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THE TECTOGENESIS OF THE TELFER GOLD-COPPER ORE SYSTEM IN THE PROTEROZOIC PATERSON OROGEN, NORTH WESTERN AUSTRALIA

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Abstract: This paper reviews the tectonic genesis of the Telfer Au-Cu ore system in the Paterson Orogen, NW Australia. Most previous tectonic interpretations have focused on the regional compression-related tectonic processes. These interpretations, however, could neither explain the tectonic deformation nor the distribution of mineralisation. Tectogenetic analysis indicates that the Telfer deposit comprises two overlapping structural domains, both developed as a result of the upward propagation of basement fractures. The first domain represents a local compression-shear-related regime that initiated tectonic deformation and tectonic shortening of the host rock. This regime had a limited role in the mineralising processes. The second, more important regime for mineralisation control, is associated with local shear-extensional tectonic processes. At deposit scale, concurrent development of a normal dip-slip movement along the earlier formed bedding surfaces and the basement propagated steep reverse-slip shearing along NW–SE (S2) trending structures, parallel to the strike of the Paterson Orogen, are the most important tectonic processes of this domain. Bedding surface extensional openings and development of second order structures with N–S (E3) and NW–SE (E2) orientation controlled the tectonic genesis of the majority of orebodies and mineralised zones forming the Telfer ore system.

Key words: Telfer, Au-Cu system, tectogenesis, extensional model, convex structures, basement, Australia.

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INTRODUCTION

Telfer is a world class Au-Cu deposit, and as a gold resource it ranks within the top ten ore systems in the world (Fig. 1). It lies within the largely concealed Proterozoic Paterson Orogen of North Western Australia (Fig. 2). Despite more than 30 years of exploration and research, open-cut and underground production at Telfer since its discovery in 1972, it is obvious that a tremendous amount of potential remains and our understanding of the nature and controls on mineralisation is limited (Baker, 1994).

Since its discovery, several structural models of the deposit's ore system geometry have been developed. In general, two significantly different concepts for tectonic deformation and the mineralisation-controlling mechanisms have been proposed:

(1) A mechanism comprising regional horizontal compression, including strike-slip, fold flexural-slip, thrust, and inhomogeneous tectonic shortening of the host rock sequence for mineralisation emplacement, and

(2) A mechanism comprising a local (Telfer-scale) basement upward propagated shear-extensional tectonic deformation regime and corresponding mineralisation events.

In this paper the development of conceptual ideas on the Telfer tectogenetic model, in particular for the ore system, are discussed. Despite many years of intensive exploration and mining of the deposit, satisfactory evidence has not been found in support of regional compression as an adequate explanation of relationships between deformation geometry and distribution of mineralisation.

More recently, systematic tectogenetic analysis has been applied in the search of an alternative model to be used in the interpretation of ore system forming tectonic mechanisms (Bogacz, 2001, 2002b). Based on this approach, a new Telfer ore system tectonic genesis model has been developed, with a predictive capacity indicating potential positioning of the mineralised zones. Key aspects of this model are explained in the following paragraphs.

REGIONAL GEOLOGICAL BACKGROUND

Prior to reconnaissance mapping by the Geological Survey of Western Australia during 1974–1975 geological knowledge of the Paterson Orogen was extremely limited

Fig. 1. An aerial view of the Telfer deposit prior to commencement of production (middle 1970's). Looking North

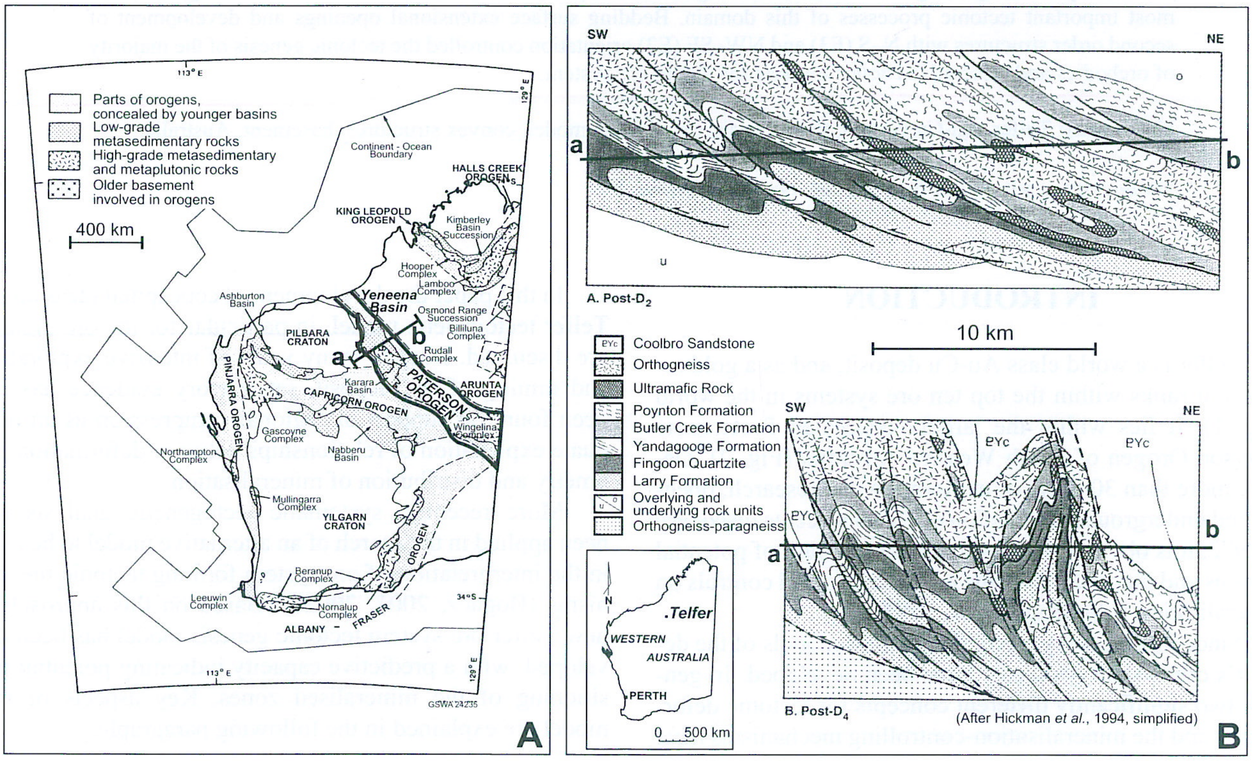


Fig. 2. Paterson Orogen: **A** – geological setting, **B** – thrust-style of tectonic deformation

(Hickman *et al.*, 1994). The mapping and investigation of regional geology and lithology (Blockley & de la Hunty, 1975; Hickman *et al.*, 1994; Bagas *et al.*, 1996), and tectonic evolution and structural setting (Ethridge *et al.*, 1987; Williams & Myers 1990; Hickman *et al.*, 1994 and, recently, Bagas, 2004) of the Paterson Orogen indicate the following.

Lithostratigraphy. The Paterson Orogen consists of the Ruddal Complex, predominantly igneous and sedimentary rocks metamorphosed to amphibolite facies, uncon-

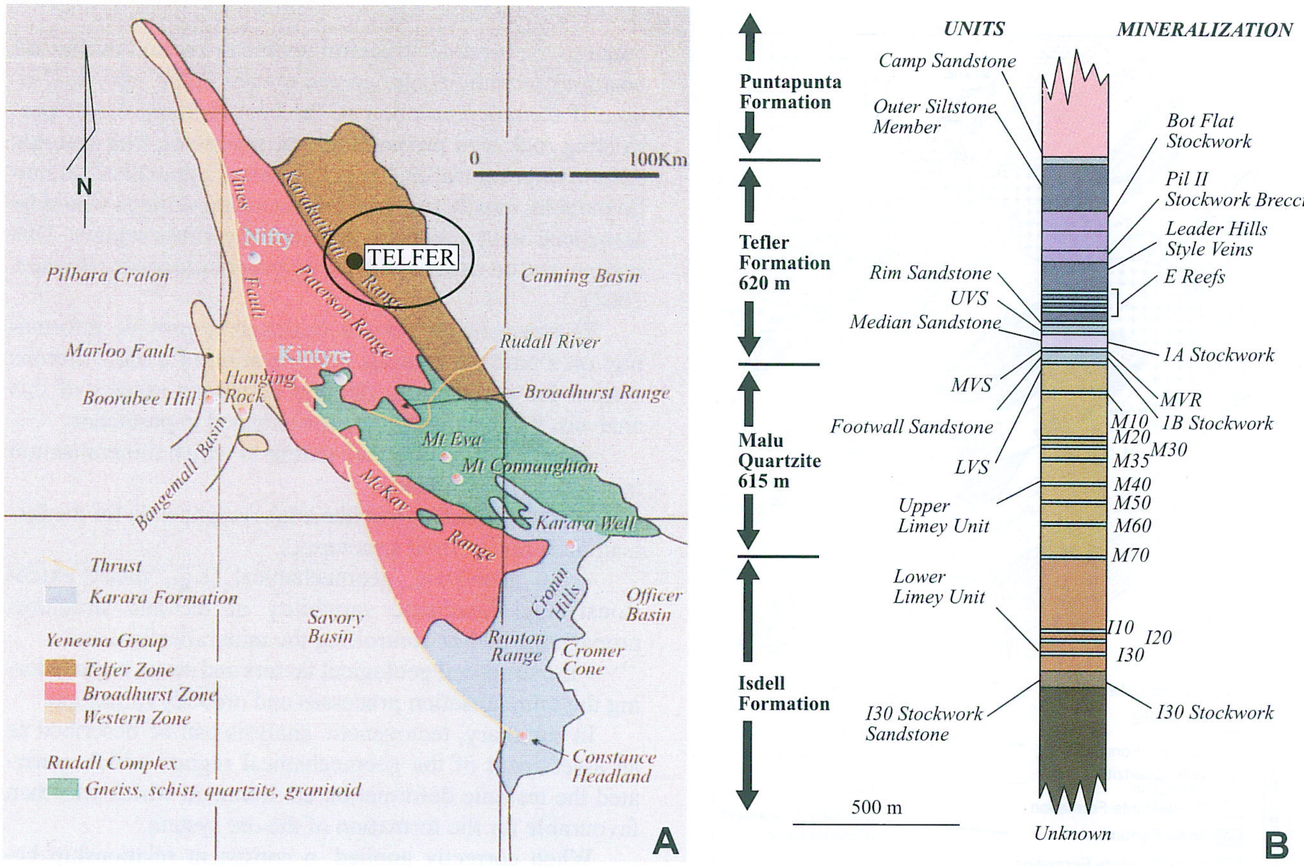


Fig. 3. Telfer deposit: **A** – location within the Paterson Orogen, **B** – lithostratigraphic profile and positioning of mineralisation

formably overlain by the clastic and carbonate sequences of the Yeneena Group, which also are unconformably overlain by the clastic and carbonate rocks of the Karra Formation (Figs 2A, 3A).

The Palaeoproterozoic Ruddal Complex has a long history of multiple deformation and metamorphic processes, however, two units, older banded orthogneiss and paragneiss, and younger quartzite and schist are distinguishable (Hickman *et al.*, 1994).

The Neoproterozoic Yeneena Group stratigraphic succession is regionally variable due to deposition in three zones of differing palaeogeographic, tectonic, metamorphic, and igneous history. The Yeneena Group predominantly consists of the weakly to moderately deformed shallow-water marine sandstones, siltstones and dolomitic carbonates which have undergone lower greenschist metamorphism (Chin & Hickman 1977; Williams, 1990). A part of the Yeneena Group geological succession is the Telfer Zone (Fig. 3A). A number of lithostratigraphic units of the Telfer Zone were distinguished, which dominate the stratigraphic profile in the Telfer area and host the Telfer mineralisation (Fig. 3B). These host metasedimentary sequences are largely exposed on the surface through thin Quaternary cover and remnant Permian fluvioglacial sediments.

Deformation and orogenic processes. The Paterson Orogen is a significant NW–SE striking regional feature. A tectonic contact along the NE margin of the Archaean Pilbara Craton determines geometry of the NW part of the orogen.

The Proterozoic Capricorn Orogen of the central Western Australia appears to the SW of the Paterson Orogen, whereas in its NE proximity, the Proterozoic Arunta Orogen/Inlier is present (Fig. 2A). In the Palaeoproterozoic, the similarities in deformation and metamorphic histories for these separated regions indicate a continent-continent collision event between the Palaeoproterozoic West Australian and North Australian Cratons between ca. 1830 and 1765 Ma. In the Paterson Orogen, this collisional event (Yapungku Orogeny) produced intensive thrust stacking of clastic sediments and volcanics, deposition of protoliths for the ca. 1790 Ma siliciclastic paragneiss succession contemporaneous with granitic intrusive activities, and up to granulite facies metamorphic processes (Bagas, 2004). During this period, the Capricorn Orogen and Arunta Orogen/Inlier were also deformed, metamorphosed at medium to high grades and intruded by granitoids (Capricorn Orogeny & Strangways Orogeny, respectively).

The Neoproterozoic clastic sedimentary sequences were deposited after 1070 Ma in the NW Paterson Orogen and deformed before 678 Ma (Bagas, 2004). This deformation event (Miles Orogeny) produced a NW–SE trending compressive tectonic deformation dominated by intensive folding, faulting, and thrusting directed to the southwest (Fig. 2B). There are equivalent tectonic developments at the Arunta Orogen/Inlier and other Neoproterozoic geological units of central Australia.

The late Neoproterozoic tectonic history of the northwestern Paterson Orogen includes emplacement of grani-

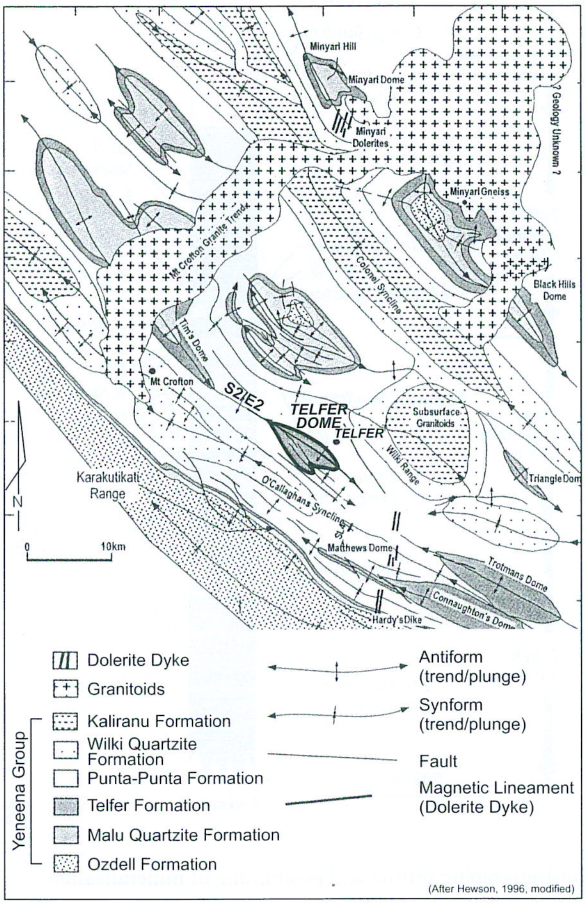


Fig. 4. Geological setting of the Telfer deposit

toid intrusions, ca. 640–690 Ma, of which the Mt. Crofton Granite is the most prominent feature in the Telfer proximity (Fig. 4), which was followed by deformation processes associated with the Paterson Orogeny (ca. 550 Ma).

The similarities of style and timing of deformation and metamorphism in the NW Paterson Orogen, Capricorn Orogen, and Arunta Orogen/Inlier indicate that these three regions were probably linked during most of the Proterozoic (Bagas, 2004).

CONCEPT AND METHOD OF INVESTIGATIONS

Metalliferous deposits, regardless of whether they are considered as originally structurally controlled or not, can be described as an association of the *host rock* and the *mineralisation*. The distribution of the mineralisation, including positioning of of high-grade zones within the host rock, determines the *ore system*.

Any ore system displays its own unique geometry, but as a rule, it is closely linked or follows the geometry and pattern of specific tectonic structures. In most cases, tectonic structures that confine the mineralisation display secondary development. As a consequence, structures and tectonic processes controlling the formation of ore systems appear to be separated and later formed tectonic features compared to the original structural geometry created during the host rock tectonic evolution and metamorphic recrystallisation. If tectonic evolution of the host rock represents pre-existing rock wall preparation type processes, then tectonic deformation controlling emplacement of mineralisation into favourable, mostly rejuvenated, structural settings would be associated with a specific and separate stress regime. This regime can be explained by *tectogenetic analysis* (Bogacz, 2001).

Tectogenetic analysis is designed to provide information on a uniform tectonic interpretation of a metalliferous system for any deposit. Among numerous aspects of this analysis, the following were investigated in particular:

– the specific structural setting in which mineralisation is, or could be confined,

– the deformation mechanism(s) responsible for the formation of mineralised structures,

– the geometric, geomechanical (e.g., shear, extensional) and kinematic variability of tectonic structures propagating and/or controlling the mineralisation, and

– the structural geological factors and stress regime during the mineralisation processes and orebody formation.

In summary, tectogenetic analysis can be described as an assessment of the geomechanical regime which generated the tectonic deformation environment which was then favourable for the formation of the ore system.

When correctly applied, a consistent relationship between tectonic deformation and the pattern of mineralisation can be identified. If the formation of this model could be linked with the structural geological factors, e.g., the surrounding granite or other magmatic body updoming, or basement fracture activity, the explanation of the origin for the ore system could be reached. Then, this may be used to define a uniform tectonic deformation and mineralisation model, which is the *ore system tectogenetic model*.

This paper is constructed in a way that the description and nature of mineralised zones, and historical outline of interpretations and views by various authors on the tectonic model and the formation of the Telfer deposit are discussed first. Then, the results and conclusions from the author's own investigations are presented in a way to build up a progressive understanding of the Telfer ore system tectogenesis. This is based on tectogenetic analysis of the data collected at Telfer over several years, particularly between 1996 and 1998. The findings were sufficient to explain Telfer mineralisation in a uniform tectogenetic model.

TELFER MINERALISATION

Although a number of mineralised zones and deposits were discovered, including important deposits, like Nifty (Cu) and Kintyre (U), the Telfer Au-Cu deposit is the only world class mineralised system identified in the Paterson Orogen, at this stage (Fig. 3A). Telfer is located in the northeast proximity of the Karakutikati Range, a regionally significant NW–SE trending shear-fault system. In the Telfer district large synclinoria and anticlinoria are present. These mega-structures strike NW–SE and generally are parallel to the trend of the Karakutikati Range. This is mim-

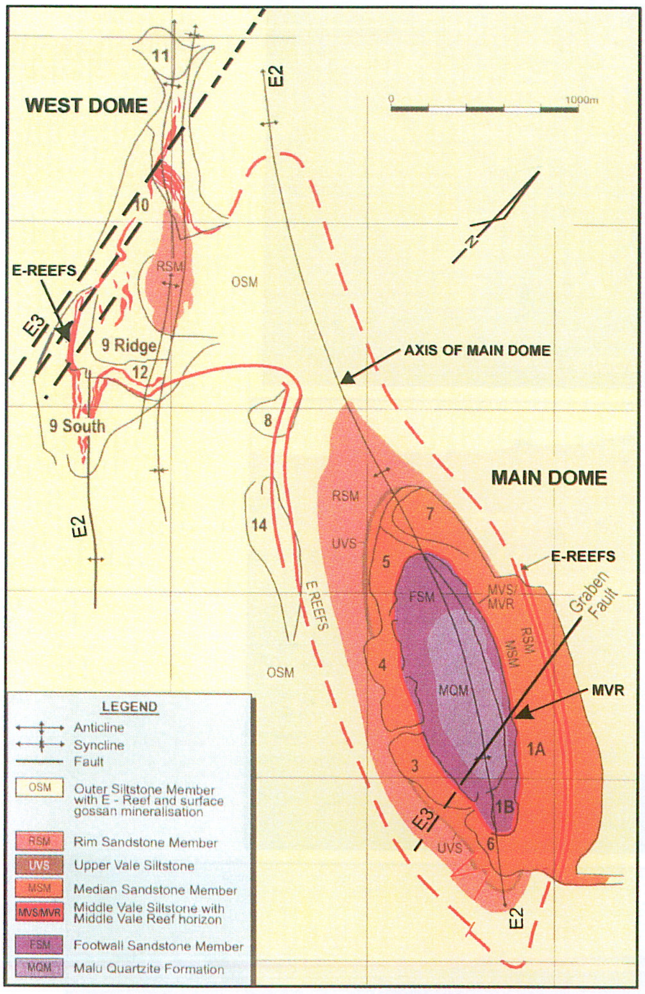


Fig. 5. Major geological and tectonic features. West Dome and Main Dome of Telfer deposit

icked by smaller regional domal antiform and synform culminations, and the Neoproterozoic granitoids, including the Mt. Crofton Granite suite (Fig. 4). These may have been instrumental in gold, copper and other mineralisation during later phases of the Paterson orogenic activities, as mineralisation is, or is interpreted to be, coincident with emplacement of the granitoids (Goelnicht *et al.*, 1989; Bogacz, 1990; Goelnicht *et al.*, 1991; Laing, 1993b; Sexton, 1994).

The Telfer deposit displays a weathering profle at the near surface development, which is superimposed on a primary Au-Cu system with the mineralisation that occur both in strata-concordant reefs and strata-discordant stockwork/vein system and tectonic breccia zones. Quartz, quartz-carbonate, quartz-sulphide and sulphide veins dominate throughout the mineralisation profile of the deposit. The oxidised upper level of the deposit is gold in quartz vein, free gold, and gossan material after stockwork with copper less than 100 ppm. The transition zone is gold with copper carbonate minerals, such as azurite and malachite, native Cu and secondary chalcocite. The primary zone is gold with pyrite and chalcopyrite.

The nature of the mineralised zones at Telfer has been the subject of numerous conflicting concepts and hypotheses (Switzer, 1994). Early genetic models invoked syngenetic-exhalative processes (Tyrwhitt, 1985), however, later epigenetic replacement (of fine-grained siltstone units within a specific geological formation, e.g. the Telfer Formation) models suggest that mineralisation was derived predominantly from magmatic fluid sources (Goelnicht *et al.*, 1987; Dimo, 1990; Goelnicht, 1992). This is in contrast to the interpretation of Rowins (1994), who points that granites acted as heat sources to circulate hydrothermal fluids throughout the sedimentary sequence. Recent thinking on the origin of mineralisation has moved away from these concepts, being a syngenetic or replacement to a structurally-controlled epigenetic that could occur in any formation within the mine sequence (Howard *et al.*, 2000).

At Telfer, the host rocks form an ellipsoidal, NW–SE elongated domal structure. This includes two major subdomains called the Main Dome and West Dome (Fig. 5). In the geological literature, these domes are described as "en-echelon doubly plunging anticlinal features". The traditional understanding of the Telfer ore system is that strata-concordant reefs, which are economically most important, occur in both domes and as bedding parallel features follow their domal geometries. However, results of this tectogenetic study indicate that the bedding parallel reef mineralisation is accompanied by a number of specific internal settings of second and lower order structures and is but one of several styles of tectonic deformation and associated mineralisation of the West and Main Domes. Additionally, lower grade strata-discordant stockwork, vein array, and tectonic breccia zones are developed in certain structural geometric patterns that form internal complexity of both domes. More important structural styles of mineralised zones are briefly discussed below.

Reef mineralisation. This forms a deposit-scale mineralisation pattern, which has traditionally been understood and presented as the Telfer deposit's only mineralisation style. The reefs are laterally extensive, formed mainly as relatively thin, continuous low-angle bedding parallel (stratabound) horizons. These include the most prominent mineralised features of the West and Main domes, such as MVR and E-Reefs (Fig. 5).

Although continuous and laterally extensive, the reefs display significant variations of tectonic deformation, thickness, and grade distribution. Several sets of mineralised veins and/or breccia zones form internal complexities in the reefs (see Fig. 12D). In fact, zones of high-grade mineralisation occur in specific locations, primarily forming a series of ore shoots within the reefs. As a rule, these are oblique to the host domes. In the Telfer Main Dome the reefs have been intersected down to 1000 m below the surface.

Intensive bedding parallel normal dip-slip movement is developed in the reef zones and in many situations the bedding surfaces have undergone significant rotation from typical low- to high-angle dipping, vertical, and even overturned attitudes leading to other style of deformation and mineralisation control (Figs 6A, 7A).

Flexure controlled mineralisation. Flexures and flexural bending of beds are important in the control of mineralisation in certain locations throughout West and Main Domes (Figs 6C, 6D). Flexure formation processes pro-

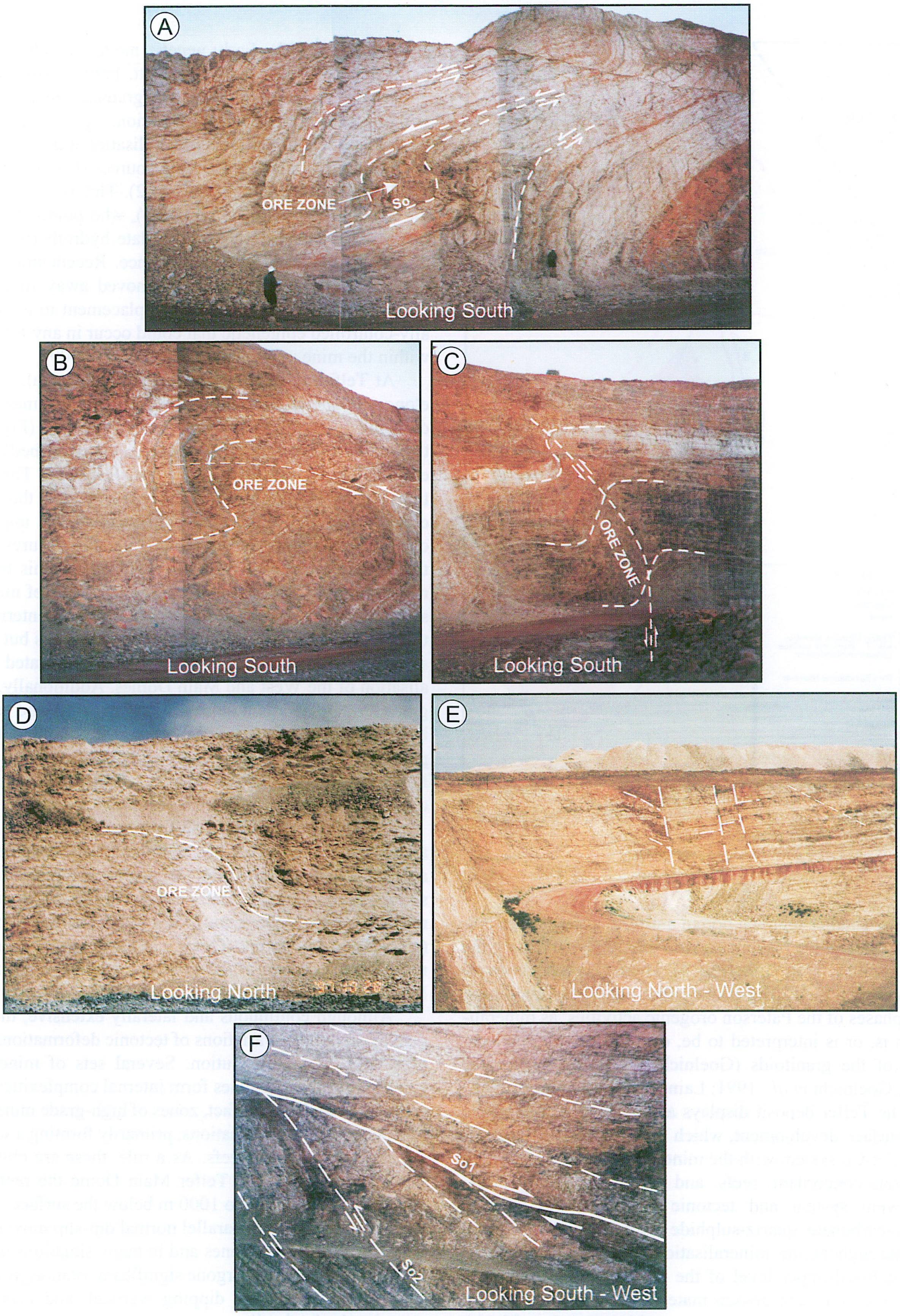


Fig. 6. Field examples of tectonic deformation and controls on mineralisation: **A** – normal dip-slip movement along the bedding controlling ore zone formation within the low-angle dipping western limb of West Dome, **B** – FF-structure controlling ore zone formation in West Dome, **C** – flexure and associated ore zone formed as a result of extensional openings of the bedding planes, upward flattening of axial zone and transition to FF-structure, West Dome, **D** – flexure controlling mineralisation, Main Dome, **E** – Graben Fault Zone of Main Dome, **F** – two-set system of bedding foliation (So1& So2) controlling E-Reefs mineralisation, West Dome

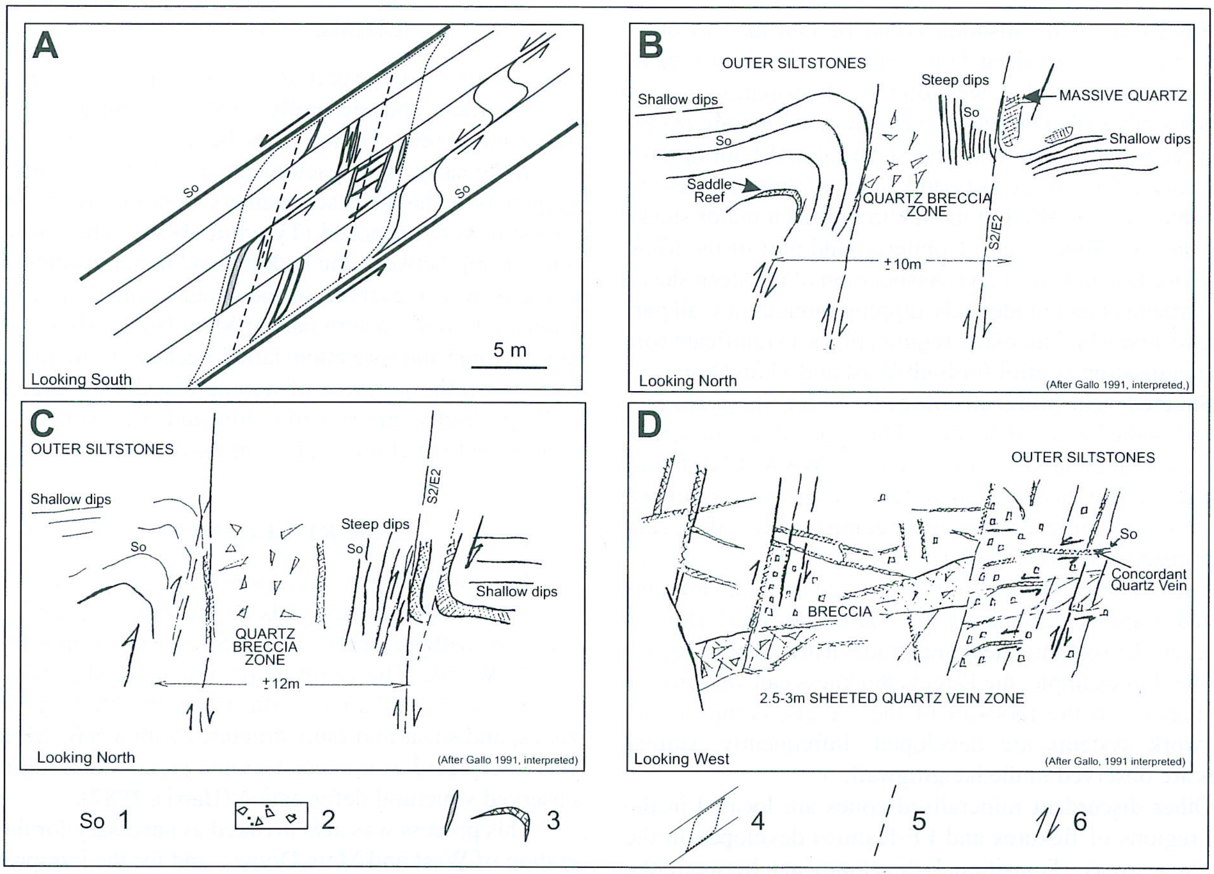


Fig. 7. Field sketches for structural deformation style in West Dome: **A** – bedding (So) parallel normal dip-slip movement and related pattern of mineralised veins and ore zones, **B, C** – steep reverse-slip S2/E2 shear/fault structures, related flexural bending of beds (So), and bedding-parallel extensional structures controlling mineralisation, **D** – pattern of low- and high-angle dipping shear, fracture and vein sets, Leader Hill vein mineralisation style. *1* – bedding (So), *2* – tectonic breccia, *3* – mineralised veins, *4* – zone of extensional deformation and/or ore zone, *5* – axis of propagation of mineralised vein system, *6* – arrows indicating direction and sense of tectonic movement

duced extensional openings of pre-existing bedding surfaces and accompanied lower order fault and fracture sets, all contributing to control of the placement, location and pattern of the mineralised vein sets and breccias (e.g., Fig. 14A).

Fold-flexure (FF-structure) controlled mineralisation. In this paper, the fold-flexure type structures are called FF-structures (Fig. 6B). These exhibit transitional tectonic characteristics between flexure and fold and many flexures upward gradually convert into FF-structures (Fig. 6C). The FF-structures display convex geometry of axial surface, and a specific indicative asymmetry always suggesting west and/or SW over east and/or NE directed and upward propagated movement (Fig. 14).

Although confined to the areas of certain structural complexity, where interference and/or gradual transition of low-angle and high-angle bedding surfaces develop specific FF-type geometry, this style of mineralisation forms an important part of the Telfer ore system in both domes (Fig. 6B). In contrast to laterally more extensive reef structures, these are locally controlled quartz vein and breccia systems that form *shoot type* orebodies and mineralised zones being particularly well developed in the core zones of the FF-structures. These occur in the regions, where intensive bedding parallel normal dip-slip movement is developed (Figs 6A, 7A) and the bedding surfaces together with mineralised veins have often undergone significant rotation from low-angle typical of the reef mineralisation, to high-angle dipping, vertical and even overturned attitudes.

Stockwork mineralisation. Stockworks form localised vein systems and breccia controlled ore bodies that are often present in areas of irregular bedding geometry, most commonly developing along moderately to steeply propagated shear/fault structures controlling mineralisation (Figs 7B, 7C), and in the axial zones and/or eastern steep to overturned limbs of asymmetric FF-features (Fig. 11A). As a consequence, the stockwork orebodies usually display a cross-bedding development along the structures to which they are confined, however, with stronger development when intersecting the bedding parallel structures.

Shear/fault related mineralisation. This mineralisation style is closely associated with and represented by localised stockwork breccia, and by vein and bedding parallel reef-type openings. These are developed in the vicinity of and result from the formation of steeply west and/or northwest dipping to vertical shears and faults. The Graben Fault Zone (GFZ) of Main Dome (Fig. 6E) and steep shear/fault structures with reverse-slip kinematics (Figs 7B, 7C) in West Dome are prominent features of this type of mineralisation.

Significant mineralisation could be confined to other types of reverse-slip shear/fault structures. These are moderately southwest and/or west dipping deformation/breccia zones, locally called *monoclines* (the monoclines are classified as representing reverse-slip shearing and faulting processes in Telfer and are not equivalents of "monoclines" in traditional sense). The I30 monocline forms a major stockwork breccia orebody in the underground part of the Main Dome ore system (Fig. 12A). Association of the steep shear/fault structures and moderately dipping monoclines, all part of the reverse-slip kinematic regime, plays a significant role in mineralisation control for both West and Main Dome.

Sheeted vein mineralisation. In Telfer, these are recognised as the Leader Hill veins. This type of vein mineralisation is predominantly represented by a WSW–ENE trending system. The sheeted vein system seems to be associated with a more brittle environment compared to other vein mineralisation styles (Fig. 7D).

The stratabound auriferous reefs are the dominant mineralised features throughout the Main and West Domes. However, the reef thickness and grade distribution is highly variable. For example, the E-reefs thickness can vary from 1 to 7 meters. In the footwall of these reefs, complex 3-D stockwork systems are developed. Infrequently, similar zones are observed in the hangingwall.

Other discordant mineralised zones are located in the axial regions of flexures and FF-features developed in the reef zone areas. Transitional developments between the flexure and FF-deformation and mineralisation style are observed (Fig. 6C). These commonly are understood as being marginal to well developed reef horizons. However, there is structural evidence indicating their independent development and significant roles in the mineralisation tectogenesis compared to the reef forming processes. Additionally, strong control on the mineralisation distribution by steep shear/fault and monocline type structures is present.

Unclear dominance of the reef controls on mineralisation and the presence of a number of other styles of mineralisation have required interpretation in a tectonic deformation context, and the creation of a uniform tectonic deformation and mineralisation model that explains all observations.

CONCEPTUAL MODELS ON MINERALISATION CONTROLS

Since its discovery, the Telfer ore system has been the subject of numerous interpretations. Among many scientific papers, the most comprehensive geological and structural geological studies of the Telfer deposit were undertaken by Ph. D. researchers from the University of Western Australia in Perth (Goelnicht, 1992; Rowins, 1994) and James Cook University in Townsville (Hewson, 1996). Also a number of other research studies contributed to the interpretation of the tectonic deformation and explanation of tectonic evolution and controls on the mineralisation. As a consequence, several models on the Telfer deformation and mineralisation controls have already been discussed. A short review of each is presented below.

SEDIMENTARY MODEL

At Telfer, a large part of the mineralisation is developed in concordant and, generally, shallow-angle dipping, bedding parallel reefs. Hence, at the beginning of mining activities in the early 70's, a sedimentary stratabound model and syngenetic-exhalative sedimentary controls for the mineralisation were proposed (Tyrwhitt, 1985). The concordant relationship between the bedding and mineralisation is particularly well preserved in the Malu Formation in the top hinge and in the eastern part of Main Dome. However, this non-tectonic interpretation failed because it could not explain, with the progress of mining and deeper exploration drilling results, grade variability and increasingly strong evidence of structural control on the ore system.

STRIKE-SLIP MODEL

This model suggests that most tectonic deformation observed at Telfer corresponds to horizontal regional compression, with σ_1, the Principal Stress Direction being oriented SW–NE. The resulting dextral strike-slip movement along regional foliation surfaces, main lithology contact zones, and shear and fault structures with a NW–SE strike, was interpreted as a major tectonic process controlling the observed structural deformation (Harris, 1987).

This process was also invoked as necessary for the generation of West and Main Domes, and for the interpretation that these structures are *en echelon* (Fig. 8A). Despite this, a flexural-slip mechanism of folding for the domes' formation was additionally required in this model to explain the nature and pattern of the mineralised reefs (Fig. 8B). Eventually, the strike-slip model was not supported by sufficient field evidence and later structural data led to the development of other concepts.

FOLD FLEXURAL-SLIP AND THRUST MODEL

In this model, SW–NE regional compression-related folding, fold flexural-slip and thrusting mechanisms are used to explain the tectonic deformation pattern and distribution of corresponding mineralisation (Hill, 1989; Vearncombe & Hill, 1993). This interpretation suggests that thrusting and fold flexural-slip mechanisms are critical tectonic processes in the development of "fault-controlled folds in the hinges of both domes", asymmetry of the domes, and the extensional character of tectonic features with accompanying mineralisation (Figs 9A, 9B). The asymmetry and frequent thrust association with the domes is understood as strong evidence for horizontal compression-related, fold-thrust controlled, tectonic deformation (Fig. 8C). The thrusts with a WNW–ESE trend show a SSW over NNE (reverse-slip) movement along predominantly 30°–40° SSW dipping surfaces (NNE directed thrust movement). However, this particular thrust geometry and kinematics has only been identified locally in the Telfer area. It also contrasts to the SW directed thrust movement for regional scale tectonic transport in the Paterson Orogen (Fig. 2B).

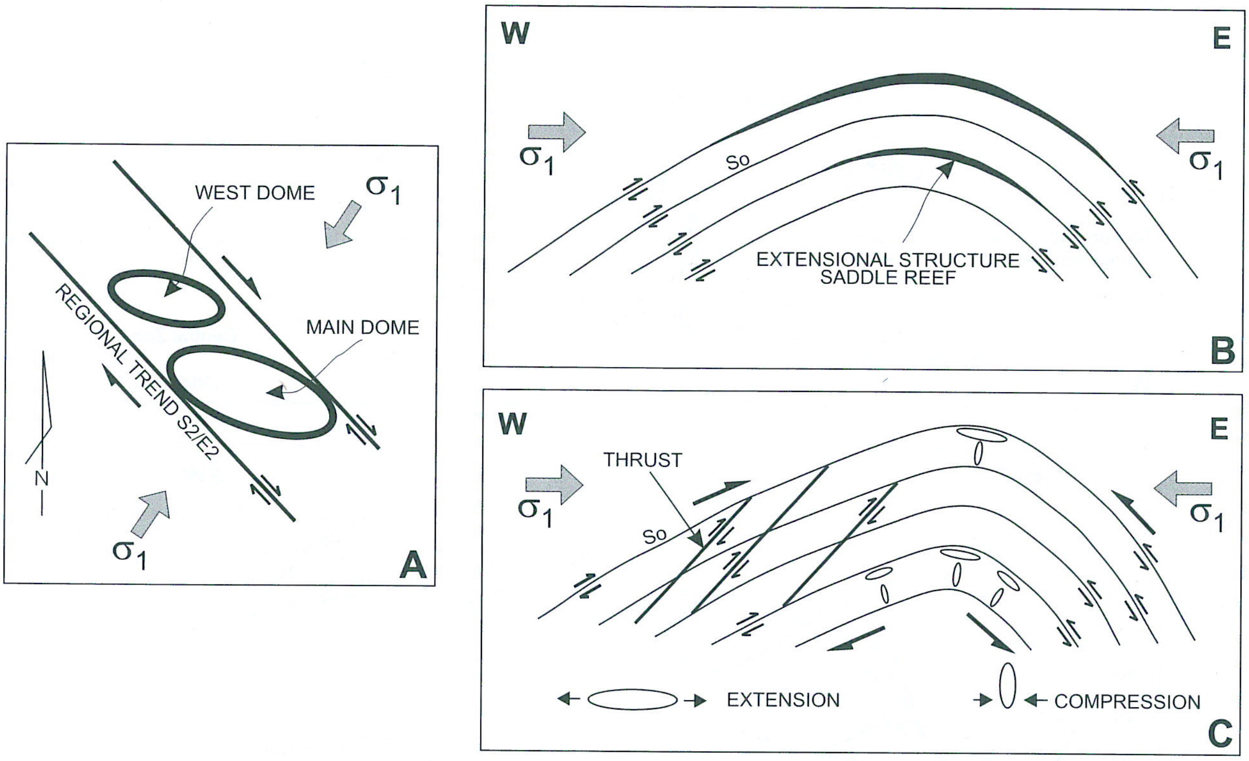


Fig. 8. Strike-slip (**A**), flexural-slip (**B**) and fold flexural-slip and thrust (**C**) mechanisms in compression related tectonic deformation models for Telfer

The fold flexural-slip and thrust model is inconsistent with the strike-slip model. Structures on the dome scale favour the (fold-) thrust model, whereas structures on the regional scale are more consistent with a strike-slip regime. Additionally, inconsistent dome asymmetries, the orientation of lineaments interpreted by airborne geophysics, the lack of visible *decollements* and thrusts to the south of the Telfer district with SW-directed movement are not definitive of structures formed in a thrusting regime (Hill, 1989).

Significant support for the fold-thrust model, including the principal role of horizontal compression, is expressed in a "progressive structural deformation model" (Fig. 9C) with regional structures indicative of a compressional, thrust-and-fold-belt tectonic regime. Evidence cited indicates that a dextral strike-slip movement is equally important as a thrust tectonic environment, and the major known geological structures are compressive (reverse faults and folds) rather than transcurrent (Windth, 1991).

Windth (1991) denies any role of vertical activity and basement propagated deformation in the mineralising process suggesting that vertical basement movements are unlikely to occur on any large scale, as neither regional compressive nor tensile forces can produce vertical movement on vertical structures. It is worth noting that the generation of extensional features does not require large-scale tectonic movement in vertical, horizontal or any other direction. Primary extension and corresponding structures are normally produced in early stages of tectonic deformation controlling mineralisation, and often only a tendency to movement is sufficient.

INHOMOGENEOUS SHORTENING AND SADDLE REEF MODEL

In this model, the Telfer doming and associated saddle reef-type mineralised zones are interpreted as resulting from a compressional SW–NE orientated regime that induced an inhomogeneous shortening of the geological sequence (Laing, 1993a). During this process, a fold flexural-slip mechanism and corresponding bedding parallel (reverse-slip) faults were developed, thus facilitating bedding plane extensional openings and accompanying *saddle reef* type mineralisation (Figs 8B, 8C, 9D).

According to this author "the granite-related saddle reef system, flexural-slip movement with bedding planes forming faults which are transtensional, some of which openly dilated during folding for the Telfer style of mineralisation" are regional compression-related mineralisation controlling processes. Further exploration of the Telfer ore system by application of compressional tectonics is proposed, as several past studies have not been absorbed as fully as could have been (Laing, 1993a).

DISCUSSION ON COMPRESSION RELATED ORE SYSTEM FORMING PROCESSES

The first tectonic-deformation related interpretations suggested that Telfer domes are *en echelon* structures produced in a regional compressional regime in response to dextral strike-slip tectonic shearing along the NW–SE regional trend of the Paterson Orogen (Harris, 1987). Al-

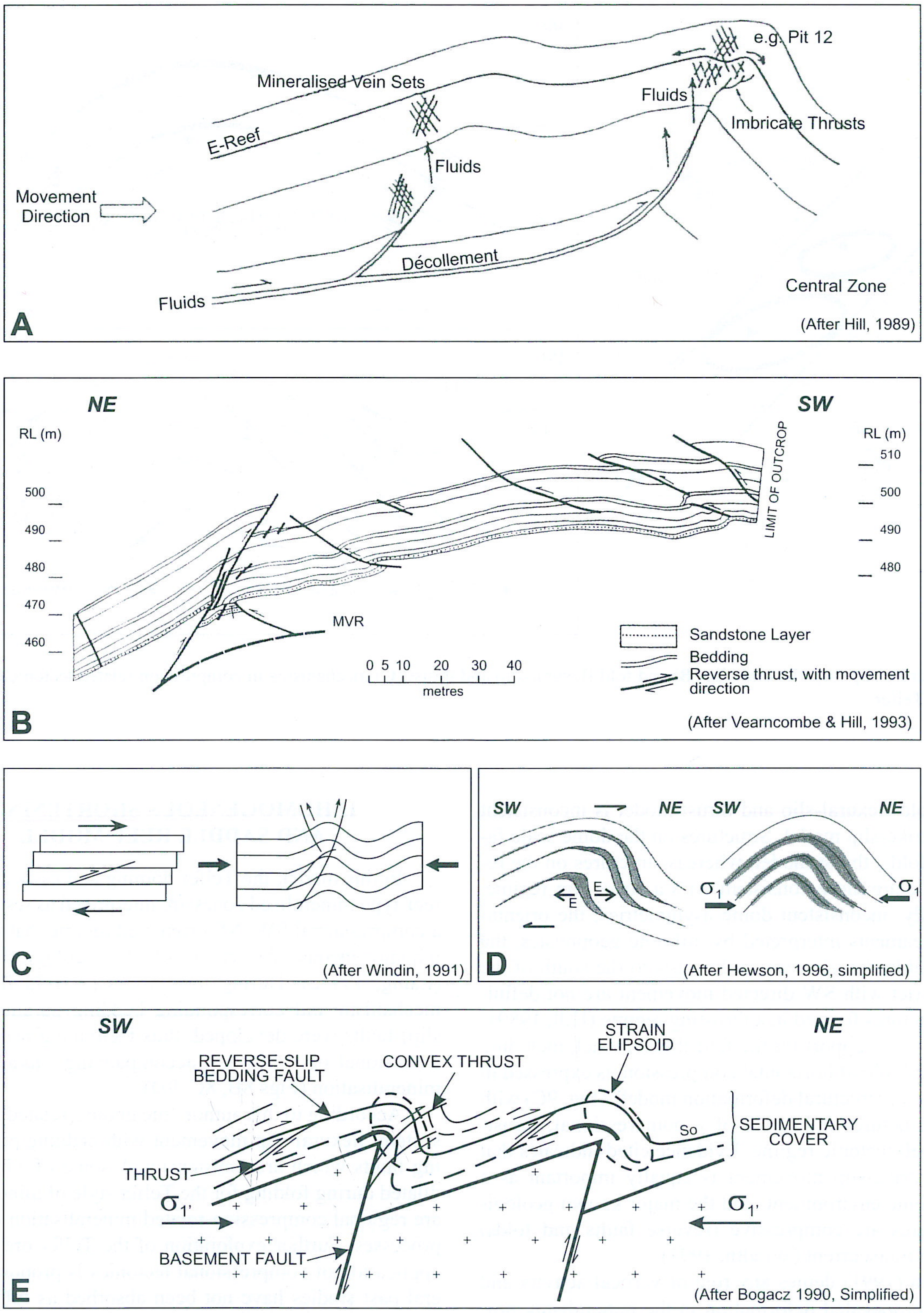


Fig. 9. Former conceptual interpretation of tectonic deformation controlling Telfer mineralisation: **A** – thrust and saddle reef model, **B** – compressional-thrust model, **C** – progressive thrusting model, **D** – inhomogeneous tectonic shortening and related saddle reefs model, **E** – basement fault and horizontal compression model

though it was possible that a NW–SE orientated deep basement fracture/fault system, which parallels that trend could exist in the region, no further comments on the possible implications of such a basement feature on Telfer structural deformation and mineralisation were made. Other data indicated that ore-synchronous folding and doming was also synchronous with emplacement of the Mount Crofton granite batholith (Laing, 1993b). This may suggest that during the deformation and mineralisation event, the granite batholith emplacement had to propagate structures developing concurrently with the emplacement, including those propagated into the Telfer metasedimentary sequence. However, an investigation into this possibility has not been undertaken.

Other studies have also supported a dominant role of regional horizontal compression, associated fold flexural-slip, and thrusting mechanisms for the formation of the Telfer domes and controls for the ore system forming processes, with mostly the bedding parallel reefs being observed (Hill, 1989; Windh, 1991; Vearncombe & Hill, 1993).

Although "the regional domes show no identifiable *en echelon* pattern" and "there is no evidence that thrust or wrench faulting played a role in ore formation", in the development of ideas for the tectonic genesis of the Telfer ore system, a model suggesting that horizontal compression was a driving force for inhomogeneous tectonic shortening of the sequence and accompanying processes, such as saddle reef formation, was expressed in Laing (1993a). Additionally, there is no clear correlation observed for E-Reefs between West and Main Domes (Rowins *et al.*, 1997).

Despite these authors explaining Telfer tectonic deformation and ore distribution mechanisms in terms of compression-related models, some of the observations made are inconsistent with the models. As a result, these models cannot fully explain all structural and mineralisation controlling features identified into one cohesive structural model that could be used as a predictive model for future deposit exploration.

An alternative interpretation to horizontal compression-related models, and involving a significant role of a basement rooted and upward propagated structural regime as an explanation has been proposed for the Telfer ore system in Bogacz (1990). This interpretation also includes horizontal compression component acting contemporaneously with the basement-propagated forces (Fig. 9E). In later studies by the same author, the basement vertical kinematics and corresponding tectonic structures are interpreted to be dominant ore system controlling factors (Bogacz, 1997, 1999).

TECTOGENETIC ANALYSIS OF THE TELFER DEPOSIT

HOST ROCK DEFORMATION VERSUS ORE SYSTEM FORMATION

Structural geological studies at Telfer have for many years focused on regional compression-related structural evolution, tectonic deformation and metamorphic processes of the host rock. Although studies concentrated on the *host rock*, the results were considered adequate explanation for the structural control and overall nature of the Telfer *ore system*. Hence, conclusions from these studies of the ore system geometric model and its tectonic genesis were indirect. The author considers that if the ore system is structurally controlled, direct investigation of its own geometry, kinematics and tectonic genesis of mineralising structures will provide essential information on specific stress regime(s) and associated ore system forming mechanisms, and that these regimes are unlikely to be the same as those for the host rock. Identification of these regimes and associated tectonic processes was important part of the Telfer tectogenetic investigations.

For the Telfer host rock, several phases of structural evolution and corresponding tectonic deformation features were distinguished (Hewson, 1996). More recently applied tectogenetic analysis suggests, however, that most of these features were formed prior to, or are not associated with, tectonic processes forming the Telfer ore system (Bogacz, 2001, 2002a).

MAJOR ELEMENTS OF THE ORE SYSTEM STRUCTURAL GEOMETRY

The West and Main Domes are prominent tectonic features that contain the majority of the known mineralisation in the Telfer area. Major structural elements that contribute to their internal structural complexity and the structural geometry of the ore system have been distinguished. These include:

– bedding (So structural system); mostly extensional system of bedding and/or bedding foliation surfaces; represents the domal geometry of West and Main Dome; displays lower angle 15°–20° west, and higher angle 30°–35° east dipping surfaces; steep to vertical and overturned surfaces are present, particularly in easterly dipping limbs; many earlier reverse-slip and later normal dip-slip shears and or faults are developed along the bedding surfaces.

– NW–SE striking structures (S2 structural system); mostly shearing system that parallels the trend of the Paterson Orogen; a regionally significant system formed by steep SW dipping to vertical shear/fault, foliation and lithological contact structures; locally in Telfer, predominantly with reverse-slip SW up – NE down kinematics; minor dextral strike-slip component.

– WNW–ESE striking structures (S4 structural system); local compression-related Telfer-scale shear-thrust system; surfaces dip 30°–40° to SSW and display convex geometry; thrust movement from SSW toward NNE; minor dextral strike-slip component.

– NW–SE striking structures (E2 structural system); Telfer-scale system; mostly extensional or extension propagating along steep, SW dipping to vertical surfaces; parallel and probabaly the same kinematics as the S2 shear structural system.

– N–S striking structures (E3 structural system); Telfer-scale system; mostly extensional or extension propagating along steep and moderately west dipping surfaces; mostly reverse-slip, but also including normal dip-slip features; minor sinistral strike-slip component.

Continuous transition of one system into another, in both horizontal and vertical directions, is a common feature at Telfer. Most frequently, gradual transition of the NW–SE (S2) into WNW–ESE (S4) and NW–SE (S2, E2) into N–S (E3) oriented structures is observed. This specific feature determines many aspects of the structural geometry and tectonic genesis of the Telfer ore system.

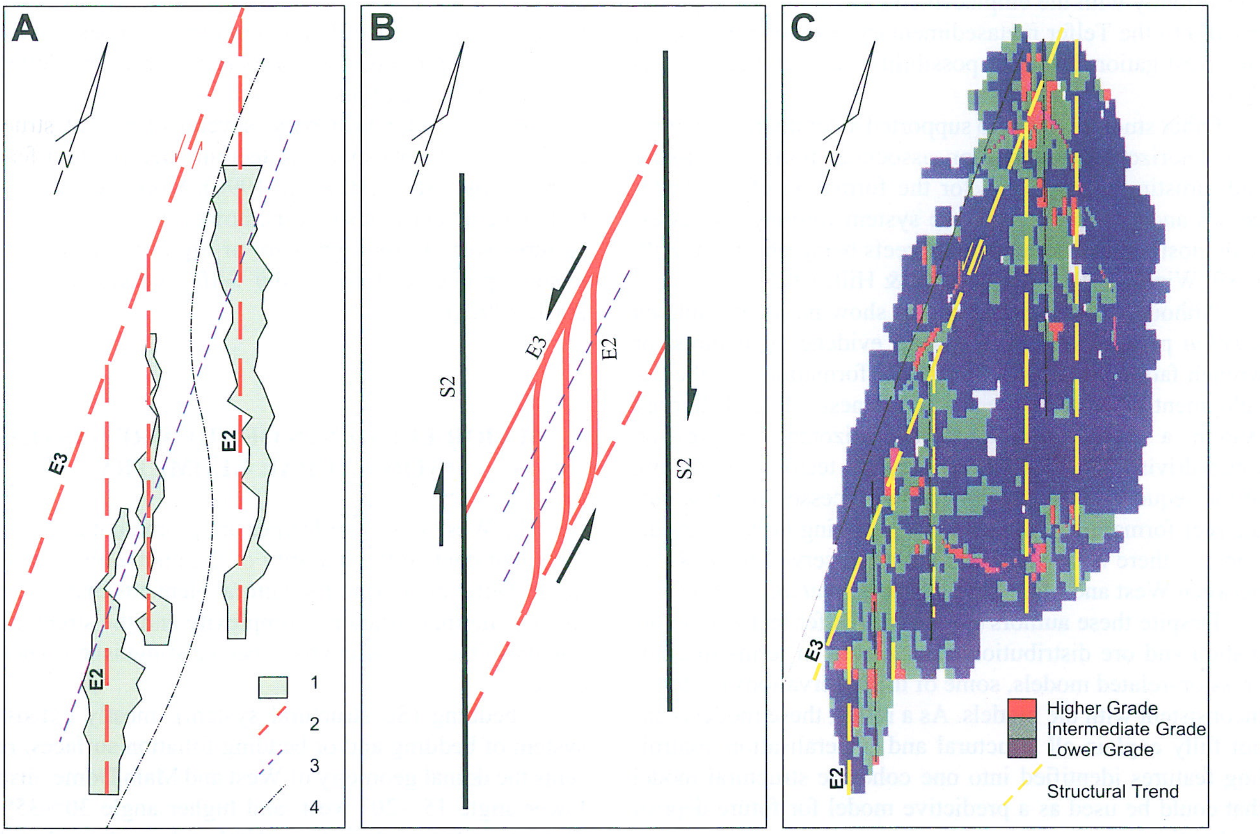


Fig. 10. Tectonic deformation and pattern of mineralisation in West Dome: **A** – pattern of tectonic structures. *1* – shear zone, *2* – extensional fault system (E2, E3), *3* – axial trend for *en echelon* pattern of E2 shear zones, *4* – axial zone of West Dome, **B** – tectogenetic interpretation of West Dome. Pattern of shear (S2) and extensional (E2, E3) structures. Arrows indicate direction and sense of tectonic movement, **C** – distribution of mineralisation controlled by E2–E3 extensional structure association

West Dome

The bedding (So) of West Dome defines a N–S (E3) elongated feature (Fig. 5). To investigate the domal geometry of this feature, a field tectonic and stereonet statistical interpretation of the attitude of the beds was undertaken. Distribution of the bedding surfaces displays a highly variable pattern. The majority of these surfaces are concentrated in two structural sets. The first set includes low-angle westerly dipping surfaces, and the second one includes steeper high-angle easterly dip or even vertical and overturned attitudes.

In more detail, in a number of locations, continuous rotation of the beds over relatively short distances, from low-angle to high-angle and vertical geometry, indicates that West Dome could form much more complex geometric settings than the expected regular shape with gentle dip and asymmetry of the limbs showing east-directed fold movement. As a consequence of these rotations, local scale second order tectonic features are developed, including FF structures (Figs 6A, 6B), flexures (Fig. 6C), and flexural bending of the beds (Figs 7B, 7C). Localised orebodies and high-grade mineralised zones (ore shoots) are confined to these structural features. Also, the lower-angle dipping bedding-controlled reefs show highly variable geometry, thickness and grade distribution. For example, E-Reefs may be controlled by two sets (So1, So2) of the bedding surfaces (Fig. 6F) and can have thickness varying from 1 to 7 meters, whereas the MVR reef displaying an averaging 0.8m true thickness attains a width in excess of 2 meters. Variability of bedding attitude and corresponding tectonic complexity in West Dome is considered to reflect intensive shear/fault tectonic deformation processes that contribute significantly to the formation of the ore system.

According to Hill (1989), the axial zone of West Dome is difficult to trace as it is complexly folded and faulted. The strike of the dome's axial zone changes sigmoidally from approximately N–S (E3) in the southeast closure to NW–SE (S2, E2) in the central part and tends to return to a N–S (E3) strike in the faulted, northwest closure. The dip direction of this axial zone appears to be to the southwest. The majority of the bedding surfaces and shear/fault structural elements identified can be classified as representing the S2 and E2–E3 structural pattern. The most characteristic feature is an *en echelon* pattern of the E2 oriented extensional structures (Figs 10A, 10B). The axis of the pattern and direction of propagation of the E2 openings is parallel to the E3 oriented extensional system of West Dome. This is why the West Dome mineralised system is elongated along the E3 orientation.

Tectonic interpretation of this structural complexity suggests that the shear tectonic movement along certain S2 orientated structures has produced the E2 oriented shear-extensional to extensional features, along with the E3 orien-

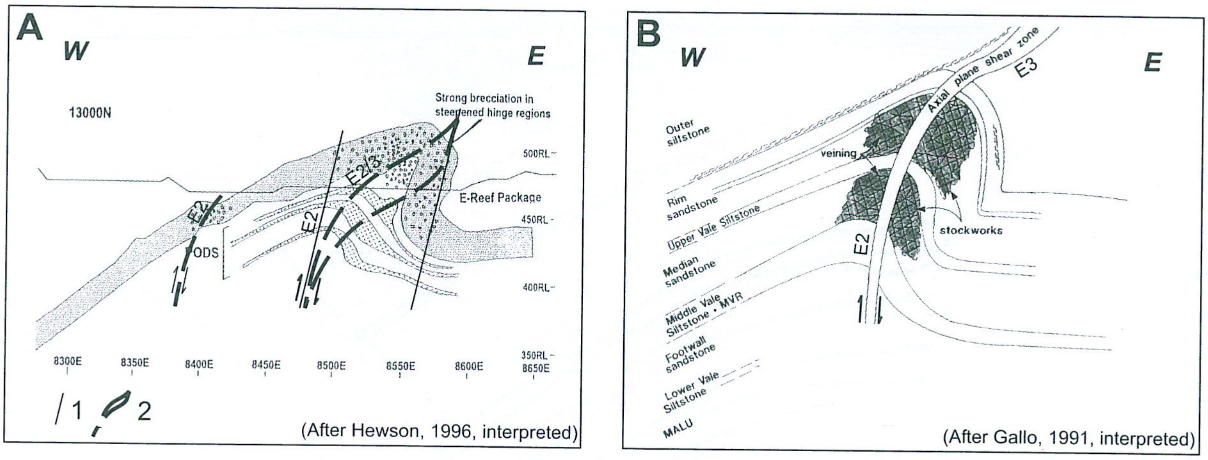


Fig. 11. Geometry of FF-structures and pattern of reef and stockwork mineralisation: **A** – E-Reefs of West Dome. *1* – E2 structure, *2* – E2/E3 structure with convex geometry. Arrows indicate direction and sense of tectonic movement, **B** – FF-geometry and convex curvature of axial zone of West Dome

tated extensional openings. Gradual transition between E2 and E3 structures is a specific feature throughout the dome. The direction of propagation for the E2 extensional structures coincides with the N–S (E3) strike of the axial zone in the central part of West Dome. As a result a sigmoidal curvature with maximum ore system development along the E3 strike, but with the E2 orientated component of particularly well developed *en echelon* structures, can be interpreted in the central part of the dome (Fig. 10B). A major E3 structure controls the western (and possibly eastern) limit of the dome extensional and mineralised domain with the E2 mineralised *en echelon* system developed on the east side of this structure. This structural complexity determines irregular shape of West Dome and the positioning of orebodies and high-grade mineralised zones that are mostly confined to the E2–E3 geometry, rather than following principally the inferred domal shape (Fig. 10C). Normal dip-slip movement along low-angle dipping bedding surfaces and mineralised reefs, and formation of associated flexural bendings of the beds, flexures, FF-structures in the vicinity of the E2–E3 orientated features is observed (Figs 7B,7C).

The tectogenesis and distribution of E2 and E3 extensional features controlling most of the mineralisation in West Dome is primarily associated with the reactivation of the NW–SE (S2) orientated basement shear/fault system. It is interpreted as being steep SW dipping to vertical, with reverse-slip (and minor dextral component) kinematics and southwest side up/northeast side down movement sense.

West Dome displays a low-angle west dipping western limb, and a steep to vertical, and in some situations overturned, eastern limb. Many lower order structures with this asymmetry, indicating west over east movement display convex curvatures of axial surfaces (Figs 6B, 6C). These are FF-structures, whose presence and features are indicative of a tectonic regime that produced many localised mineralised features of this type, e.g., within E-Reef horizon (Fig. 11A), and corresponding flexures throughout the dome.

Similar FF-geometry, including asymmetry with an axial zone having initially steep west dipping and upward flattening convex curvature can be interpreted for the entire West Dome (Fig. 11B). A tectonic regime forming this geometry is interpreted to result from the S2 orientated basement-rooted structural system formation. In this interpretation, the S2 tectonic features developing upward (with a reverse-slip SW up NE side down movement) gradually rotate to the E3 positions, which together with the E2 structures form the near-surface mineralised West Dome domain.

The majority of the mineralisation in West Dome occurs in the bedding parallel concordant reefs. Positioning of the high-grade zones in the reefs is controlled by low-angle dipping bedding openings, but a series of these openings are along steep (to moderate) directions that constitute the axes of the upward propagation of the E2–E3 structural geometry. This is why the reefs, although continuous, have strong E2–E3 orientated high-grade ore shoots and orebody distribution patterns. This mechanism also controls positions of FF-structure and flexure related mineralisation.

Stockwork breccia and its common development across bedding is interpreted as corresponding to the same basement-driven regime. This is particularly strong along the steep S2/E2 orientated features in the eastern limb of West Dome, however, many lower order breccia zones may be observed in areas of the E2–E3 structure interference (Figs 11A, 11B).

This interpretation for the development of an extensional structural domain in West Dome limits the possibility that horizontal compression-related flexural-slip folding and thrust-type mechanism would be involved in processes directly controlling the mineralisation pattern. Instead, the NW–SE (S2) orientated basement-rooted shear/fault system is interpreted as a major force leading to the formation of lower order extensional E3–E2 tectonic deformation and accompanied mineralising processes. In such a regime, σ_1 – the Principal Stress Direction is steeply orientated.

Main Dome

Main Dome is much larger than West Dome. In the near surface, it forms a NW–SE (S2/E2) striking tectonic feature that hosts the significant portion of the Telfer deposit. This

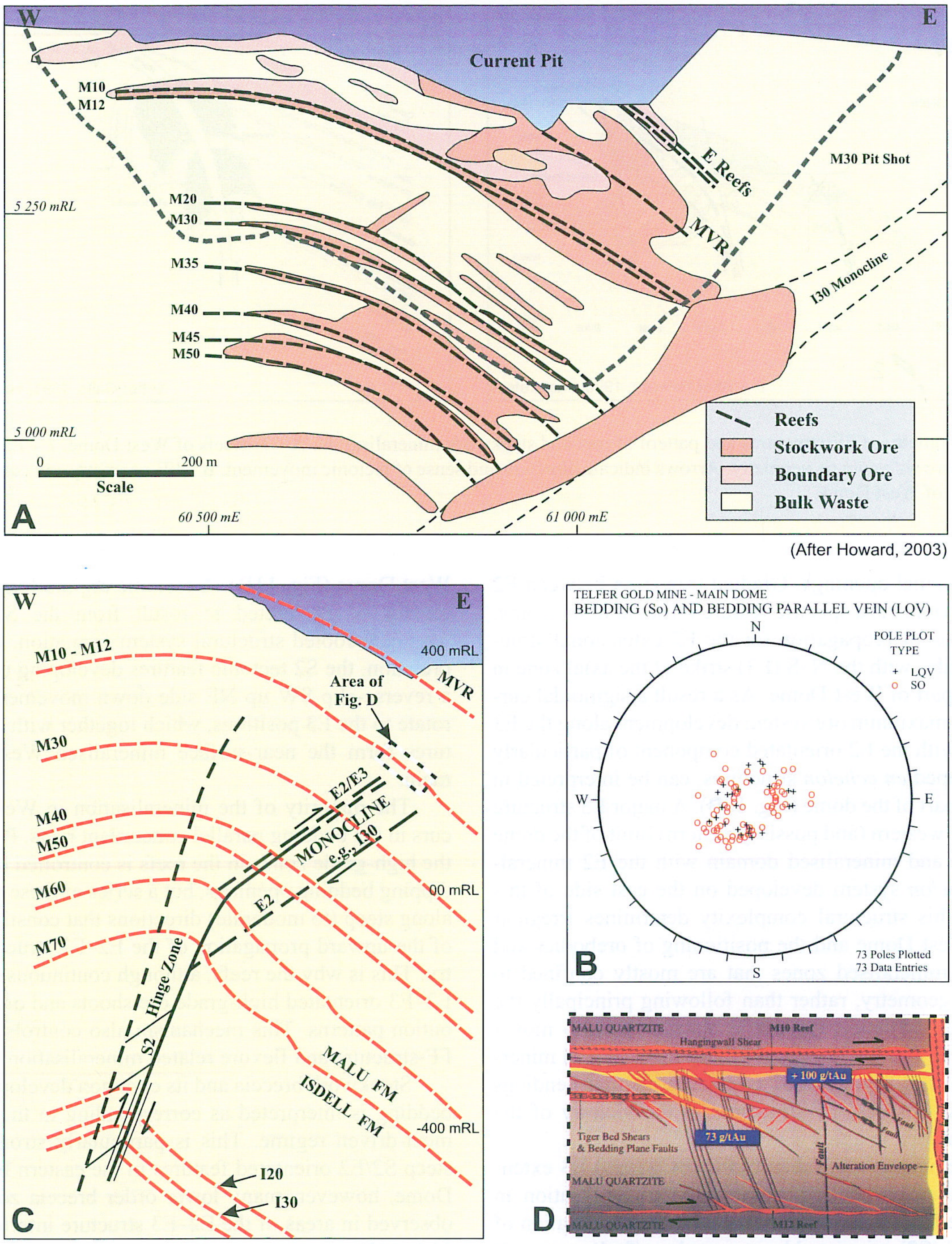


Fig. 12. Bedding-controlled geometry, ore zone distribution, and interpretation of Main Dome mineralisation: **A** – geometry and positioning of bedding-parallel reefs and I30 Monocline, **B** – attitude of beds and bedding parallel veins, **C** – Conceptual model on tectonic relationship between S2 shear system in hinge zone of Main Dome and E2 or E2/E3 monocline and/or fault type structure(s) developed in east limb of Main Dome, **D** – M10-M12 reef internal structural complexity (location in Fig. C)

strike is different to the N–S (E3) overall trend for West Dome (Fig. 5). However, there are similarities between the two domes in structural geometry and tectonic development. Compared to West Dome, the Main Dome displays similar assymetry with low-angle dipping west and steeper eastern limbs (Figs 12A–C). This asymmetry suggests a west over east fold movement.

A distinct bedding-parallel pattern for a number of low-angle dipping mineralised reefs has been identified. The internal structure of the reefs is controlled by several sets of shears and extensional (mineralised) veins bounded by bedding-parallel normal dip-slip shears and faults, such as the M10–M12 reef zone (Fig. 12D). In the upper parts of the stratigraphy, the reefs appear both in the gently dipping western and in the steeper eastern limb of Main Dome. With depth, higher-grade mineralised zones have migrated eastwards being preferentially developed in the eastern limb of the dome (Fig. 12A).

The axial zone of Main Dome displays an arcuate shape. Its strike changes from the NW–SE in the southwest-

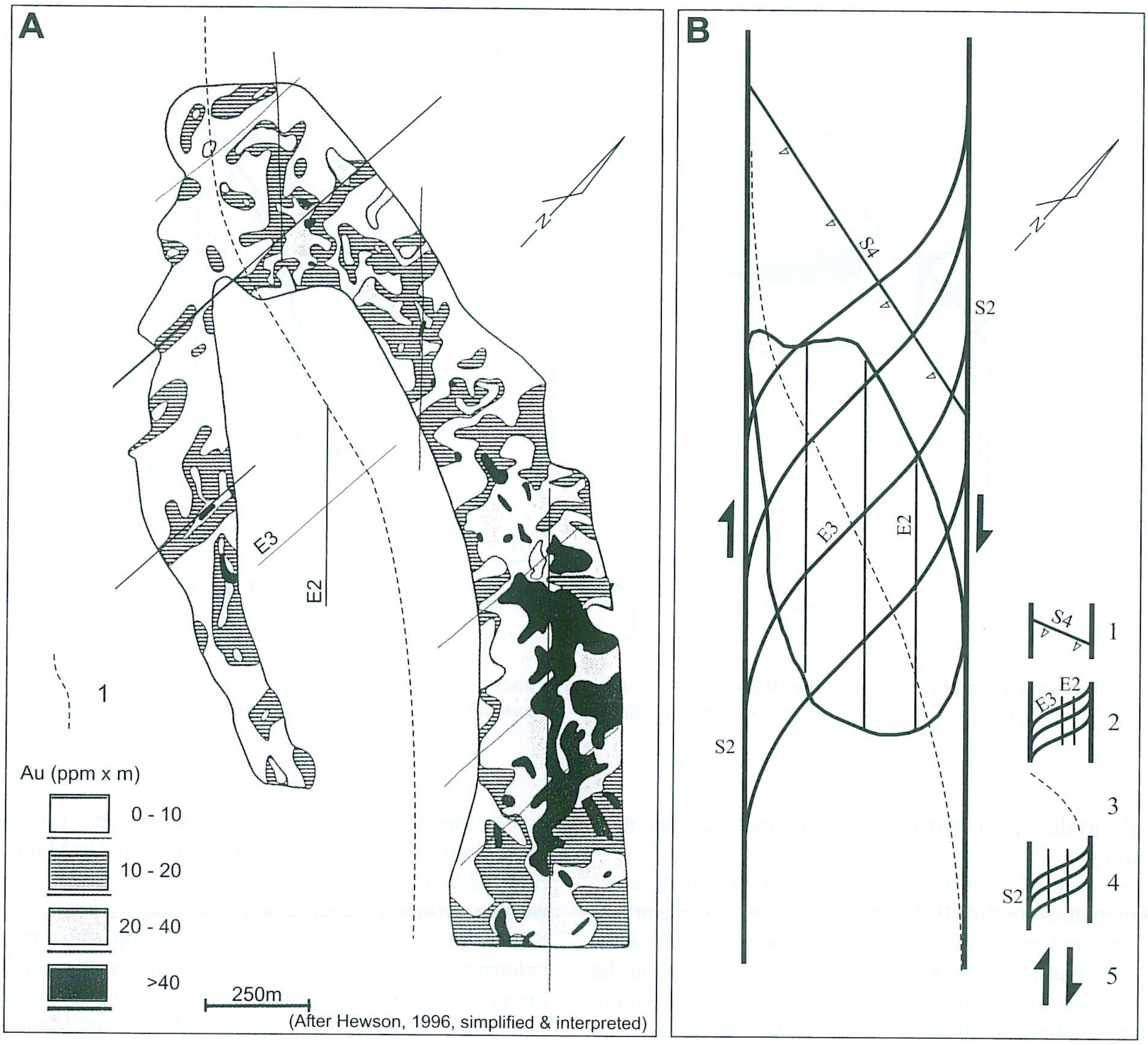


Fig. 13. Structural geometry, mineralisation distribution and tectogenetic interpretation of Main Dome: **A** – E2–E3 controlled pattern of mineralisation (grade distribution after Hewson 1996). *1* – axial zone of Main Dome, E2 & E3 – accentuated mineralised trend, **B** – Tectogenetic interpretation of Main Dome. *1* – S2/S4 shear structure system, *2* – E2/E3 extensional structure system, *3* – axial zone of Main Dome, *4* – shear-extensional S2 – E2/E3 structure pattern, *5* – arrows indicating direction and sense of tectonic movement

ern closure to WNW–ESE in the northwestern periphery, and generally dips steeply to SW, defining an axial plane arcuate curvature open to the SW (Fig. 13A). There are indications that the northwestern closure of the dome may in fact shift back to a NW–SE trend forming a sigmoidal shape between the interpreted S2 orientated structures (Fig. 13B).

Generally, across Main Dome, the high-grade reef mineralisation is associated with the N–S (E3) and NW–SE (E2) structural systems (Fig. 13A). A minor WNW–ESE (S4) trend of mineralisation is also present. These structural features and confined ore distribution patterns for both individual reefs and reef series, are closely linked with a major structure, the Graben Fault Zone (GFZ), representing the most important extensional E3 orientated structural system in the Telfer area (Fig. 5). From the distribution of mineralisation, it is evident that higher-grade reef zones are better developed in the vicinity of the GFZ. Comparing massive scale of extensional reef-type mineralisation associated with this fault formation, flexural bending of the beds, flexures and FF-structures control rather localised high-grade ore zones and orebodies throughout Main Dome (Figs 14).

In more detail, to the south and at depth, the GFZ is a steep SW dipping and NW–SE orientated feature, thus paralleling the S2 orientated reverse-slip shear/fault zone apparent in deeper levels of the hinge zone of Main Dome (Fig. 12C). To the north and east away from the axial zone of the dome, in the near surface development, this fault gradually rotates to become the N–S (E3) orientated structure. It also gradually flattens upwards, developing stronger sets of associated lower-angle dipping structures (Fig. 6E). As a result, the GFZ forms an arcuate convex geometry, in both horizontal and vertical directions (Fig. 15A). Indications of both reverse-slip and normal dip-slip shearing and displacements are present on component shear and fault surfaces forming this fault zone. A minor sinistral component of movement has been identified. Overall kinematic data suggests that the GFZ is mostly a reverse-slip feature with normal dip-slip component structures developing more

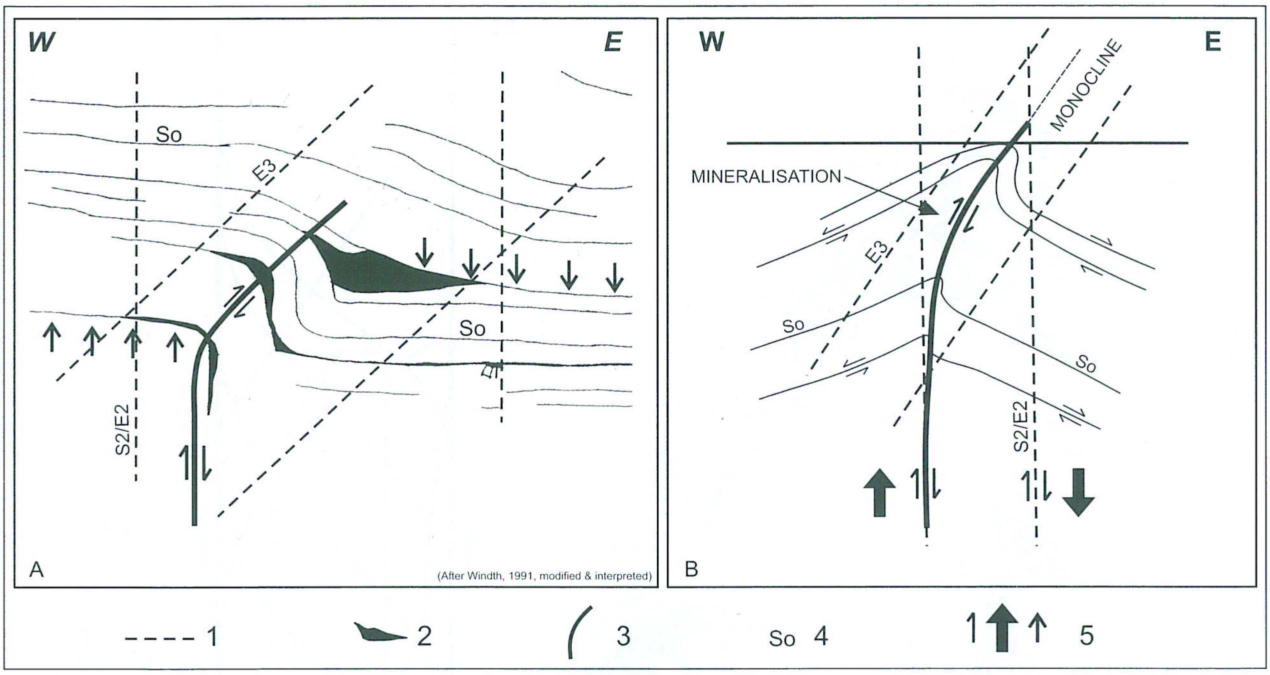


Fig. 14. Flexure (**A**) and FF-structure type (**B**) deformation in Main Dome. *1* – zone of S2/E2 shear-extensional and E3 extensional deformation, *2* – ore zone, *3* – convex axial zone, *4* – bedding (So), *5* – arrows indicating direction and sense of tectonic movement

strongly in the upper part of the geological sequence near the surface.

Approximation of the NW–SE (S2) trend and reverse-slip kinematics for the GFZ at depth indicates its strong tectonic link and propagation as a splay structure from the S2 orientated basement fracture, a dominant shear trend in the Paterson Orogen. At shallower depths, the fault trends more northerly and eventually becomes N–S (E3) oriented. Rotation from the S2 in deeper levels toward E3 orientation near surface is understood as a result of a conversion of the basement-rooted S2 shear regime into an extensional regime, with the E3 dominant but E2 extensional features also being present. E3 and E2 shear-extensional and extensional features that directly control the mineralisation distribution are developed as lower-order structures with respect to the S2 features (Fig. 13B).

The convex shape of the GFZ, in both horizontal and vertical directions, seems to be complementary with the overall E2–E3 deformation style of West Dome (Fig. 10B, 11B). The GFZ is a structure that significantly influenced the extensional openings and formation of the bedding parallel reefs in its sides and throughout large areas of Main Dome. The location of this structure in the eastern limb of the dome might explain the better development and higher-grade of the reefs and finally with depth, their gradual migration towards the eastern limb of the dome.

The absence of the GFZ in the western limb of the Main Dome is interpreted as associated with the fading out of this structure due to its origin as a splay structure from the S2 basement feature in deeper levels along the axial zone of Main Dome. This interpretation significantly increases the prospectivity of the eastern limb of Main Dome compared with the western limb.

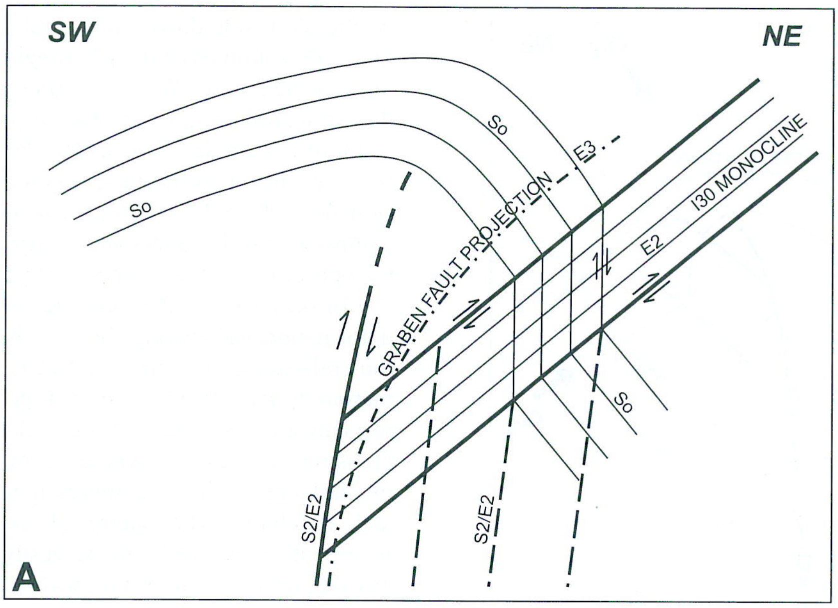
A characteristic set of monocline-type reverse-slip shear/fault structures has also been identified in Main Dome (Fig. 12A, 12C). The monoclines are recognised as northwest to northerly trending and moderately (about 40°–50°), SW to west dipping zones of reverse-slip shear to shear-extensional deformation. A substantial contribution to the ore system is associated with monoclines, including the I30 monocline located in the steeper NE limb of Main Dome (Fig. 12A, 15). This structure is a lower-order feature, with the same reverse-slip kinematics, with respect to the steep NW–SE (S2) orientated basement-rooted shear/fault zone developed in the axial zone of the dome (Fig. 12C).

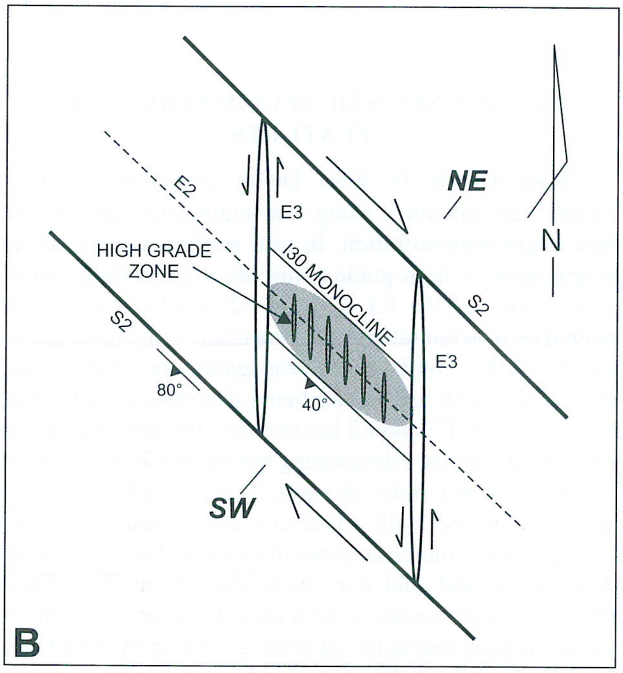
The tectogenetic analysis of Main Dome suggests that deep rooted steep NW–SE (S2) striking structures developed upward as mostly E3 and E2 oriented, including steep (GFZ) and moderate (I30 Monocline), west dipping features. These control extensional openings and the bedding parallel reef mineralised zones, which concentrate in the steeper eastern limb of Main Dome. Flexural bending of the beds, flexures and, FF-structures control localised high-grade ore zones and orebodies throughout Main Dome.

TECTOGENETIC MODEL OF THE TELFER DEPOSIT

ORE SYSTEM FORMING PROCESSES

The Telfer compressional model suggests that west over east thrusting and the fold flexural-slip mechanism with associated bedding-parallel reverse-slip kinematics are critical factors, particularly in developing reef mineralisation during formation of the domes (Figs 8B, 8C). In the *Telfer*





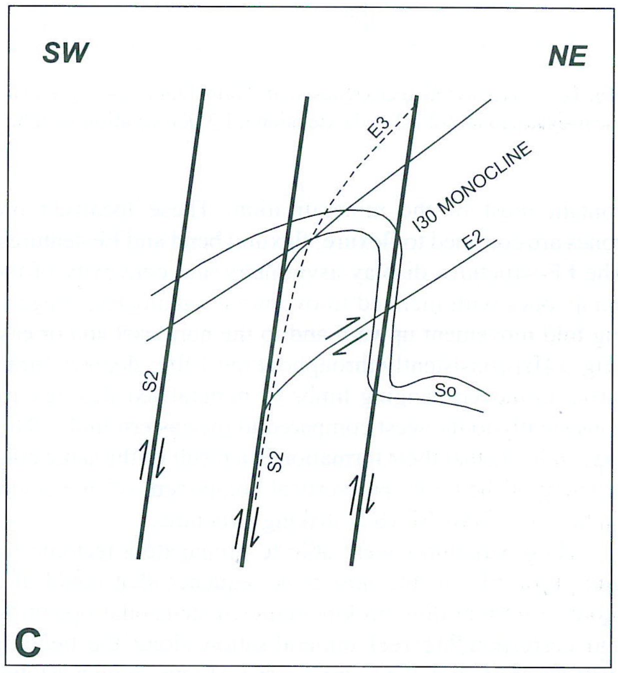


Fig. 15. Schematic sketches on tectogenetic interpretation of I30 Monocline in Main Dome. I30 Monocline is: moderately SW dipping reverse-slip kinematic feature (**A, C**), originated from S2 shear structure with reverse-slip kinematics (**A, C**) causing characteristic FF-structure geometry (**C**), E2 orientated structure (**B**) with high-grade zones of E3 geometry (**B**), terminated along strike by E3 orientated features (**B**). Arrows indicate direction and sense of tectonic movement. Note also geometry of Graben Fault Zone projected in sketch A

tectogenetic model, these processes represent earlier stage of tectonic deformation required for tectonic shortening of the geological sequence during initiation of the domes. These may be described as wall-rock preparation processes that played a limited role in directly controlling later mineralising processes.

Following the compression-related processes, normal dip-slip movement along the bedding developed. This movement is opposite to the reverse-slip kinematics of a fold flexural-slip mechanism. The normal dip-slip movement is of secondary nature as it developed mostly on bedding surfaces formed earlier during flexural-slip folding. The structural geometry of West and Main Dome, to which the Au-Cu mineralisation is confined, seems to result from a different mechanism that produced intensely propagated normal dip-slip kinematics along the bedding surfaces.

The tectonic genesis of these two structures and their extensional nature is interpreted as resulting from a contemporaneously developing, regionally significant S2 structural system. Although bedding-parallel reefs appear to be continuous features on a dome scale, related localised shoots and high-grade zones with a strong directional preference

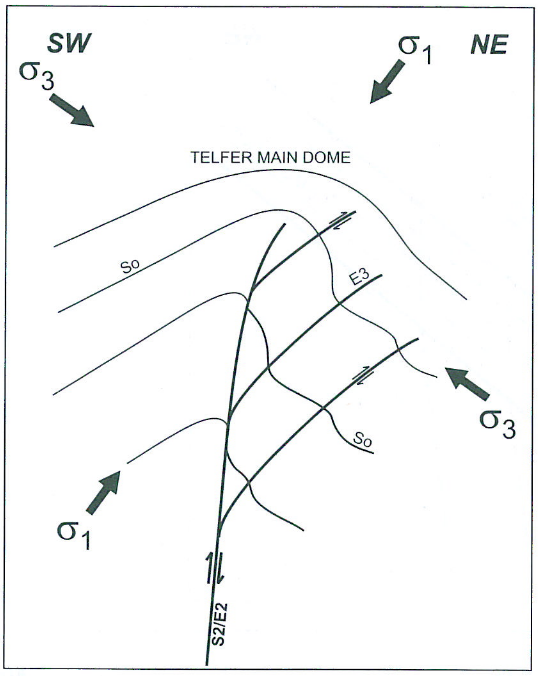


Fig. 16. Interpreted tectogenesis of Main Dome as a result of shear-extensional S2/E2 and extensional E3 deformation system

contain most of the mineralisation. These localised ore zones are confined to flexure, flexural bend and FF-features. The FF-structures display asymmetry and convexity of the axial zones with inclined to overturned geometry, suggesting fold movement upward and to the northeast and/or east (Fig. 14B) consistently throughout the Telfer deposit. Similarly, up-moved hanging limbs of mineralised flexures are consistently to the west compared to the eastern limbs. This may indicate that their formation is a result of the same consistency of the basement vertical component of movement on the steep NW–SE (S2) striking structures.

These structures were able to propagate a tectonic regime upward into the host rock sequence that could also produce normal dip-slip kinematics, extensional openings, and corresponding reef mineralisation along the bedding surfaces. Although these are a series of low-angle west dipping features, their axes are steep to vertical, following the geometry of E2 and E3 extensional features associated with the basement structures. In this model, the basement originated steep to vertical NW–SE (S2) orientated reverse-slip (with a dextral component) shear/fault system is a critical tectonic factor propagating upward the E3–E2 extensional deformation systems that controls most of the reef-related and other mineralisation.

This extensional regime favouring mineralisation is also associated with the formation of monoclines (Fig. 15). These tectonic features either did not have any explanation in previous models, or were associated with regional compression-related thrust type processes. In the basement-driven Telfer tectogenetic model, the monoclines along with other mineralised features discussed, are second order reverse-slip structures associated with the formation in the basement of the steep reverse-slip S2 orientated shear/fault system, with the reverse-slip southwestern side up and northeastern side down movement (Fig. 16). The Principal Stress Direction (σ_1) of such a regime is steep, acting from the basement and SW upward and toward NE. In the past, this structural complexity was mistakenly interpreted as a result of low angle SW over NE thrusting processes. If this was the case, it would develop due to horizontal compression from the SW, in contrast to the fact that the overall compression-related tectonic transport in the region is quite the opposite, ie., NW over SE (Fig. 2B).

In summary, in the Telfer tectogenetic model, tectonic deformation influencing the distribution of orebodies and mineralised zones is driven by a basement controlled deformation system. In the host rock geological sequence, this mechanism produced extension-related structures and mineralising processes, whose formation followed non-mineralising, called "compressional", tectonic processes and structures. The nature of the compression is also basement-related and can be easily linked with the local basement pre-mineralisation wall-rock preparation tectonic activity.

TECTOGENESIS OF MAJOR STRUCTURAL FEATURES

West Dome. In West Dome, extensional bedding-parallel reef openings along low-angle west dipping zones host major mineralisation. In near surface regions, axes of propagation of high-grade zones are preferentially parallel to the strike of the E3, and the E2 structures and are arranged *en echelon* rather than consistent with domal geometry (Fig. 10C). With depth, propagation axes for the reefs are mostly steep to vertical, being determined by the steep propagation of E3 and E2 lower order structures that are linked with the upward developing basement S2 shear system.

Many lower order flexures, flexural bending of beds, and FF-structures with asymmetry and typical convex axial zone curvature indicates generally west and up over east and down shear and fold movement throughout West Dome. The dome itself seems to be a large FF-structure with convex axial zone curvature suggesting west up over east down movement (Fig. 11B). This kind of structural geometry, commonly observed throughout the Telfer deposit, is interpreted in the tectogenetic model as being associated with the basement-rooted shear/ fault system.

This interpretation of the West Dome, and lower order extensional structural components, limits the possibility of flexural-slip folding and thrust-type mechanisms associated with horizontal compression to be involved in the processes directly controlling the mineralisation pattern. Instead, the NW–SE (S2) orientated basement-rooted shear/fault system is interpreted as a major driving force leading to the extensional E3–E2 tectonic deformation and mineralisation pattern in West Dome. In this model, thrust-compressional structures may exist, however, these are also associated with the same basement-controlled structural regime.

Main Dome. The Main Dome tectonic deformation and mineralisation pattern changes with depth. Near surface, the most extensional environment of this, generally NW–SE (S2) elongated ellipsoidal feature, is associated with a

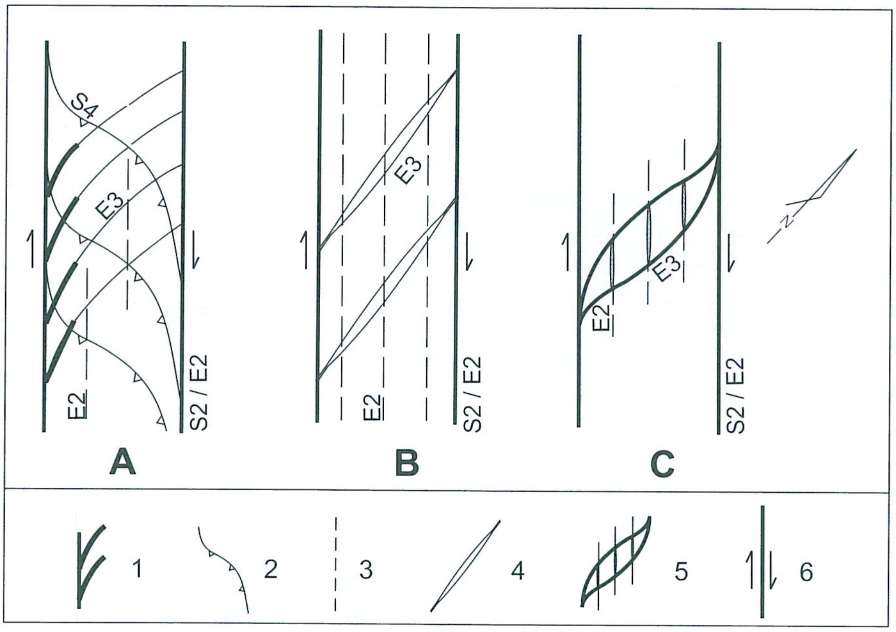


Fig. 17. Interpretation of tectogenetic link between near surface (**A**), deeper level and basement (**B**), and mineralised structure pattern (**C**) in Main Dome. *1* – transitional from shear (S2) or shear-extensional (S2/E2) to extensional (E3) structure pattern, *2* – thrust (S4) structure system, *3* – extensional (E2) structure system, *4* – extensional (E3) structure system, *5* – extensional (E3) system with lower order (E2) oriented structures, both controlling mineralisation, *6* – shear or shear-extensional (S2/E2) system and sense of movement

strong development of E3 structures, such as the Graben Fault Zone and those with E2 orientation. In the near surface environment, the S4 striking thrust system is also present (Fig. 17A). In deeper levels, tectonic extension along E2 and E3 features is also present, however, there is observed to be a closer association of the ore system with the NW–SE (S2) striking basement-rooted regional structural system (Fig. 17B). This tectogenetic interpretation indicates that the S2 orientated structural system is a prominent shear feature in the basement of Main Dome. It develops upward as predo- minantly E3, but also E2 extensional system (Fig. 17C).

Structures with E3 geometry splay off the S2 system in the deeper levels and develop upward as more independent extensional and/or extension controlling systems. Near surface, intensive extensional openings of bedding surfaces and the formation of lower order high-grade mineralised fold-like structures, flexures, flexural bends, and monoclines is determined by the E2–E3 structural geometry.

In this tectonic genesis model, the majority of higher-grade Au-Cu reef mineralisation concentrates along E2 and E3 trends throughout Main (and West) Dome rather than following a simple domal shape. In the Telfer compressional model, there is no correlation of bedding-parallel reefs, such as E-Reefs, between the Main and West Domes (Rowins *et al.*, 1997). It is because the reefs have undergone individual development, both along strike and down dip, as structures confined to certain E3 and E2 extensional features. These do not conform to the bedding-parallel horizon(s) that are typical gently dipping features of the Telfer domal shape, but rather follow the geometry of basement-propagated deformation.

DEFORMATION DOMAINS

The relationship between tectonic deformation and mineralisation, particularly with respect to the distribution of high-grade zones, positioning of known orebodies, and mineralisation, suggests that at least four major structural systems were involved in the formation of the Telfer deposit. These are shear-compressional S2 and S4, and shear-extensional to extensional E2 and E3 orientated structural systems. Possibly, these were developing as one continuous deformation event, however, in a specific chronological sequence. Hence, tectonic deformation at Telfer comprises two distinct structural deformation styles (domains):

1. Compressional Structural Domain (CSD). This domain includes NW–SE (S2) trending shear-fault and WNW –ESE (S4) orientated thrust type structures (Figs 18, 19AB).

2. Extensional Structural Domain (ESD). This domain predominantly includes NW–SE (E2) and N–S (E3) shear-extensional to extensional structures (Figs 19, 20).

The CSD is interpreted to be an earlier stage tectonic deformation system with a limited control on mineralisation. This also includes a flexural-slip folding mechanism that initiated the West and Main Dome formation, being then followed by ESD formation. The CSD contributed to wall-rock preparation, and tectonic shortening of the sequence prior to the main mineralising phase.

The later shear-extensional to extension related tectonic deformation (ESD) controls most known mineralisation. Major structures active during this event are E2 and E3 orientated, and the majority of the mineralisation follows these two trends. Each of these tectonic systems might produce additional lower order mineralised shear-extensional and

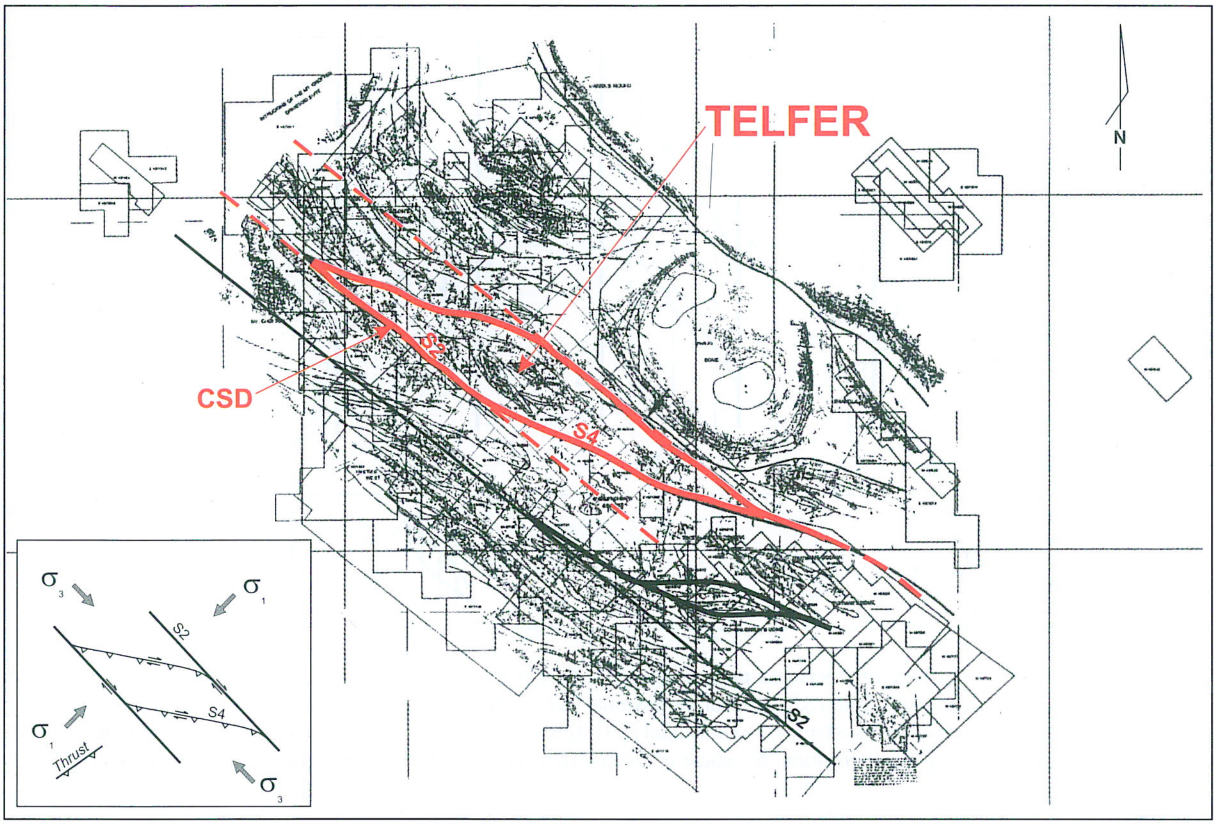


Fig. 18. Interpretation of structural geometry and kinematics for Compressional (shear-compressional) Structural Domain (CSD) at Telfer. S2 – shear structural system, S4 – thrust structural system with dextral component of movement. Arrows indicate direction and sense of tectonic movement. σ_1, σ_3 – principal stress directions of stress field

extensional features. Pre-existing tectonic structures such as the bedding surfaces were commonly used for their secondary development. Structures of the ESD domain mostly exhibit semi-brittle to brittle deformation type. It seems that these were produced in one continuous, possibly long-lasting tectonic event.

The structural geometry, kinematics, and tectonic genesis of both West (Fig. 10B) and Main (Fig. 13B) Domes are consistent and represent the dominant component of a uniform overlapping CSD–ESD domain regime controlling the formation of the Telfer ore system (Fig. 21).

TECTONIC GENESIS OF ORE SYSTEM

In the Telfer tectogenetic model, the formation of the Telfer ore system, the normal dip-slip movement interpreted along bedding planes is particularly important. This is quite the *opposite* movement when compared to the reverse-slip kinematics associated with flexural-slip folding mechanism required to explain initiation of folding processes and corresponding tectonic shortening of the host sequence. Most previous interpretations used this latter mechanism and attendant thrusting processes to explain the Telfer ore system being compression-related.

The Telfer tectogenetic model suggests that a stage of a normal dip-slip movement occurred along the bedding. This is a secondary process utilising pre-existing bedding (So) surfaces, formed originally as a result of earlier fold flexural-slip mechanisms, and occurred in response to a basement-rooted and upward developing tectonic regime. This regime activated a major fault/fracture system in the basement of the Telfer deposit parallel to the trend of the Paterson Orogen. Many lower order structures, including FF-structure, flexure, flexural bending, and monocline types are present. These control the mineralisation pattern. The geometry, convexity and kinematics of these structures are consistent with their development from the west towards the east, and generally with the reverse-slip west up/east down movements along the S2 basement fracture system.

At a deposit scale, a *flexural bending of the beds* is interpreted as controlling the entire Telfer domain (Fig. 22A). This interpretation explains in a single, uniform tectonic genesis model all the features identified within the Telfer ore system and its tectonic boundaries. In more advanced interpretations, it can be viewed as a first order, Telfer scale, *FF-feature* (Fig. 22B). The latter interpretation is consistent with features of various magnitude with this character observed throughout the deposit, from very low order to West and Main Dome scale, all of which correspond to an origin from a propagation by the basement-rooted S2 structural system.

DISCUSSION ON THE TELFER TECTOGENETIC MODEL

For many years, regional horizontal compression with strike-slip, fold flexural-slip and thrusting have been con-

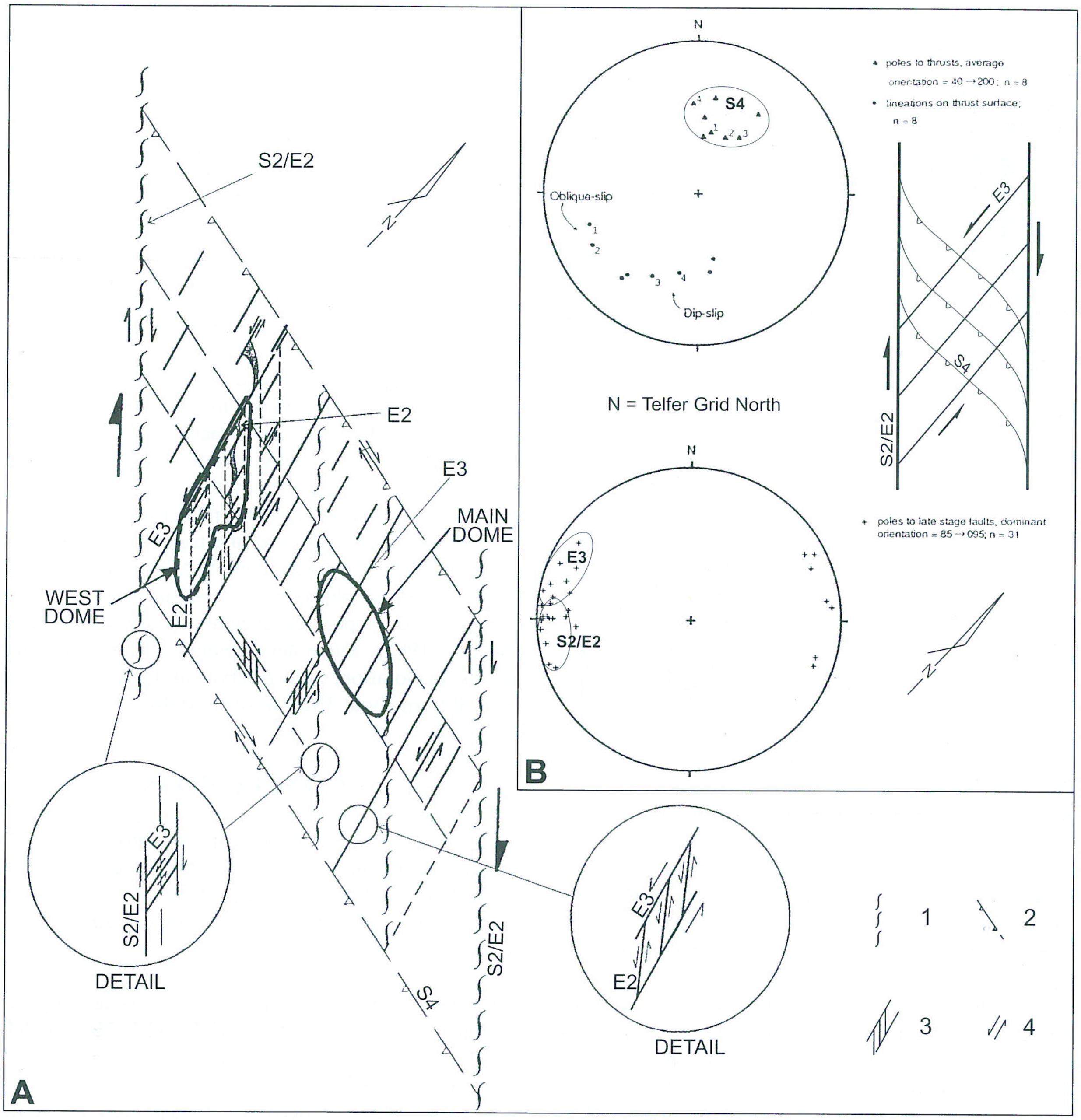


Fig. 19. Interpretation of geometric and kinematic interference between shear and extensional structure systems: **A** – schematic and conceptual diagram for structures controlling Telfer ore system. *1* – shear (S2), shear-extensional (S2/E2) or extensional (E2) structure, *2* – thrust (S4) structure, *3* – internal geometry and kinematics of small scale shear-extensional (S2/E2) and extensional (E2, E3) structures, *4* – arrows indicating direction and sense of tectonic movement. **B** – Example of interpretation for shear-extensional (S2/E2 – S4 – E3) structure interference in West Dome

sidered the key tectonic factors controlling mineralisation emplacement at Telfer. However, relating geometric and kinematic relationships observed are inconsistent to explain a mineralisation model. Further, the predictive capacity of compression related models and associated tectonic mechanisms have so far demonstrated limited exploration success. Eventually, it became inevitable that solely compressional model for ore system development and its exploration implications required critical re-evaluation.

Using tectogenetic analysis, a comprehensive re-examination of the Telfer ore system has been undertaken by the author. The results suggest that tectonic forces that produced shear and extensional (mineralised) structures were propagated upwards into the Telfer host rock by basement-rooted shear/fault structures, leading to tectonic deformation exploiting pre-existing bedding surfaces and other resultant secondary structures to develop the Telfer mineralised system.

The relationships between host rock tectonic deformation and mineralisation, particularly with respect to the distribution of high-grade zones, positioning of known orebodies and mineralised zones, suggests that at least four major

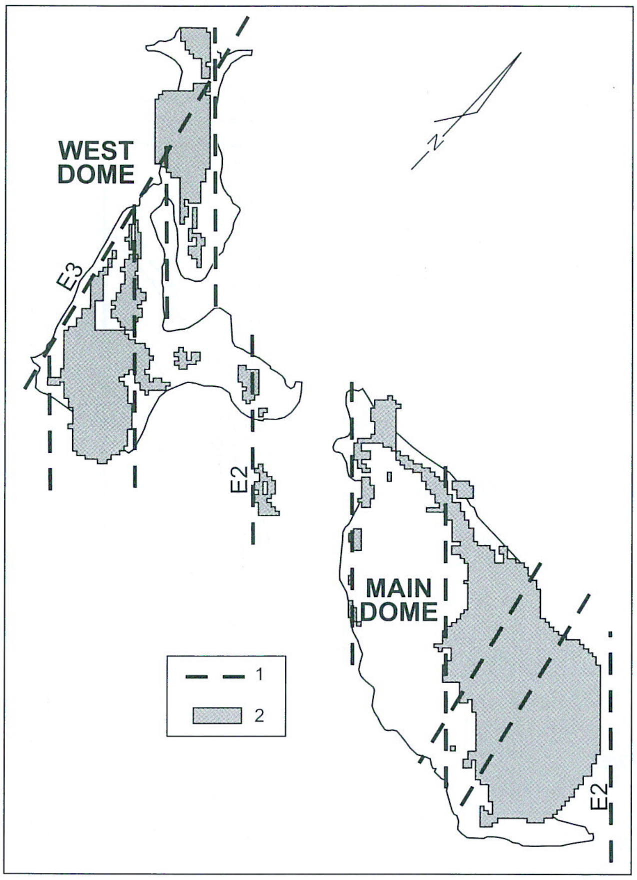


Fig. 20. Interpretation of extensional structural geometry controlling ore system at Telfer. *1* – extensional structure (E2, E3), *2* – zone of mineralisation

structural systems were involved in the observed deformation at Telfer. These are shear-compressional S2 and S4 (Figs 18, 19), and shear-extensional to extensional E2 and E3 (Figs 19, 20) orientated structural systems. These appear to have developed as sequential deformation event but with specific chronology. The earlier stage of deformation is interpreted as being shear-compressional (CSD) involving active S2 and S4 (thrust) structures and includes a flexural-slip folding mechanism, which initiated dome formation. The CSD domain has limited impact on mineralisation distribution but played a role in wall-rock preparation and tectonic shortening of the sequence prior to the major mineralising phase. Later shear-extensional to extensional deformation (ESD) controls most known mineralisation (Fig. 21A). Major structures active during this event are E2 and E3 orientated, and the majority of the mineralisation follows these two trends, both along strike and down dip. Each of these tectonic trends might produce additional lower order shear, shear-extensional, and extensional (mineralised, e.g., So surfaces) features.

The tectogenetic concept for the entire Telfer ore system suggests that it could have developed as a flexural bending of the beds (Figs 22A) or, in a more advanced state of tectonic deformation, it may form a FF-feature (Fig. 22B), both of which would have been in response to active basement role. Additional internal complexities in the Telfer ore system include the presence of at least two major flexural bends or FF-feature, i.e., West Dome (Fig. 11B) and Main Dome (Fig. 16).

This model for tectonic genesis provides a fully synthesised explanation for the Telfer ore system, with the most important role being played by steeply dipping reverse-slip structures with S2 orientation. The geometry of the whole system and the pathways required for the migration of mineralising fluids to form the Telfer ore system, all are definable in terms of this model.

It may be said that at Telfer a deep-rooted basement-derived shear system propagated upward. It penetrated covering sediments (host rock), producing extensional E2–E3 tectonic deformation and providing mechanisms and emplacement sites for intensive mineralising processes. Near surface, these structures form a specific anisotropy that controls the ore system geometry, in both plan view and cross section. At depth, the E2–E3 structural system interference is weakening and gradually transitions into more accentuated the S2 basement-rooted system.

The proposed tectogenetic model integrates all available geological, geophysical and tectonic data into an uniform concept and a practical exploration model that consistently explains all observations made at Telfer, and has been demonstrated to provide excellent predictive capabilities (Bogacz, 1998). Since development of this model and its use for exploration, gold reserves at Telfer have been increased from about 3Moz to over 20Moz.

CONCLUSIONS

1. Early conceptual models for tectonic deformation and accompanying mineralisation developed for the Telfer ore system based on horizontal compression had limited application, as they could not satisfactory explain tectonic features and observed mineralisation.

2. Systematic *tectogenetic analysis* applied to the Telfer ore system and host sequences has led to the development of an integrated *Telfer tectogenetic model*. This model explains both tectonic deformation of the host rocks and distribution of mineralisation.

3. At Telfer, two separate overlapping tectonic deformation systems are present, each with own specific geometric and kinematic characteristics. These developed as one continuous deformation event associated with upward basement movement. An earlier compressional event (CSD) was followed by a shear-extensional/extensional tectonic deformation processes (ESD). The CSD domain with the S2 and S4 (thrust) orientated structures is responsible for tectonic shortening and wall rock preparation processes prior to the main mineralisation phase, whereas structures with the E2 and E3 orientation form the ESD domain controlling most of mineralising processes and patterns that characterise the Telfer ore system. The basement propagated upward-directed shear/fault structural system penetrated the cover rocks resulting in extensional deformation and accompanying Au-Cu mineralisation at specific ESD sites.

4. Upward flattening of S2 structures and gradual transition into E3 geometry is a specific characteristic of the Telfer ore system. Many lower order structures, including

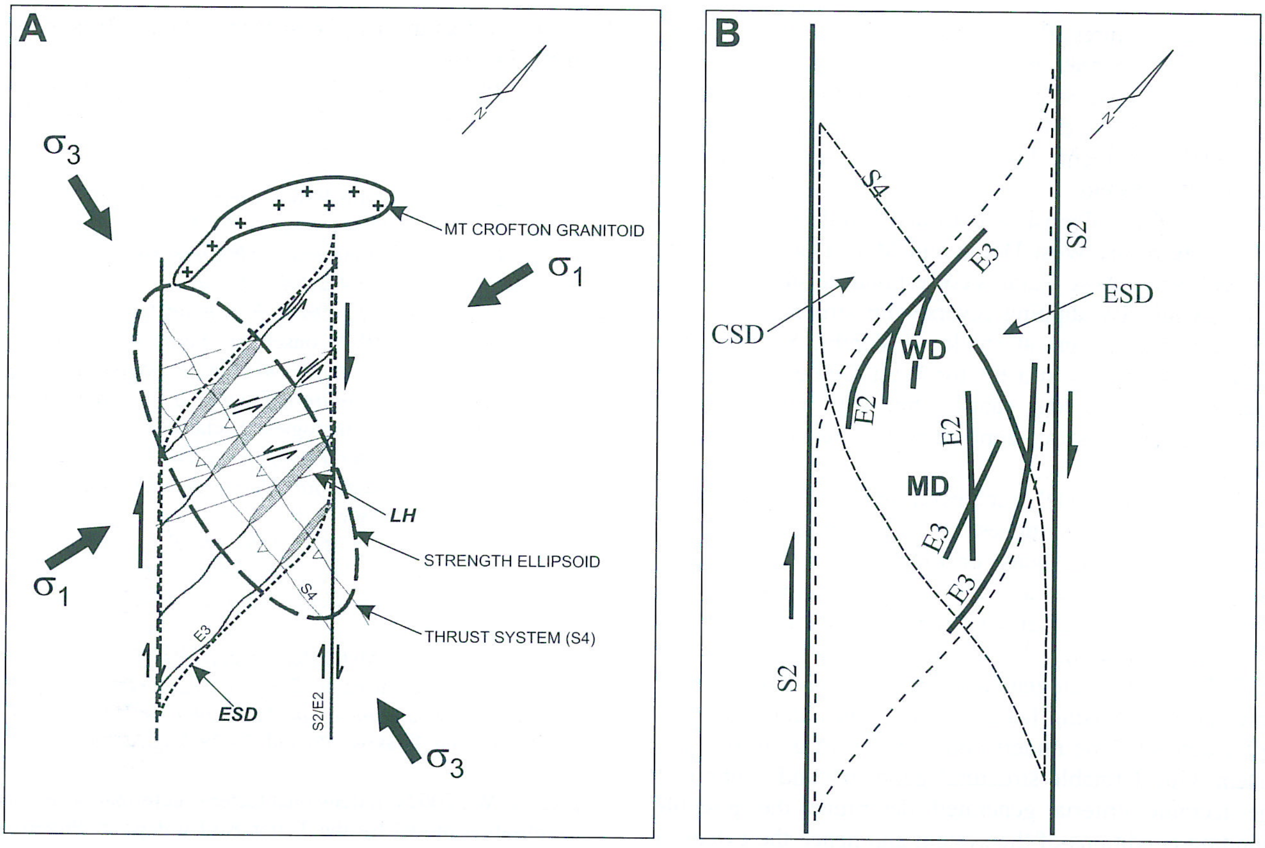


Fig. 21. Telfer tectonic deformation model. **A** – generalised interpretation for shear-compressional and extensional tectonic structure systems. S2/E2 – shear-extensional structure, S4 – thrust system, E3 – extensional system, LH – Leader Hill vein mineralised system, ESD – extensional structural domain, σ_1, σ_3 – principal stress directions of the stress field, **B** – interpreted shear-compressional (CSD) and extensional (ESD) domain pattern. S2 – shear structural system, E2 & E3 – extensional structural systems, WD – West Dome, MD – Main Dome. Arrows indicate direction and sense of tectonic movement

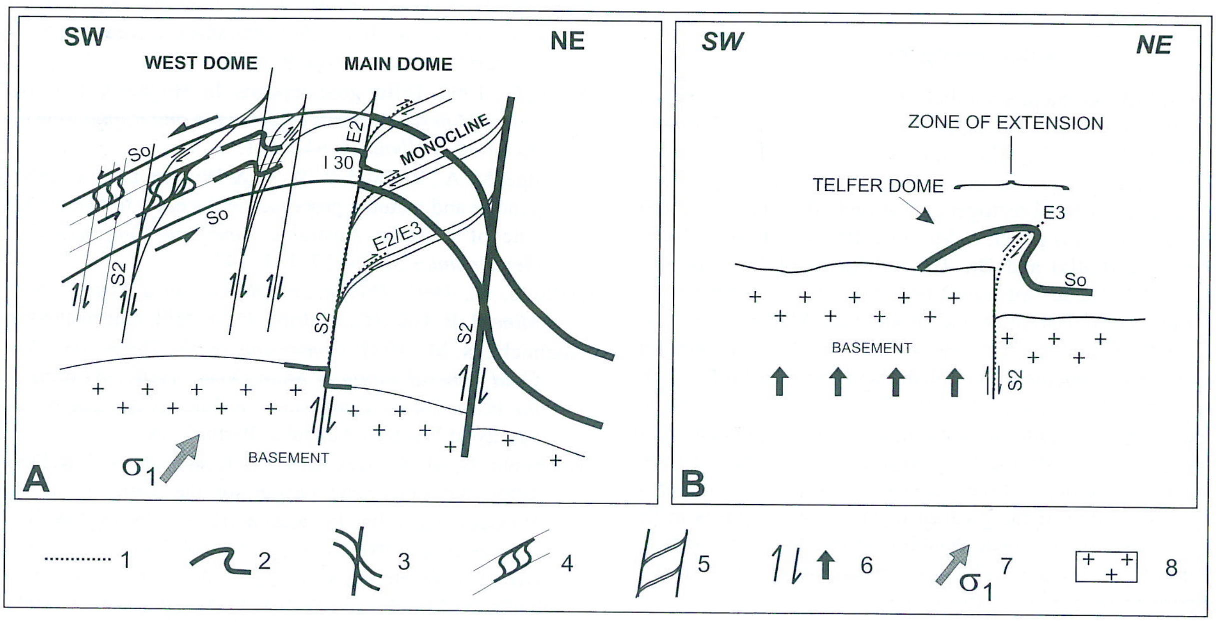


Fig. 22. Conceptual basement-related tectogenetic model of the Telfer ore system: **A** –Telfer scale flexural bend of the beds and tectonic factors controlling local mineralisation; **B** – conceptual sketch of Telfer scale FF-structure. *1* – S2 – E2/E3 structure association, *2* – Telfer scale FF-structure, *3* – Telfer scale flexural bend, *4* – orebody/ore zone formed as a result of normal dip-slip movement along bedding (So), *5* – deformation pattern of S2 – E2/E3 and S2 – So structures controling mineralisation, *6* – arrows indicating direction and sense of tectonic movement, *7* – σ_1 – principal stress direction of stress field, *8* – basement (granitoid), So – bedding

FF-features, flexures, flexural bends, and monoclines with E2 and/or E3 orientation are developed throughout the deposit. Their geometry and/or sense of fold movement suggest NE propagation direction and SW up NE down (reverse-slip) movement along the basement-rooted regional S2 structural system.

5. The Telfer deposit is confined mainly to two major mineralised areas, West Dome and Main Dome. The tectonic genesis of these features corresponds to steep NW–SE (S2) striking, SW dipping reverse-slip structural systems with basement origins at shallower depths, S2 geometry gradually transitions into E3 for West Dome, and E2 for Main Dome ellipsoidal shapes, but with E3 orientated prominent mineralisation controlling features, including the Graben Fault Zone.

6. A uniform model is achieved for tectonic genesis and mineralisation, which suggests that the formation of a flexural-bending of the beds, or FF-feature initiated in the basement along, and as a result of, active S2 structural system development is essentially the mechanism that formed the Telfer ore system.

7. The Telfer tectogenetic model explains observed tectonic and mineralising features at all scales and allows the Telfer deposit to be understood in terms of a uniform ore system with definable structural geometry and continuity. The tectonic criteria generated determine the possible bounding conditions of the system and hence the extent of the system is also definable with significant exploration implications. It has been demonstrated that the proposed model provides excellent predictive capabilities.

8. The Telfer tectogenetic model provides a unique conceptual solution for further exploration, both locally and regionally, throughout the Paterson Orogen.

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Streszczenie

TEKTOGENEZA ZŁOŻA RUD ZŁOTA I MIEDZI TELFER, PROTEROZOICZNY OROGEN PATERSON, PÓŁNOCNO-ZACHODNIA AUSTRALIA

Wiesław Bogacz

Telfer jest światowej klasy złożem Au-Cu, którego zasoby złota plasują go w obrębie 10 największych systemów rudnych na świecie. Złoże to jest uwarunkowane strukturalnie, genetycznie związane z charakterystyczną kopułą (brachyantykliną) tektoniczną, która uformowała się w obrębie późnoproterozoicznych utworów tzw. grupy Yeneena orogenu Paterson północno-zachodniej Australii (Fig. 1–3). Profil geologiczny Yeneena Group, w tym rejonu złoża Telfer, obejmuje serię utworów metaosadowych sfałdowanych wzdłuż kierunku NW–SE, z intensywnie rozwiniętą tektoniką nasunięciową (nasuwanie z NE na SW) oraz licznymi intruzjami skał granitoidowych (Fig. 3B, 4).

Skały macierzyste (*host rock*) złoża Telfer przeszły wielofazowy rozwój strukturalny i metamorficzny wyprzedzający procesy tektoniczne, z którymi związane jest okruszcowanie. Struktury powstałe w tych procesach zostały odmłodzone i wtórnie użyte podczas późniejszego ich rozwoju warunkującego mineralizację rudną.

Badania autora, w tym analiza tektogenetyczna złoża, dotyczyły struktur tektonicznych aktywnych podczas procesów okruszcowania oraz ich integracji z geometrią systemu rudnego, ustalenia kontroli mineralizacji oraz tektogenezy złoża.

Zdecydowana większość mineralizacji systemu rudnego jest skoncentrowana w dwóch podstawowych obszarach kopuły Telfer. Są to tzw. Kopuła Zachodnia i Kopuła Główna (Fig. 5). Okruszcowanie jest reprezentowane przez system ciał rudnych i stref mineralizacji typu żył kwarcowych, kwarcowo-węglanowych, kwarcowo-siarczkowych i siarczkowych, stref sztokwerków oraz brekcji tektonicznej.

W konwencjonalnym rozumieniu złoża Telfer większość mineralizacji występuje w połogo zapadających, równoległych do powierzchni warstwowania strukturach typu *reef* (Fig. 12A). Analiza tektogenetyczna tych struktur, powszechnie uważanych za stefy o znacznej ciągłości wzdłuż powierzchni warstwowania obu kopuł wskazuje, że w istocie ciała rudne oraz strefy o wyższej koncentracji rudy są związane ze szczególnymi ekstensyjnymi strukturami tektonicznymi niższego rzędu, stanowiącymi wewnętrzną budowę obu tych kopuł (Fig. 6, 7). Lokalizacja tych stref i struktur decyduje o przestrzennej geometrii systemu rudnego Telfer. Sytuacja ta sugeruje potrzebę rewizji uproszczonej koncepcji, że ekonomiczne okruszcowanie jest związane z rozległymi strukturami typu *reef* genetycznie ściśle związanymi z fałdową genezą kopuł Telfer.

Mechanizmy tektoniczne prowadzące do powstania struktur niższego rzędu wpłynęły w zasadniczy sposób na styl i budowę wewnętrzną stref mineralizacji, lokalizację ciał rudnych i rejonów z wyższą zawartością metalu oraz – w szerszym znaczeniu – na tektoniczną genezę całego systemu rudnego Telfer. Struktury warunkujące mineralizację można sklasyfikować w kilku kategoriach, obejmujących:

– struktury żyłowe typu *reef* powstałe z ekstensyjnego otwierania powierzchni równoległych do warstwowania (So), jednak wykazujące znaczne różnice rozwoju, wahania grubości i zmienność budowy wewnętrznej oraz rozwoju tektonicznego (Fig. 12D),

– *struktury typu FF* (Fig. 6A, 6B), fleksury (Fig. 6C, 6D) oraz fleksuralne przegięcia warstw oraz

– strome i pionowe strefy ścięciowo-uskokowe (Fig. 6E) oraz związane z nimi umiarkowanie zapadające na zachód strefy ścięciowo-uskokowe, lokalnie tzw. *monokliny* (Fig. 12A).

Pierwotna koncepcja genezy złoża Telfer sugerowała, że może być ono typu sedymentacyjnego, gdyż okruszcowanie w większości było interpretowane jako związane ze strefami równoległymi do warstwowania. Wraz z postępem rozpoznania geologicznego, w późniejszych koncepcjach, podjęto próby tektonicznej interpretacji genezy złoża, z których większość skoncentrowała się na roli struktur związanych z regionalną (poziomą) kompresją (Fig. 8, 9). Zwłaszcza mechanizm fałdowy ze zginania z poślizgiem (Fig. 8B) był uważany za bezpośrednio kontrolujący okruszcowanie (typu *reef*) podczas formowania się Kopuły Głównej oraz Kopuły Zachodniej.

Brak wystarczającego uzasadnienia związku geometrii systemu rudnego ze strukturami kompresyjnymi doprowadził do podjęcia przez autora próby wyjaśnienia genezy tektonicznej złoża Telfer przy użyciu koncepcji sugerującej związek poziomej kompresji z równoczesnym rozwojem struktur propagowanych z podłoża (Fig. 9E). Dalsze badania autora potwierdziły zależność geometrii systemu rudnego od struktur podłoża.

Analiza tektogenetyczna wskazuje, że w Telfer istnieje kilka podstawowych systemów strukturalnych, których interferencja oraz rozwój – zależnie od lokalizacji w obrębie złoża – od ścięciowego i ścięciowo-ekstensyjnego do ekstensyjnego, w zasadniczy sposób wpłynął na ukształtowanie geometrii całego systemu rudnego. Systemy te można sklasyfikować nastepujaco:

1. system połogo zapadających struktur ścięciowych, ścięciowo-ekstensyjnych i ekstensyjnych równoległych do powierzchni warstwowania (system strukturalny So),

2. system struktur inwersyjno-przesuwczych, ścięciowych o przebiegu NW–SE, stromych i zapadających na SW (system strukturalny S2),

3. system nasunięć (ze składową przesuwczą) o przebiegu WNW–ESE, zapadajacych 30°–40° na SSW (system strukturalny S4),

4. system struktur inwersyjno- i/lub normalno-przesuwczych, ścięciowo-ekstensyjnych oraz ekstensyjnych o przebiegu NW–SE, stromych i zapadających na SW (system strukturalny E2, równoległy do S2),

5. system struktur inwersyjno- i/lub normalno-przesuwczych, ekstensyjnych lub ekstensyjno-ścięciowych o przebiegu N–S, zapadających na W (system strukturalny E3).

Charakterystyczna cechą złoża Telfer są stopniowe przejścia jednego systemu strukturalnego w drugi, zwłaszcza struktur S2–S4, S2–E2/E3 oraz E2–E3, zarówno wzdłuż biegu jak i upadu. Analiza tektogenetyczna tych zależności pozwala na określenie wielu aspektów kontroli mineralizacji oraz geometrii i tektogenezy systemu rudnego.

Kopuła Zachodnia posiada nieregularny kształt wydłużony w kierunku N–S (E3). Oś kopuły wykazuje charakterystyczny sigmoidalny przebieg, ogólnie dopasowujący się do planu strukturalnego i kinematyki systemów E2–E3 (Fig. 10A, 10B). Układ geometryczny kontrolujący mineralizację obejmuje struktury E2, które występują w układzie kulisowym, oraz struktury E3 (Fig. 10C). Oś układu kulisowego struktur E2 jest równoległa do biegu systemu strukturalnego E3.

Mimo, że znaczna część mineralizacji Kopuły Zachodniej jest związana z połogo zapadającymi strefami typu *reef* (równoległymi do warstwowania, system So), zasięg obszarów ekonomicznego okruszcowania tych stref wyznacza geometria struktur ekstensyjnych E2–E3. W konsekwencji, układ geometryczny tych struktur decyduje o lokalizacji (wzdłuż ich biegu i upadu) podwyższonej zawartości metalu w obrębie struktur typu *reef*. Tektogeneza tych stref okruszcowania jest niezależna od procesów fałdotwórczych prowadzących do powstania Kopuły Zachodniej i wiąże się ze ścinaniem i ekstensją wzdłuż struktur E2–E3. Te z kolei sa propagowane wskutek rozwoju struktur podłoża o przebiegu NW–SE (S2), równoległych do przebiegu Orogenu Paterson (Fig. 10, 11).

W obrębie Kopuły Zachodniej obserwuje sie wiele struktur drugiego rzędu, z którymi wiążą sie lokalne strefy okruszcowania. Są to struktury typu FF, fleksury oraz fleksuralne przegięcia warstw. Podobnie jak w przypadku struktur typu *reef*, ogólna geometria rozmieszczenia tych struktur dopasowuje sie do planu strukturalnego wyznaczonego przez układ strukturalny E2–E3. Najbardziej charakterystycznym zjawiskiem tektonicznym jest obecność oraz związek okruszcowania z geometrią struktur typu FF. Struktury te – niezależnie od lokalizacji – wykazują asymetrię oraz odwróconą (malejący w górę upad) lub sigmoidalną krzywiznę stref osiowych oraz cechy kinematyczne sugerujące ich propagację wzdłuż stromych, w górę wypłaszczających się i/lub zanikających, struktur E2 lub E2–E3. Sytuacja strukturalna wskazuje na związek tych struktur z procesami tektonicznymi systemu S2, propagujacymi deformacje ścięciowo-ekstensyjne z głębszych poziomów kopuły do góry oraz z południowego-zachodu na północny-wschód (Fig. 11, 14B).

Kopuła Główna charakteryzuje się mniejszym stopniem deformacji tektonicznej w porównaniu do Kopuły Zachodniej, jednak ogólne mechanizmy kontroli geometrii oraz tektogenezy systemu rudnego pozostają podobne. Układ stref okruszcowania typu *reef* wykazuje bardziej regularny rozwój (Fig. 12). W rejonach przypowierzchniowych strefa osiowa Kopuły Głównej wykazuje sigmoidalny przebieg od kierunku NW–SE na południowym-wschodzie, poprzez sigmoidalne przegięcie, do kierunku zbliżonego do WSW–ENE w części centralnej oraz ponownie powrót do kierunku NW–SE na północnym-zachodzie (Fig. 5, 13). Podobnie, jak w Kopule Zachodniej, strefy okruszcowania dopasowują się do geometrii systemów E2–E3 (Fig. 13A).

Jednymi z najbardziej charakterystycznych struktur kontrolujących znaczną część okruszcowania Kopuły Głównej są: Monoklina I30 (Fig. 12A, 12B, 15) oraz strefa uskokowa Graben Fault Zone (GFZ) (Fig. 5, 15, 16). Obok powyższych, ciała rudne i strefy ekonomicznej mineralizacji związane są ze strukturami niższego rzędu typu fleksur (Fig. 14A) oraz struktur FF (Fig. 14B).

GFZ jest największą strukturą tektoniczną o przebiegu E3 wystepującą w Kopule Głównej. Formowanie się tego uskoku odegrało zasadniczy wpływ na ekstensyjne otwieranie się w jego pobliżu powstałych wcześniej powierzchni warstwowania oraz genezę i zasięg okruszcowania typu *reef*. GFZ oraz Monoklina I30 są strukturami zlokalizowanymi w północno-wschodnim skrzydle Kopuły Głównej. Znacznie intensywniejsze okruszcowanie w tym skrzydle w stosunku do południowo-zachodniego skrzydła tej kopuły jest związane z formowaniem się tych struktur.

Interpretacja tektogenetyczna Kopuły Głównej wskazuje na jej ścisły związek tektoniczny z uskokami i strukturami ścięciowymi systemu podłoża (S2), ich propagacja do góry oraz dalszym rozwojem jako struktur ścięciowo-ekstensyjnych i ekstensyjnych o geometrii E2 oraz E3. Struktury te kontrolują okruszcowanie. Porównanie planu strukturalnego z głębszych partii z przypowierzchniowym planem strukturalnym Kopuły Głównej potwierdza powyższą interpretację (Fig. 17).

Cechy tektogenetyczne i relacja geometryczna pomiędzy strefami deformacji i mineralizacji, zwłaszcza pozycja i geometria ciał rudnych oraz stref mineralizacji z podwyższoną zawartością metalu, pozwalają na wyróżnienie w Telfer dwóch domen strukturalnych:

1. Domenę kompresyjną (CSD), obejmującą strome struktury ścięciowe i uskokowe o przebiegu NW–SE (S2) oraz nasunięcia systemu WNW–ESE (S4), zapadające na SSW (Fig. 18, 19)

2. Domenę ekstensyjną (ESD), obejmujaca struktury o orientacji NW–SE (E2) oraz N–S (E3) (Fig. 19, 20).

Domena kompresyjna reprezentuje wcześniejszy etap deformacji, w tym mechanizm fałdowy ze zginania z poślizgiem, który wpłynął na formowanie się kopuły Telfer oraz związane z tym skrócenie tektoniczne formacji geologicznej skał macierzystych. Jednak ten etap deformacji wywarł nieznaczny wpływ na procesy mineralizacyjne. Nieco później uformowana domena ekstensyjna obejmuje struktury ścięciowo-ekstensyjne i ekstensyjne, których rozwój i geometria zadecydowały o rozmieszczeniu/kontroli większości okruszcowania (Fig. 21).

Model tektogenetyczny domeny ekstensyjnej (ESD) sugeruje etap ruchu normalno-zrzutowego po powierzchniach warstwowania. Jest to proces wtórny, nałożony na pierwotnie uformowane struktury inwersyjne równoległe do warstwowania, związane z mechanizmem fałdowym ze zginania z poślizgiem.

Relacje geometryczne i tektogenetyczne oraz sekwencja czasowa struktur ścięciowo-kompresyjnych (CSD) oraz ścięciowo-ekstensyjnych i ekstensyjnych (ESD) wykazują wszelkie cechy dwóch nałożonych systemów tektonicznych (domen), powstałych wskutek ruchów propagowanych z podłoża w górę (Fig. 22). W głębiej położonych poziomach obserwuje się ściślejszy związek ze stromymi i pionowymi strukturami o przebiegu NW–SE (S2) i kinematyce inwersyjnej. Struktury te ku górze stopniowo zmieniają character ścięciowy na ścięciowo-ekstensyjny i ekstensyjny oraz dopasowują się do orientacji struktur E2–E3, określających geometrię całego systemu rudnego (Fig. 21, 22). Ponadto, ku stropowi obserwuje się "wypłaszczenie" systemu co determinuje odwróconą krzywiznę wielu struktur o geometrii E2 i E3, w tym charakterystycznych struktur typu FF (np. Fig. 11B, 16).

Tektogeneza systemu rudnego Telfer może być zinterpretowana jako wynik przede wszystkim pionowej (z prawoprzesuwczą składową o mniejszym znaczeniu) aktywności propagowanych z podłoża ścięć i uskoków inwersyjnych o przebiegu NW–SE. Całość systemu rudnego może tworzyć strukturę typu fleksuralnego przegięcia warstw (Fig. 22A), a nawet strukturę typu FF (Fig. 22B). W obrębie aktywnego rozwoju takiej struktury powstały pochodne struktury ekstensyjne, w tym typu *reef*, fleksur i przegięć fleksuralnych warstw oraz struktur typu FF. Struktury te wyznaczają lokalne obszary okruszcowania oraz łącznie, wyznaczają geometrię całego systemu rudnego Telfer.

Geneza każdego złoża musi być rozpatrywana kompleksowo z uwzględnieniem wszystkich faktów poznanych w trakcie ich badania. Opieranie się tylko na pewnej grupie spostrzeżeń, wynikających z badań specjalistycznych, np. geochemicznych, mineralogicznych czy też geologicznych, może doprowadzić do nieprawidłowych wniosków (Gruszczyk, 1984; str. 53). Proponowany model tektogenetyczny integruje całość dostępnej bazy danych geologicznych i geofizycznych, a ponadto posiada cechę przewidywalności lokalizacji nieznanych stref okruszcowania w obrębie złoża Telfer.