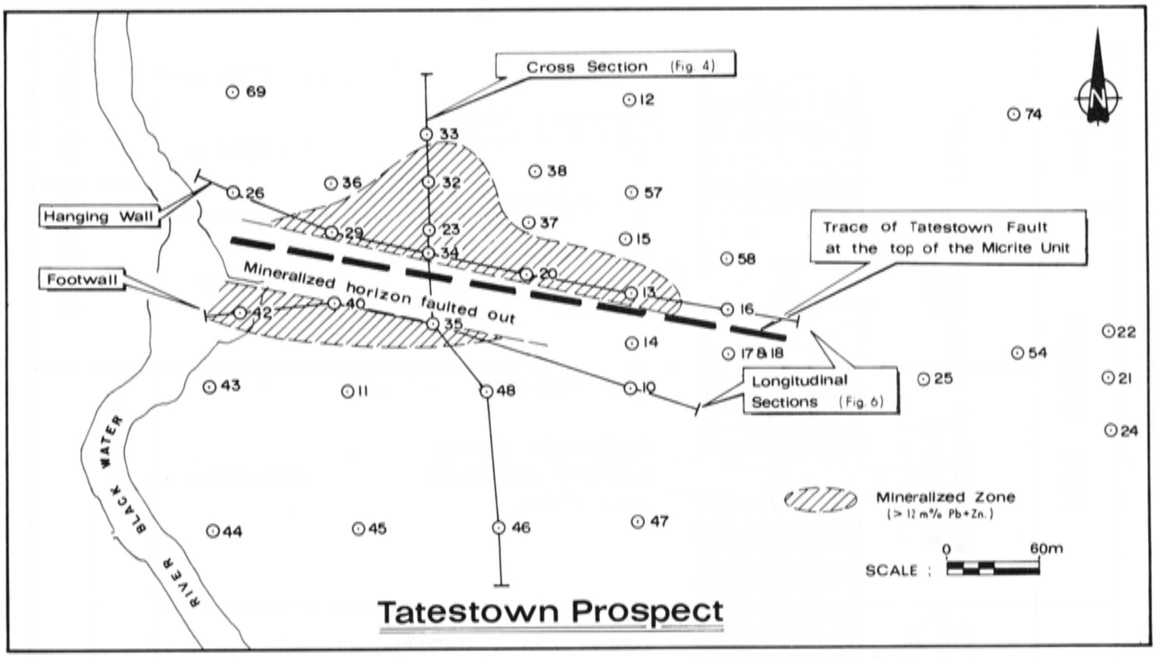

Figure 3. Local structural plan showing drilling pattern and orientation of section lines shown in Figures 4 and 6.

bioclastic calcisiltites with interbedded black organic-rich shales. An abundant and diverse fauna of abraded and disarticulated brachiopods, ostracods, crinoids, foraminifera (including the zonally important *Tetrataxis sp.*) bryozoans, dascyclads and sponge spicules is present in the ABL. The Waulsortian facies immediately overlies the ABL and is 50-200m thick but exhibits rapid facies and thickness variations. Close control of these variations by faults suggests active tectonism during Waulsortian sedimentation. Mudbank core facies of "veines bleues" stromatactid biomicrites occur as thin horizons on horst blocks, while on the hangingwall of faults prisms of relatively thick mudbank thin away towards grabens, grading into coarse crinoid biosparrudite flank facies.

The ABC Group has been found (Johnston, 1976) to contain conodont assemblages of the *Polygnathus bischoffi* and *P. bechmanni* biozones equivalent to the uppermost Courceyan and Chadian stages. The Waulsortian facies is entirely Chadian.

The ABC Group is overlain by the Upper Dark Limestones or "Calp" which comprises dark grey to black sparsely bioclastic silty mudstones passing up into graded tabular and wedge-bedded limestone turbidites of late Chadian and Arundian age (Sevastopulo, 1981).

Several drill holes have intersected transgressive sills of carbonatized olivine-basalts analagous to those seen in the Navan mine. (Andrew and Ashton, 1982, 1985; Ashton et al., this vol.). These have been dated by K-Ar techniques at 62±2Ma or 48±2Ma (Halliday and Mitchell, 1983).

Sedimentary environments

Above the post-Caledonian peneplain the Red Beds were laid down under fluviatile and alluvial plain conditions. A shallow marine transgression formed lagoons in which the finely laminated Mixed Beds were deposited. The Muddy Limestone represents deeper and cleaner water lagoonal conditions. The superceding Micrite Unit represents a transition from shallow lagoonal to intra-and supratidal conditions. The presence of bird's eye voids, formed by trapped gas bubbles, and dessication is indicative of high intertidal and supratidal environments. The sparse fauna is non-indigenous and was probably introduced by tidal action. Supratidal blue-green algal mats are very poorly and locally developed. Windblown quartz is pervasively present, whereas the sandstone and bioclastite horizons may represent storm or channel overbank sediments. The extensive development of the Micrite Unit suggests a very low palaeoslope for the region.

The upper contact of the Micrite Unit marks an incursion of shallow marine conditions. However, prior to this event the micrite flat was sub-aerially exposed. This event appears to be synchronous with the deltaic incursion of the Lower Dark Marker at Navan (Andrew and Ashton, 1985). Following this hiatus, rapid marine transgression occurred and shallow marine conditions developed. In this environment ooid shoals and sand bars of the Pale Beds were deposited in high energy environments near to wave base. With continuing transgression more quiescent deep water conditions developed with deposition of the finer grained sediments of the Shaley Pales. As deeper water conditions developed, terrigenous clastic detritus became less significant and bioclastic shelf limestones (the ABL) were deposited.

Structure

The Tatestown prospect lies on the gently (15°) westwardly dipping flank of the Randlestown anticline, (Fig. 1 and 3). The main mineralized zone straddles an E-W normal fault, the Tatestown Fault, which downthrows to the north. Minor reverse drag occurs opposite the point of maximum downthrow (Figs. 4 and 5). To the east and west the fault swings in strike by about 20° to the south and its throw diminishes from about 75m to a slight monoclinal

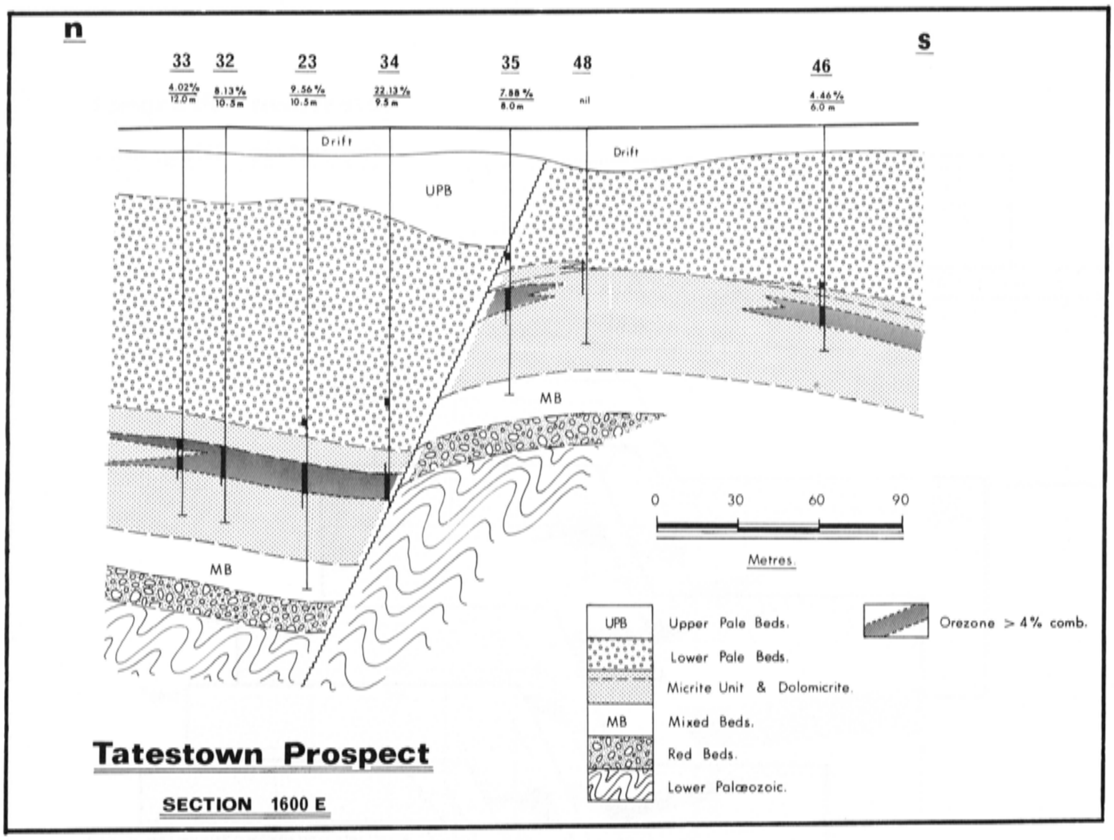

Figure 4. N-S section through the Tatestown prospect.

flexure. The total strike length of displacive fault is about 725m.

Steeply dipping fractures of random orientation are well developed in the hangingwall block of the fault and these are often occupied by sulphide and ore-stage carbonate veins. Regional, systematic, NW jointing appears to post-date faulting and transects these earlier vein sets.

Mineralization

At Tatestown sulphide mineralization occurs in a variety of styles but of dominantly simple mineralogy. Sphalerite, galena and pyrite-marcasite dominate, with microscopically identified traces of chalcopyrite, boulangerite and semseyite ($Pb_9Sb_8S_{21}$) (Catlin, 1982); silica, highly ferroan calcite, baroque ferroan dolomite and sericite comprise the ore-stage gangue mineralization.

Mineralization most commonly occurs as fracture and void fill, and locally as replacements. Sphalerite is typically pale brown, forming rhythmic fine-grained crustifications lining fractures, and as pale buff disseminated grains infilling primary and secondary leached porosity. Galena is generally later and coarser grained and commonly exhibits colloform growth in the central parts of fractures and voids. Minor pyrite-marcasite occurs in a variety of textures and grain sizes, but is generally of minor significance. However, pervasive sparse disseminations of pyrite-marcasite infilling interparticle porosity, typically replacing calcite allochems and associated with organic material, may represent an earlier phase of sulphide deposition. Barite commonly infills remnant voids in sulphide-lined cavities and veins, and also occurs as replacements of calcitic sediments.

Spatially, two controls of mineralization have been recognized, the simpler and more obvious being proximity to the fault, dominantly on the hangingwall side (Figs. 3, 4 and 5). Both thickness and grade are enhanced in proximity to the fault. The second control, although initially stratigraphically obvious in that the bulk of mineralization occurs in the upper part of the Micrite Unit, is somewhat more subtle. The upper limit of significant mineralization is generally associated with the base of 0-8m thick horizon of dolomitized and recrystallized micrite (the 'MPC') which occurs at the top of the Micrite Unit (Fig. 6). This dolomicrite horizon, however, which is developed throughout the mineralized zone, is itself unmineralized. Analogous thinner and less extensive dolomicrite horizons which developed within the top 20m of the Micrite Unit also often overlie significant concentrations of mineralization close to the fault.

Metal zoning is simply related to the Tatestown Fault; Zn:Pb ratios decrease from values of 3 away from the Fault to less than 1 in proximity to the structure. Ag is enriched in ore adjacent to the Fault, with values increasing from 20g/t to in excess of 70g/t. Above the dolomicrite, minor mineralization, dominantly as disseminations and fine fracture fill, is Zn-rich with Zn:Pb ratios mostly in the range 5 to 10.

Diagenesis of host sediments

Detailed examination of an extensive sample suite has led to a recognition of eight diagenetic stages which include the effects of mineralization (Danielli, 1982, 1983; Catlin, 1982, 1983). These stages are summarized in Figure 7 and are briefly described below.

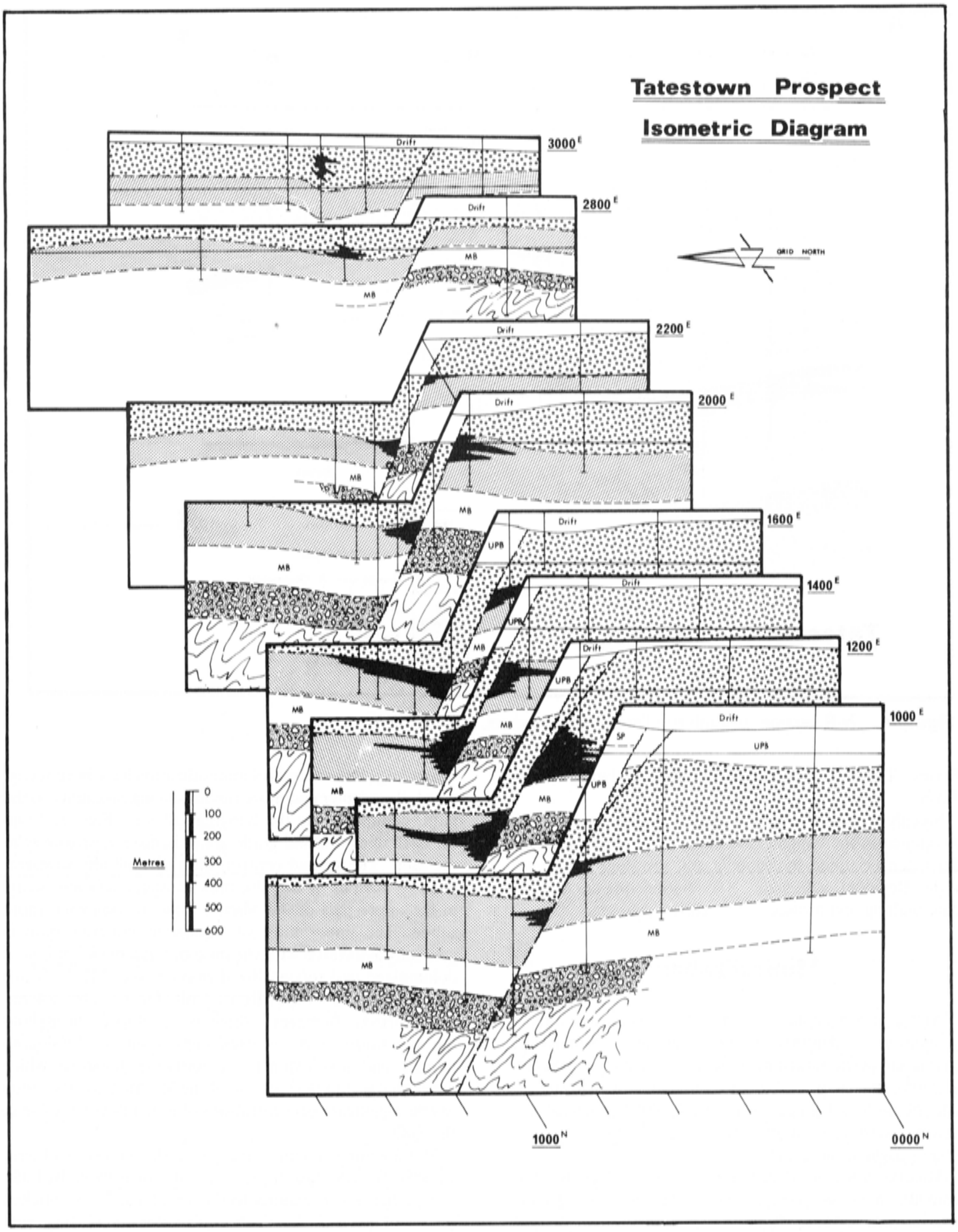

Figure 5. Isometric serial sectional view of the Tatestown prospect facing east. (Legend as for Fig. 4).

The sediments, deposited as calcite and aragonite detrital grains with fine quartz clastics, were initially cemented by rim and blocky calcite cements. Initially cemented allochems and 'hardground' laminae resisted early compaction leading to inhomogeneities in the sediments. The consequent formation of stylosolutions in coarse-grained sediments led to the development of sutured grain boundaries and organic matter was concentrated into bedding-parallel solution seams.

The fluid chemistry of pore waters within the sediments then became reducing, and much of the remaining pore space was infilled by multiple-zoned ferroan calcite. Leaching and replacement of early, low or Fe-free calcites occurred, and minor fracturing was pervasive. Stage 4 loosely defines four events in the diagenesis which are of indeterminate temporal relationship. Replacement of early cements by fine Fe-free dolomite is commonplace. Non-fabric selective leaching occurred synchronously with the development

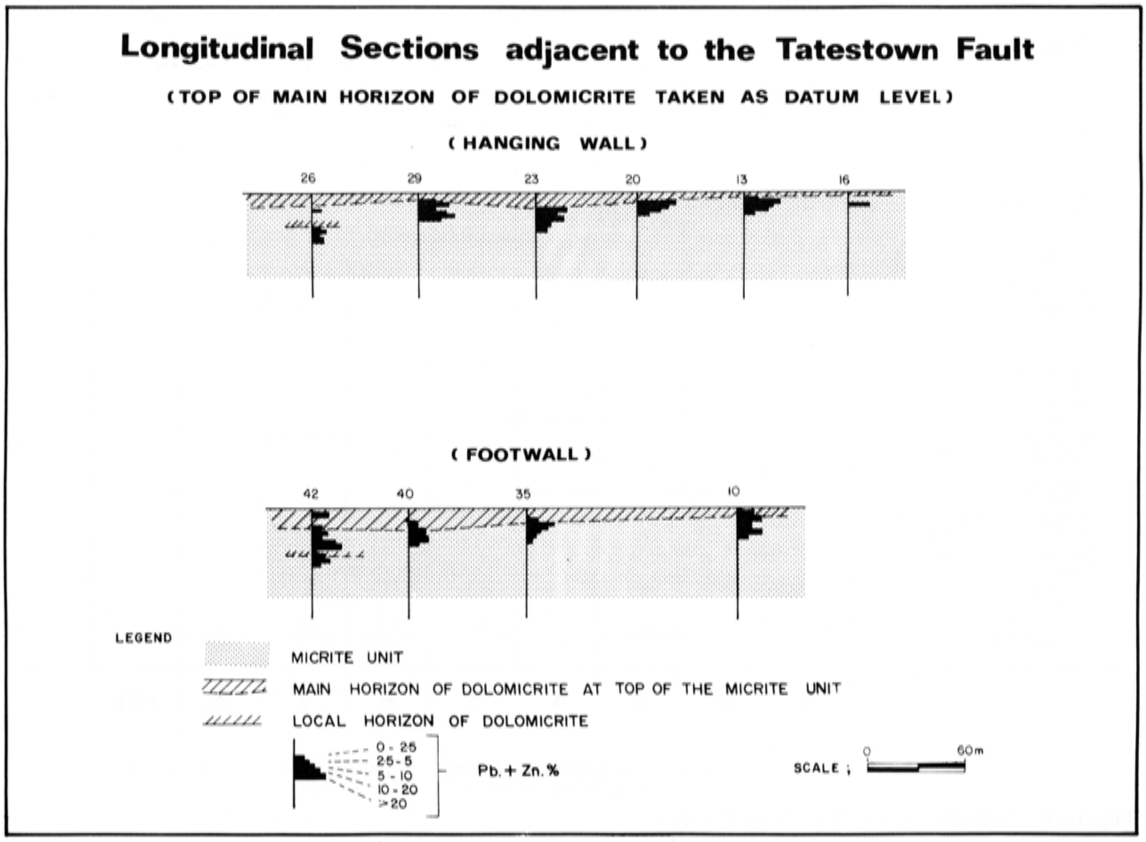

Figure 6. Pseudo-sections of the hangingwall and footwall blocks showing relative positions of mineralization and dolomicrite horizons.

of steeply dipping wavy and anastomosing solution seams lined by clay-organic matter. Silica was introduced forming overgrowths to terrigenous quartz grains and replacement of calcite allochems.

Many of the events of Stage 4 are preferentially developed in the upper beds of the Micrite Unit which subsequently became the preferred horizon for mineralization.

Subsequent sub-vertical fracturing occurred (D_2) and highly ferroan sparry calcite was deposited in fractures and in previously leached void spaces. This stage would appear to mark the onset of mineralization which is characterized by repeated fracturing and brecciation and by precipitation of the ore-mineral suite. In most cases mineralization occurs in 0-10cm steeply dipping fractures (D_3) and as disseminations in primary porosity or in synchronous leached secondary porosity. D_3 fracturing commonly followed earlier solution seams and fracturing, and occurred throughout mineralization with sulphide cemented breccias commonly seen. Minor calcite, silica and sericite were also deposited.

Baroque ferroan dolomite is locally coeval with late stage sulphides and D_4 fracturing, but is dominantly post-ore. Zoning of this dolomite is well developed with the solutions becoming increasingly Fe-rich with time.

The final stage of diagenesis is typified by regular fracturing (D_5) probably equivalent to the regional jointing, and deposition of Fe-zoned blocky calcites.

Temporally these eight stages are not evenly spread throughout lithification and diagenesis. Stages 1 to 4 probably represent processes developed prior to the sediments being significantly buried, and possibly occurred within 50m of the sediment-water interface. The variety of cements and processes in Stage 4 suggest that this stage was long-lived and marked the change in fluid chemistry from dewatering brines to hydrothermal mineralizing fluids. If this is so, the mineralizing fluids evolved from initially silica and Fe-calcite rich, to base metal and barite rich, to late stage Fe-dolomite rich. This temporal change is analogous to the fluid systematics at Tynagh, Navan and Silvermines (Boast, 1981; Andrew and Ashton, 1985; Andrew, this vol.) The mineralizing event appears to post-date the development of sub-vertical solution seams, and sulphide deposition preferentially occurs along these fractures. The development of these fractures is indicative of extensional stresses which, we infer, relate to the initiation of normal faulting along the Tatestown Fault during Stage 4, continuing through mineralization (Stage 5) and into Stage 6.

By comparison with the Navan deposit (Andrew and Ashton; 1982 and 1985) where faulting of a similar nature to the Tatestown Fault (the "B" and "T" Faults) is known to be post-ore and pre-Arundian, we deduce that stages 4-6 are also pre-Arundian and probably Upper Courceyan-Chadian. The Stage 7 systematic veins almost certainly represent regional post-Hercynian jointing.

Nature of the mineralizing fluids

Fluid inclusion studies on Stage 5 calcites and sphalerite crystals by Probert (pers. comm. 1983) and Caulfield et al. (this vol.) have shown salinities in the range 10-12 equivalent wt.% NaCl and homogenization temperatures of 140°-

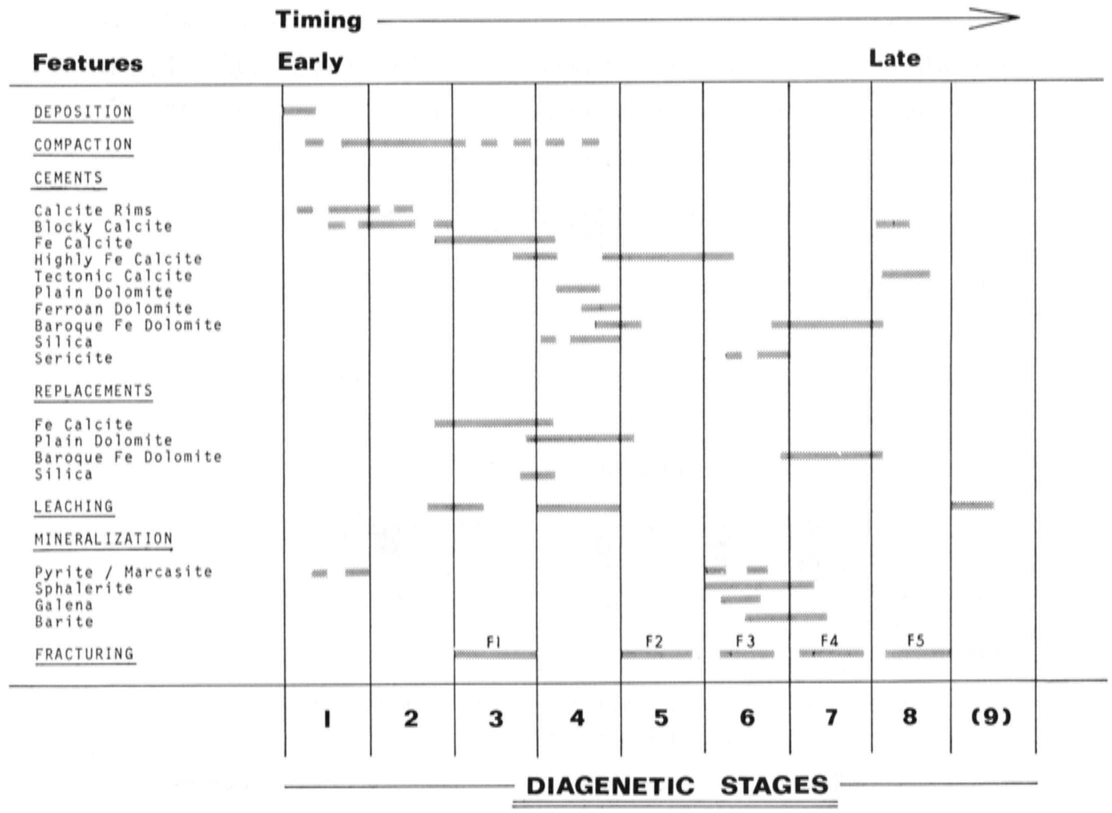

Figure 7. Summary of the diagenetic stages.

190°C. Catlin (1983) and Caulfield et al. (this vol.) have obtained sulphur isotope results which show a range of values interpreted to show derivation of sulphur from a local basement source mixing with subordinate sea-water (connate) sulphate during mineralization. Early pyrite shows an isotopic range indicative of sulphur derivation from biogenic reduction of seawater sulphate. The absence of significant dissolution of host rock during mineralization combined with the lack of Fe sulphides suggests that the ore brines were neutral to alkaline and deficient in reduced sulphur.

Genetic model

Figure 8 shows, diagrammatically, the major aspects of the proposed genetic model for the Tatestown prospect. On paragenetic evidence mineralization occurs relatively early in diagenesis but under lithic conditions. Mineralization is controlled by synchronous faulting and localized by pre-existing stratigraphic controls.

The primary stratigraphic control is thought to originate by hiatic exposure of the micrite tidal flat prior to transgression by the sub-tidal ooid shoal facies belt. This exposure led to dessication, algal mat development and local channelling. Below this surface early dolomitization took place (paragenetic Stage 4). Continued sedimentation led to the burial of this horizon.

As the Tatestown Fault was initiated, tensional sub-vertical fracturing developed which was exploited by rising hydrothermal fluids migrating from the Lower Palaeozoic basement. As the fluids moved up the incipient fault zone, focussed at the position of initiation and subsequent maximum throw, they migrated laterally below resistant, impermeable horizons. Thus the tightly cemented dolomicrites controlled lateral fluid migration, below which fracture-related permeability enabled the deposition of sulphides. On-going fracturing maintained this permeability for continued sulphide and post-sulphide carbonate deposition.

In comparison to Navan, mineralization at Tatestown was initiated later, possibly coevally with the late stage cross-cutting styles as described by Andrew and Ashton (1982, 1985) and thus no exhalative or bedding-parallel styles are seen. Sulphur isotope results concur with this late stage model by indicating a closed system and little incursion of seawater sulphate.

Acknowledgements

The authors gratefully acknowledge Ennex International PLC and Getty Mining (Ireland) Ltd. for permission to publish this paper, and to include much unpublished data compiled by staff at the Getty Research Centre, Houston, Texas.

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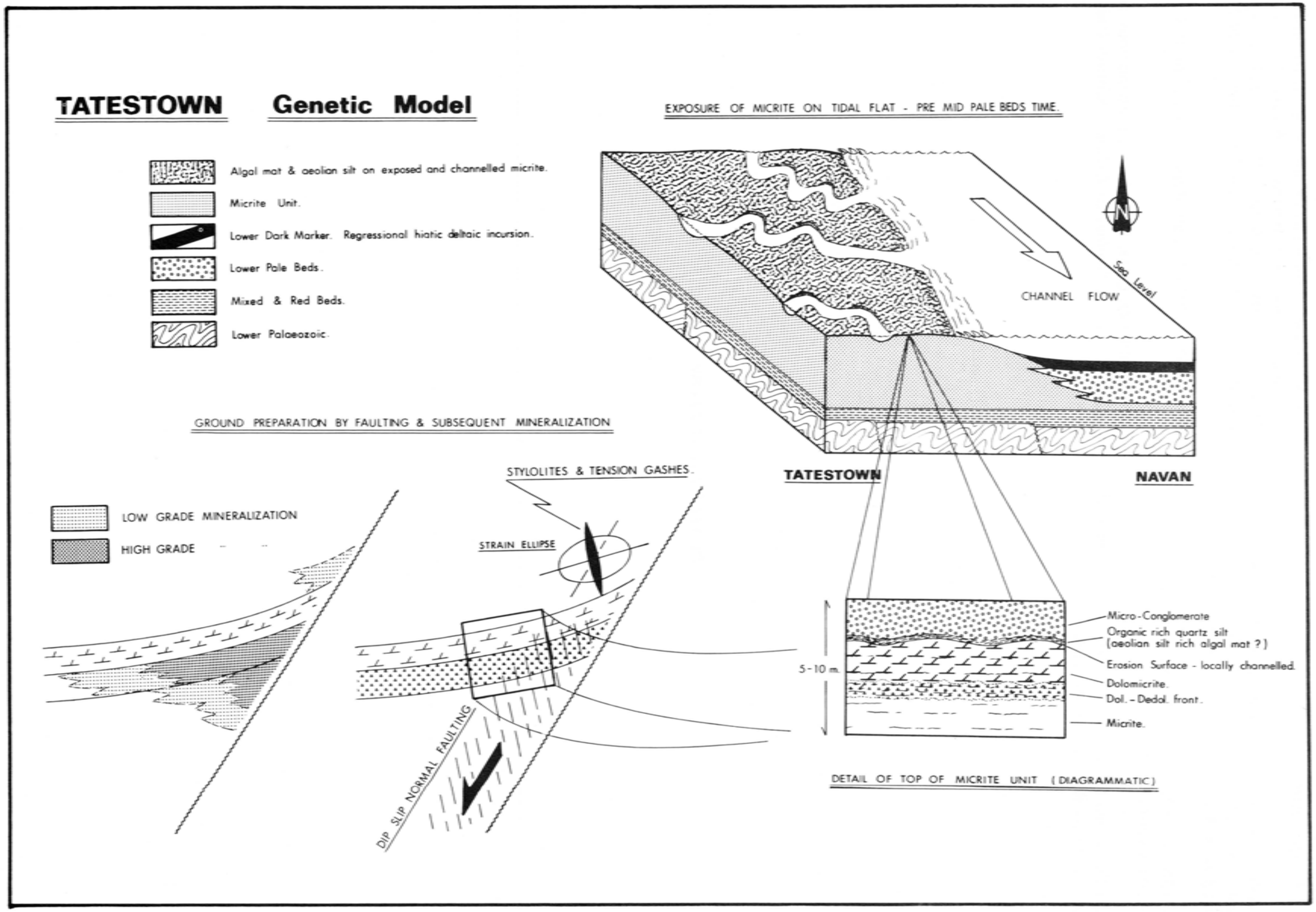

Figure 8. Diagrammatic representation of key points in the genetic model.

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PLATES 1-12 FOLLOW

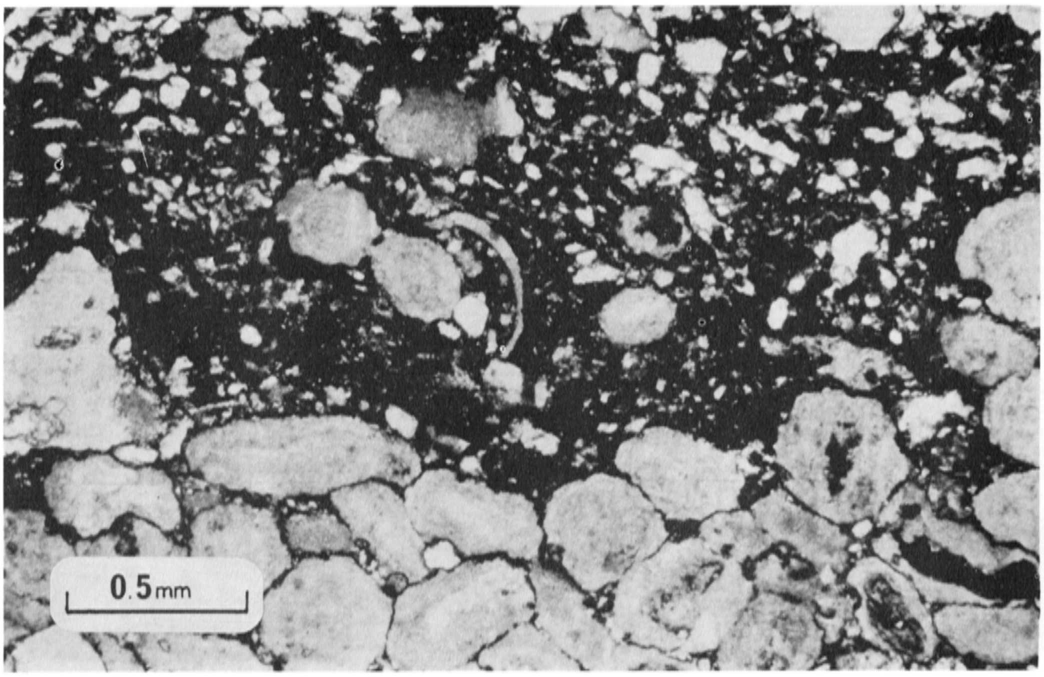

Plate 1. Ooliths distorted by compaction. Middle Pale Beds. Drillhole BF 29, 97.3m; Acetate peel.

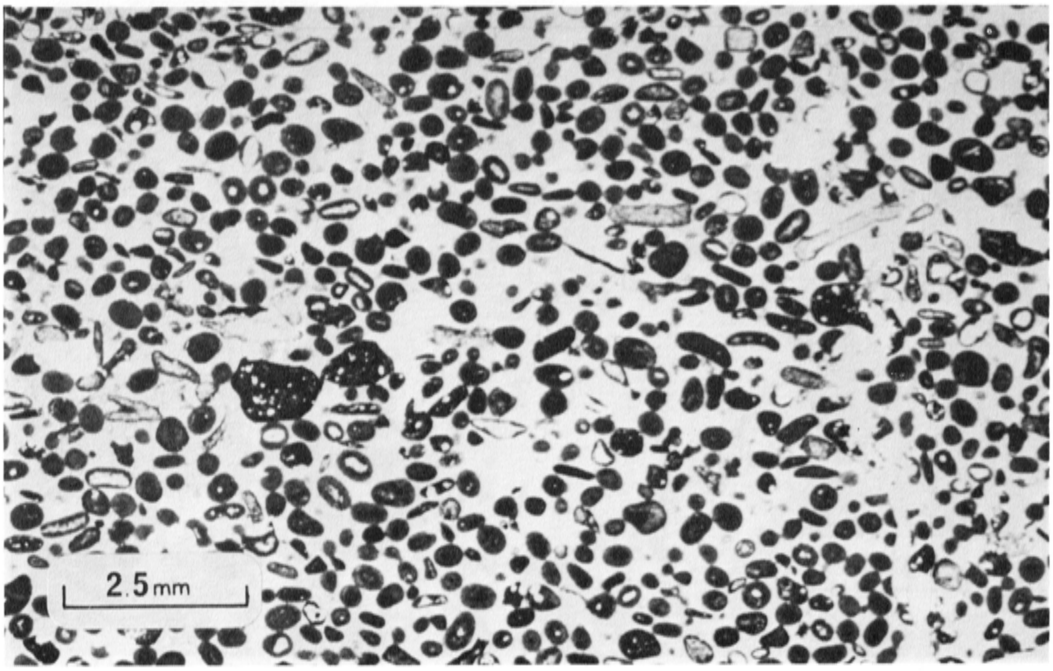

Plate 2. Oolitic, pelletal bioclastic grainstone with minor angular quartz silt. Fossil detritus includes crinoid, bryozoa and foraminifera fragments. Typical Middle Pale Beds. Drillhole BF 29, 110.0m; Stained thin section.

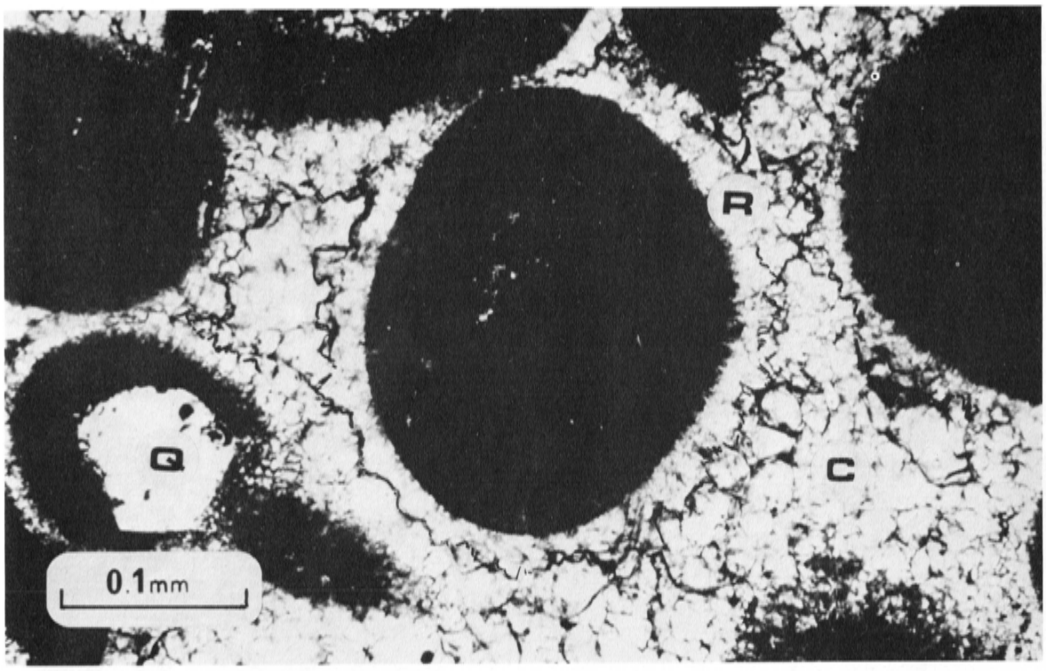

Plate 3. Oolitic grainstone showing early (Diagenetic Stage 1) freshwater phreatic bladed calcite rim-cement [R] and later blocky ferroan calcite [C]. One oolith has a detrital quartz grain as its nucleus [Q]. Drillhole BF 29, 110.0m; Detail of Plate 2; Stained thin section.

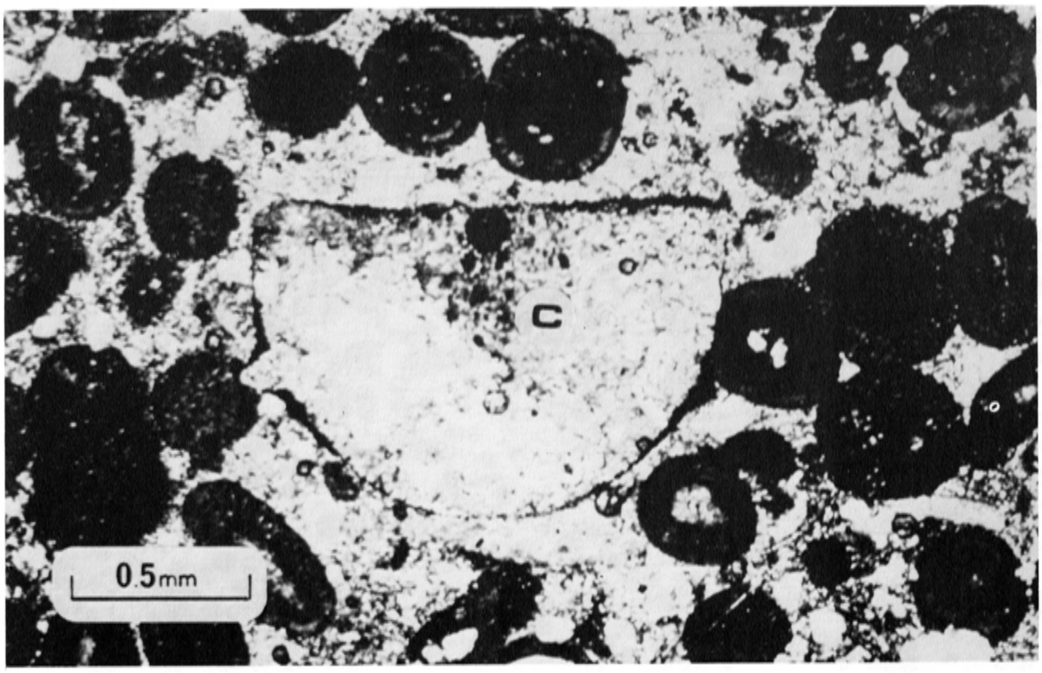

Plate 4. Bioclastic oolitic grainstone showing a fragmented crinoid ossicle [C] replaced by, in turn, ferroan calcite, dolomite and silica during Stages 3 & 4. Drillhole BF 29, 97.5m; Stained thin section.

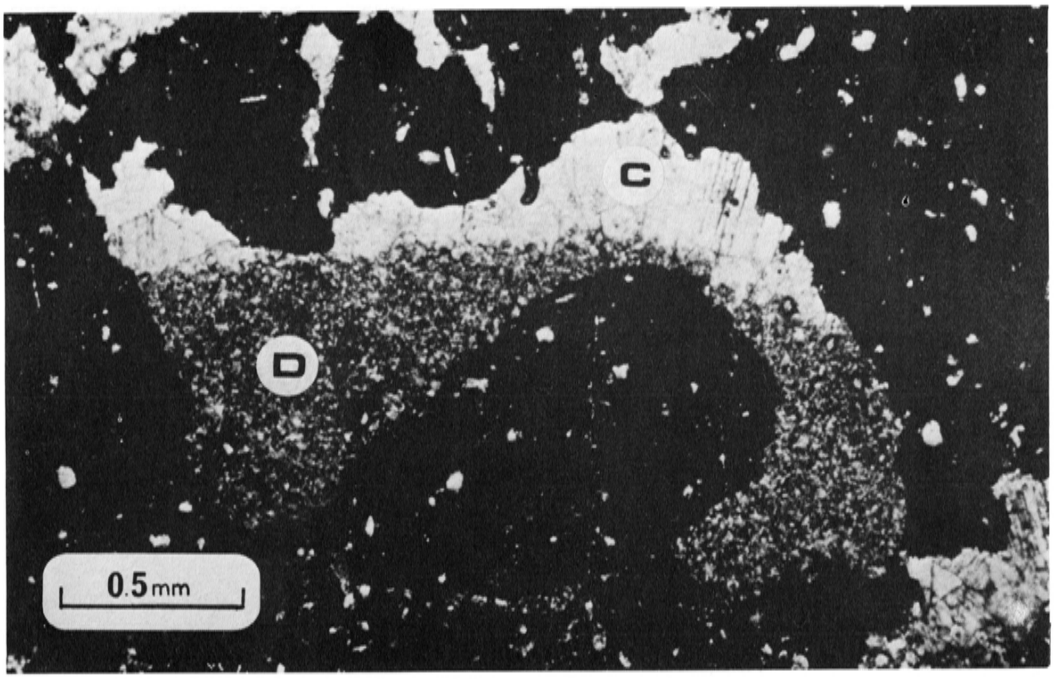

Plate 5. Carbonate mudstone, probably originally aragonite, replaced by low-iron calcite (black) with minor white quartz silt grains. A well developed 'birdseye' void shows geopetally laminated dolomite silt [D], overlain by blocky spar calcite [C] of Stage 1 and 2. Micrite Unit.
Drillhole BF 21, 49.2m; Stained thin section.

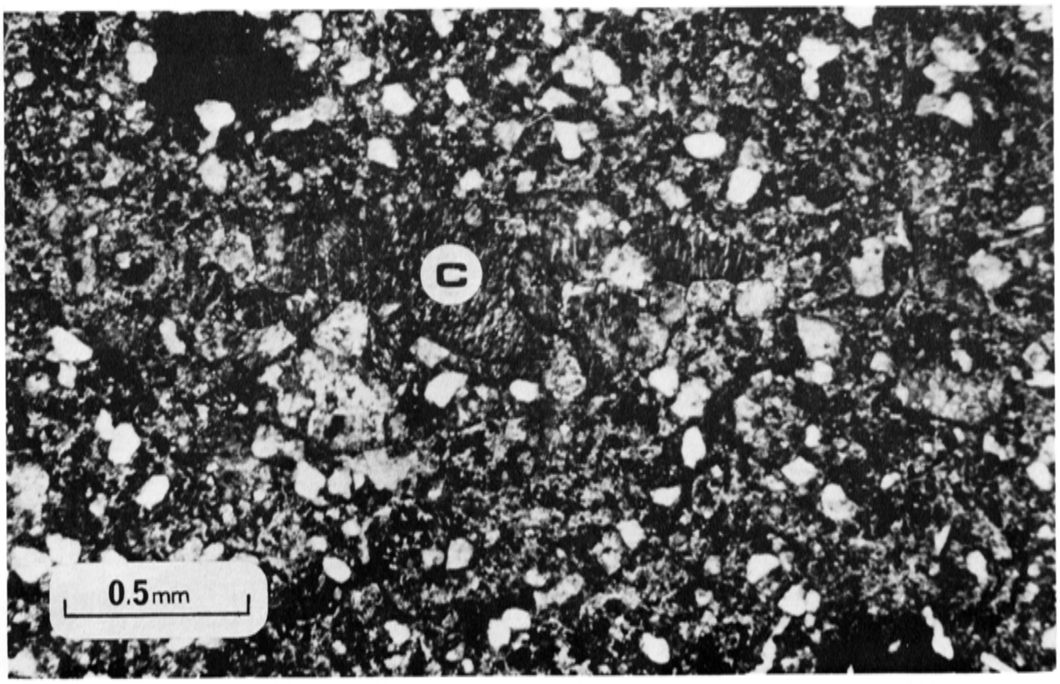

Plate 6. Replacement dolomite, Stage 4, after a primary carbonate mudstone, the 'MPC'; note terrigenous quartz grains (white) and sparry calcite [C] within a relict 'birdseye' void.
Drillhole BF 29, 142.7m; Stained thin section.

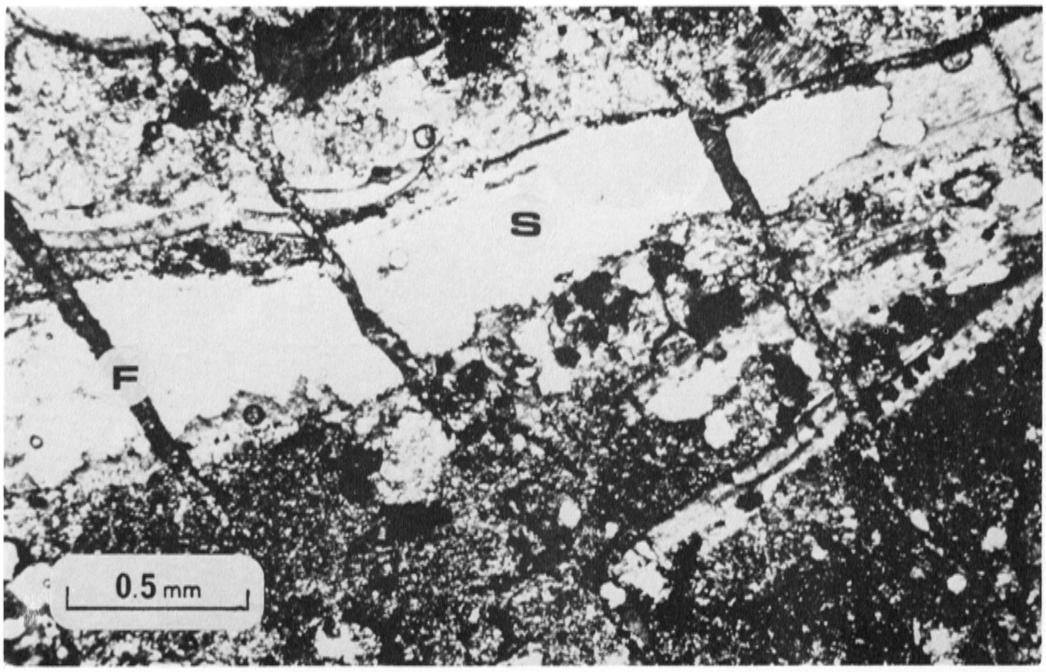

Plate 7. Brachiopod valve in Middle Pale Beds showing partial replacement by silica [S] of Stage 4, cut by fractures infilled by Stage 5 highly ferroan calcite [F]. Note micro-displacements along these fractures. Drillhole BF 29, 97.3m; Stained thin section.

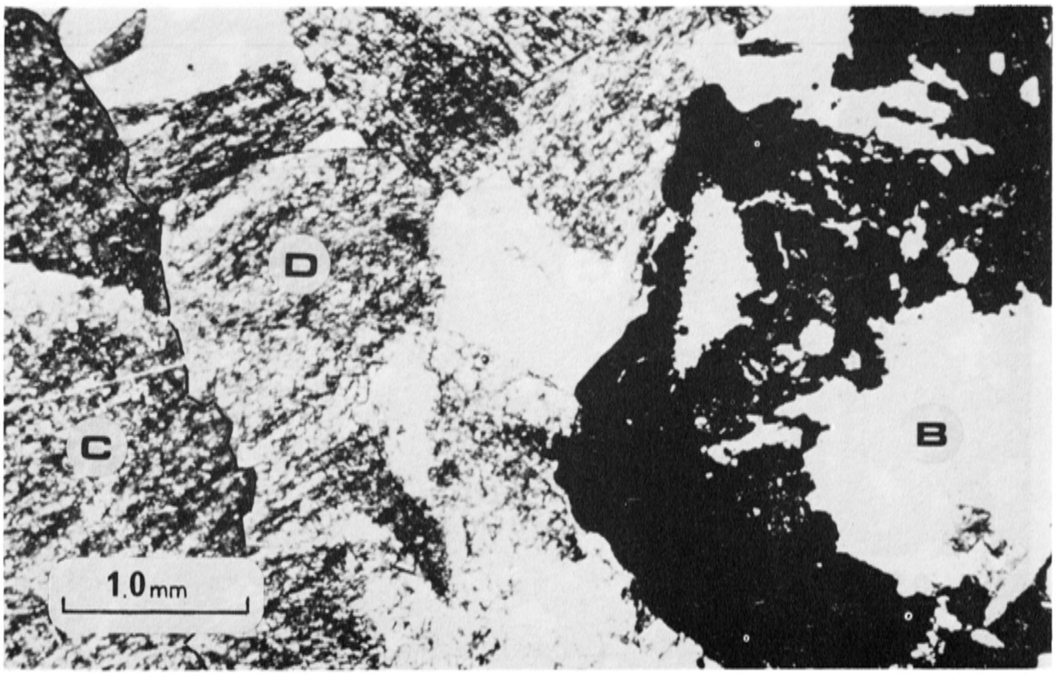

Plate 8. Stage 6 mineralization comprising intergrown sphalerite and galena (black) with barite [B]; later ferroan calcite [C] and ferroan dolomite [D] infill the breccia void. Micrite Unit.
Drillhole BF 29, 142.7m; Stained thin section.

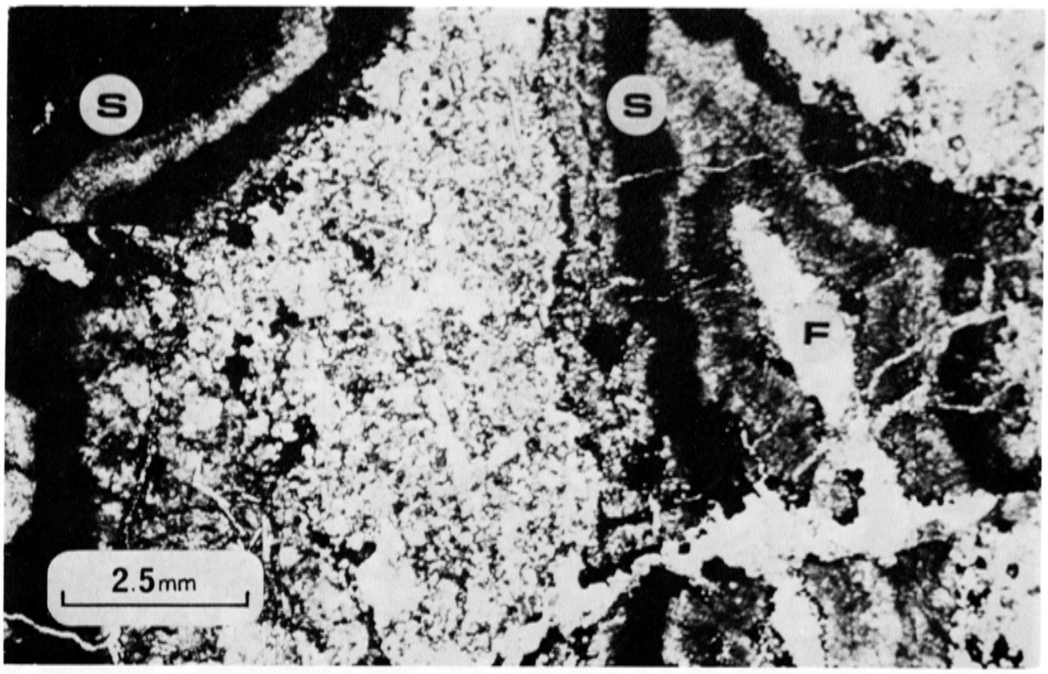

Plate 9. Colloform, colour-banded sphalerite [S] lining voids and fractures in silty micrite. Later F3 fractures are lined with small galena crystals and infilled with ferroan calcite [F].
Drillhole BF 29, 137.8m; Stained thin section.

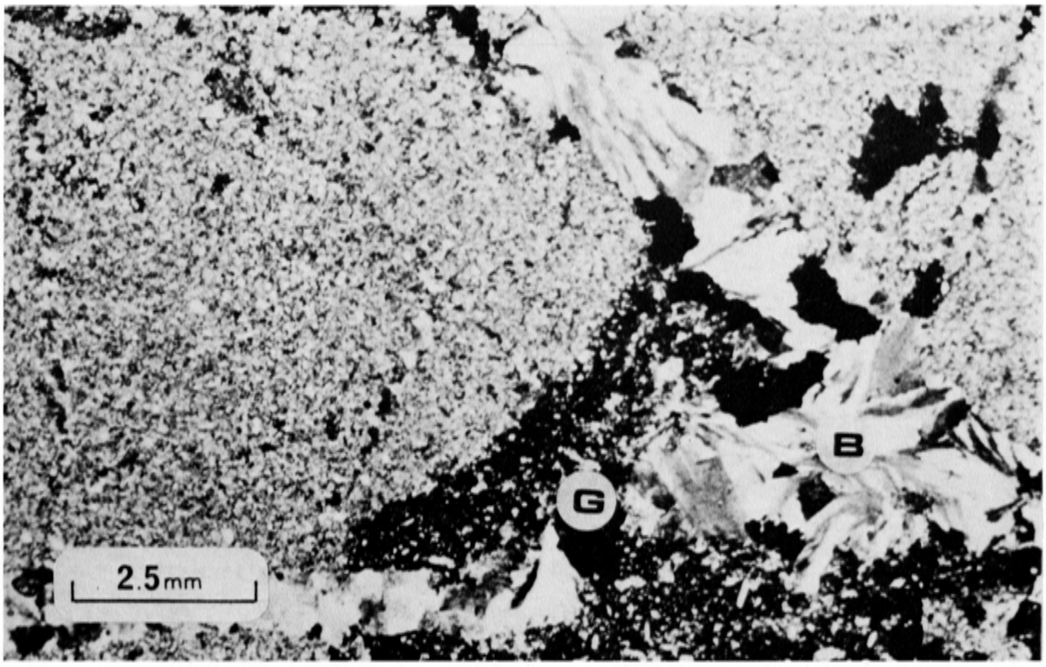

Plate 10. Finely crystalline dolomicrite cut by F3 mineralized fractures infilled with barite [B] and galena [G].
Drillhole BF29, 150.1m; Stained thin section.

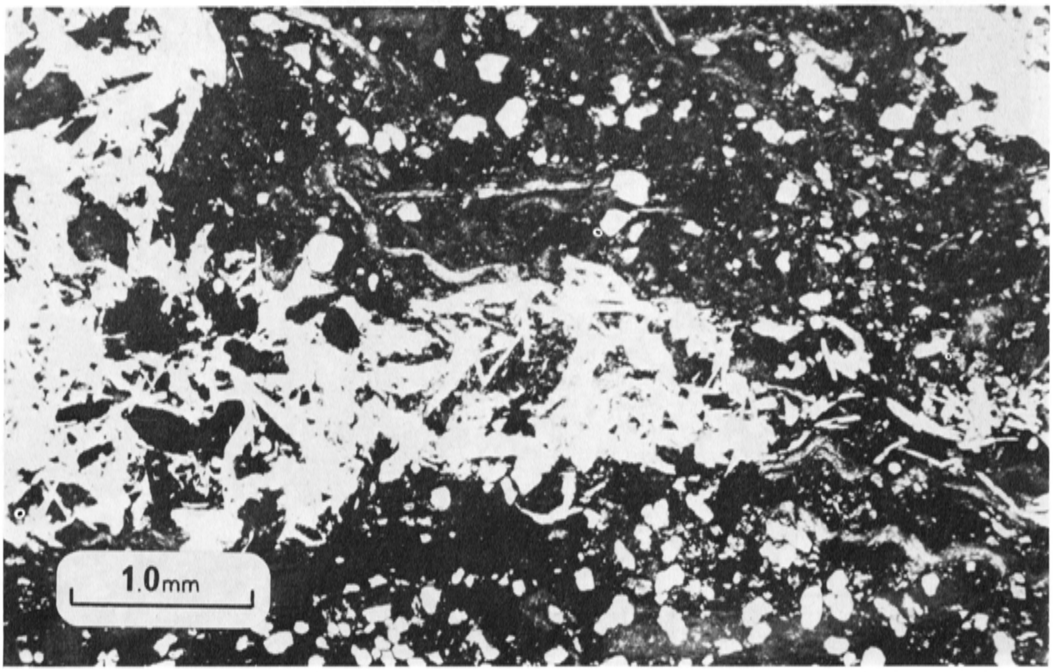

Plate 11. Barite laths (white) following the depositional texture of the host silty bioclastic wackestone, Middle Pale Beds.
Drillhole 1437-75, 246.1m; Stained thin section.

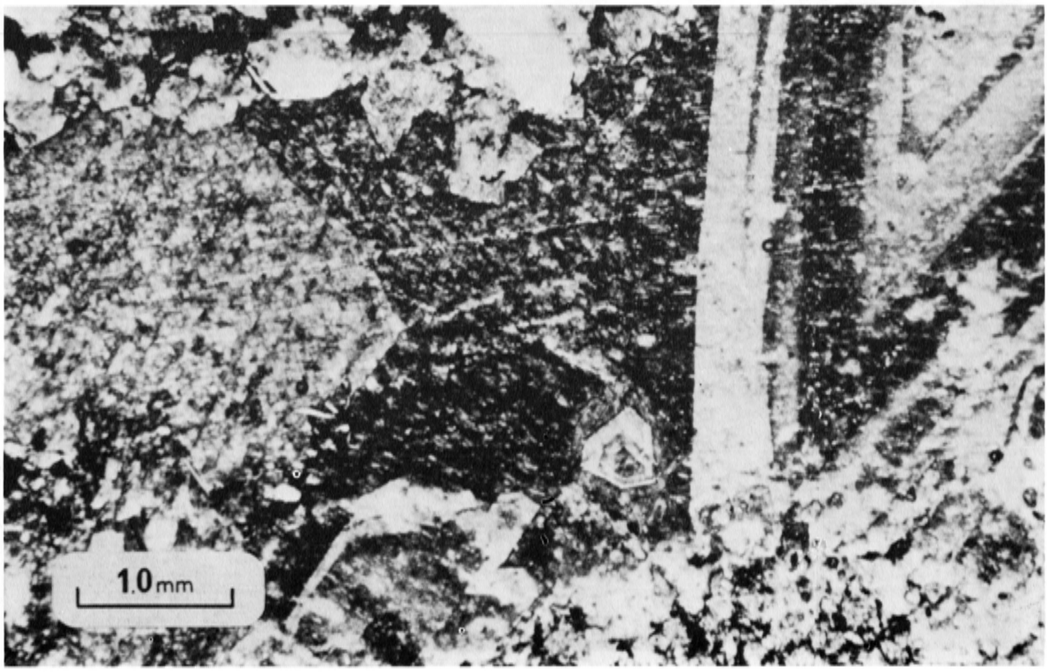

Plate 12. A late stage fracture, (F5) cutting an oolitic wackestone, Middle Pale Beds; infilled by coarse-grained zoned ferroan calcite.
Drillhole BF 29, 111.2m; Stained thin section.