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SULLIVAN EXPLORATION B.C. GROUP

WORKSHOP ON LEAD/ZINC/SILVER DEPOSITS IN CLASTIC SEDIMENTS

Harrison Hot Springs
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SULLIVAN FRAGMENTALS by G.D. DELANEY[1] and R.L. HAUSER[2]

INTRODUCTION

Variably fragmented sedimentary rocks are a key element of the footwall to the Sullivan deposit. Fragmentals are also intimately associated with many other sulphide occurrences in the Lower and Middle Aldridge Formation. In most cases investigation of these regional occurrences is limited to what is exposed in outcrop. Consequently, it is often hard to understand the significance of a fragmental occurrence, and to fully evaluate the economic potential. In contrast, fragmentals associated with the Sullivan deposit can be studied in detail because of close-spaced diamond drilling and numerous underground workings. A clear understanding of the nature and interrelationships of Sullivan fragmentals is a critical tool, not only for understanding the genesis of this deposit, but also for use in evaluating the significance of regional occurrences of fragmentals.

PURPOSE

The purpose of this paper is to report on the results and interpretation of a study of the fragmented sedimentary rocks associated with the Sullivan deposit. As this study is still in progress, some of the results must be considered preliminary.

The last investigation of fragmental rocks at Sullivan was summarized by Jardine in 1966. Since that time there has been a great deal of new underground development which provides important new insight into the interrelationships and genesis of this enigmatic rock type.

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FRAGMENTALS

The Sullivan deposit lies near the top of the Middle Proterozoic Lower Aldridge Formation. The Lower Aldridge Formation is a sequence of predominantly fine-grained, argillaceous, siliclastic sediments which accumulated in a basinal setting. A large volume of fragmental rock occurs in the Lower Aldridge Formation in the footwall to the Sullivan deposit. A minor amount of these rocks is found in hanging wall stratigraphy.

On the basis of textures, it is possible to distinguish two distince varieties of fragmentals in the footwall. One group is subangular-to subrounded, granule-to predominantely pebble-size fragments, forming a condensed-to disrupted framework. This variety will henceforth be referred to as pebble fragmental. In terms of overall volume this variety constitutes the greatest proportion of the footwall fragmentals. Distribution and thickness of the pebble fragmental is illustrated in Figure 1. The second type of fragmental in the footwall consists of angular, granule-to boulder-size fragments forming a generally intact-to locally disrupted polymodal framework. This variety of fragmental includes the chaotic breccia of Jardine (1966). Distribution of chaotic breccia is shown in Figure 2.

The nature and relationships of the pebble fragmentals are best reviewed by reference to the isopach map of this lithotype (Fig. 1) and to footwall mapping detail. For purposes of this discussion, the footwall will be subdivided in plan into three distinct geographic domains. These domains are: south of the 10,000 N latitude; north of 10,000 N and west of the transition zone between massive ore and bedded ore; north of 10,000 N and east of the transition zone.

SOUTH OF 10,000 N

South of 10,000 N, pebble fragmentals occur in several discrete bodies, most of which crosscut bedded Lower Aldridge strata. The overall morphology of fragmental dykes is variable as they pinch or swell in thickness and locally bifurcate. They range in both height and width from tens of centimetres to tens of metres. The framework of these fragmental dykes varies from condensed to disrupted. All clasts are of a similar lithologic spectrum as encompassing Lower Aldridge sediments. Clasts commonly range from granule- to pebble-size and vary from angular-to well rounded. Subrounded is more common. In some of these dykes a few clasts are characterized by wispy terminations. Some of these fragments contain smaller clasts within them. Locally near the margins of these fragmental bodies there are angular boulder size fragments which are commonly of the same composition as the surrounding wall rocks.

In addition to a general cross-cutting morphology, locally there are stratiform apophyses to the cross-cutting fragmentals.

In the bedded sequence below some of the cross-cutting fragmentals there are commonly micro-faults and sand or silt dyklets.

In order to better elucidate the nature of these cross-cutting pebble fragmentals, it is useful to review in some detail the attributes of one of the better exposed examples.

In G-13-30 block, along the north wall of the 4100 Ramp, is a fragmental body which cross-cuts a sequence of thin-to medium-bedded wacke and quartzitic wacke (Fig. 3). On the lower part of the wall on which it is exposed, the fragmental dyke bifurcates around a central bedded area. Near the top of the wall, its shape mushrooms. Locally, stratiform apophyses of the fragmental extend into the surrounding country rock. The maximum width of the cross-cutting structure is about 40 feet. Large blocks of bedded sediment, characterized by scoured tops, are contained within the body of the dyke. Bedding attitude in these blocks is the same as in the surrounding country rock. It is interesting to note that the fragmental body is not exposed on the south wall of the 4100 Ramp 4 m away.

An intact to generally disrupted framework of predominantly pebble size clasts, in an argillaceous matrix, characterizes the footwall dyke. Clasts are grey to greenish-grey argillite, wacke and quartzitic wacke similar to the host lithotypes. Some clasts are laminated or thin-bedded. Pyrrhotite, as peripheral rims, disseminations or irregular clots is present in a few of the more arenacous clasts. Locally there are clast-shaped concentrations of massive pyrrhotite.

A detailed fabric study has been made of one oriented slab collected from near the centre of the dyke. In this slab, clasts are predominantly pebble size and typically subangular to subrounded. A plot of axial ratio measurements (b/a = 53; c/b - 47) indicates that most clasts lie within the bladed field of Zing's classification of pebble shapes. A few fragments have irregular contorted shapes with wispy margins and some of these contain rounded clasts. The long axes(a) of most clasts are aligned parallel to each other. The apparent orientation of this alignment was studied by measuring (45) the orientation of the long axes of clasts on a surface cut parallel to the plane formed by their long and intermediate axes. For structurally corrected data, the mean orientation of the a axis dips at 8° toward 220°, which is sub-parallel to the contacts.

SOUTH OF 10,000 N (Cont'd)

The exposure of the cross-cutting fragmental body in G-13-30 is interpreted to be a section through a lateral apophysis of a sedimentary dyke, the main body of which lies further to the north. This interpretation is supported by the following points: (1) the absence of the fragmental rock in the wall immediately opposite that which was mapped; (2) a thick intersection of conglomerate in D.D.H. 6842, which was drilled about 10' north of the wall studied; (3) the presence of large, unrotated blocks of bedded sedimentary rock within the fragmental dyke; (4) a well-developed clast fabric which indicates that fragments moved freely and assumed an orientation imposed by a near horizontal, southwest-northeast flow.

A few of the fragmental occurrences south of 10,000 N, such as that exposed in 39-L-14 Sub A, are stratiform, composite slump deposits. These consist of discontinuous beds, several metres long between and around which are intervals of angular, pebble-to boulder-size fragments forming an intact, chaotic matrix. Some fragments are folded. Throughout these bodies there are beds and lenses of elongate pebble size clasts, the long axis of which are aligned parallel to each other and generally parallel to bedding outside of the fragmental.

NORTH OF 10,000 N, WEST OF THE TRANSITION ZONE

In this area of the footwall, the pebble fragmental is a more or less continuous body which is characterized by both an irregular top and base (Figs. 1,4, and 5) as well as a variable thickness. The basal contact of this body varies from one which is slightly unconformable to that which is distinctly cross-cutting. In the footwall to this fragmental there are commonly cross-cutting fragmental dykes. As well, within this basal zone, there are areas of angular

NORTH OF 10,000 N, WEST OF THE TRANSITION ZONE (Cont'd)

fragments, some of which are up to a few metres wide. In some of these, bedding is of the same attitude as undisturbed sediments. In others, however, bedding has been rotated with respect to normal attitudes. The top of the western pebble fragmental is also highly irregular. Locally there is a conformable contact with overlying bedded sediments of the Lower Aldridge Formation. In these instances up to 15 m of sedimentary rock occurs between the top of the fragmental and the sulphide footwall. More commonly, however, an irregular hummocky topography characterizes the top of this fragmental body. At several localities fragmental is in contact with the sulphide footwall (Figs. 4 and 5).

In plan, the thickest zone of pebble fragmental is an ellipsoidal area near to the western boundary of ore (Fig. 1). Here, much of the fragmental, which is up to 125 m thick, is bounded by sharp, cross-cutting contacts with adjacent bedded sediment. The somewhat variable thickness of this fragmental body elsewhere is illustrated in Figure 1.

Although the western pebble fragmental body is commonly described as massive, there are some textural variations within this unit. The framework ranges from condensed to disrupted. Clasts generally range from granule-to pebble size. Locally, larger fragments occur such as at the bases, near the sides and in zones where chaotic breccia forms an admixture with the pebble fragmental. In some areas, particularly near the contact, there is a well developed clast fabric.

NORTH OF 10,000 N, EAST OF THE TRANSITION ZONE

East of the transition zone the footwall pebble fragmental is a more angular, generally stratiform body (Fig. 6). It is several metres thick near the trans-

NORTH OF 10,000 N, EAST OF THE TRANSITION ZONE (Cont'd)

ition zone and gradually tapers in thickness to the northeast. The basal contact of this body varies from conformable to slightly disconformable. Immediately above the basal contact is a zone up to a few tens of centimetres thick which is characterized by scattered granule-and pebble-size clasts. Throughout much of the thickness of this body, however, is an intact-to condensed, poorly sorted framework of angular to subrounded granule-to pebble-size clasts of Lower Aldridge lithotypes. In contrast, in the top few metres there is typically a prominent clast fabric, clast stratification and intercalated intervals (up to three) of laminated sedimentary rock.

East of the transition zone, overlying the fragmental is even, parallel-laminated or cross-laminated, pyrrhotitic-quartzitic wacke and wacke (Fig. 7). Many of these beds are graded; some are separated by scoured contacts (Fig. 7). Lenses and scattered basal concentrations of aligned granule-and pebble-size clasts are common within this sequence. The contact between the bedded hanging wall and the conglomerate is undulatory in nature. Tongues of fragmental protrude into the overlying bedded sediment.

Near the transition zone there is in excess of 12 m of bedded sedimentary rock between the hanging wall of the fragmental and the footwall of the "Main Band". This thickness gradually decreases to the northeast until sulphide rests directly on fragmental (Fig. 5).

CHAOTIC BRECCIA

As noted at the outset of this paper, west of the transition zone, within the footwall, there are also areas of generally angular, pebble-to-boulder-size fragments, forming an intact-to, locally disrupted-polymodal, jumbly framework (Fig. 2). Jardine (1966 p. 45), in his description of this chaotic breccia observed: "Bedded fragments are often wispy, twisted or rotated with ends that appear torn rather than broken." Highly discordant zones of chaotic breccia occur within the pebble fragmental as well as within bedded sediment. In the latter case, breccia is reported (Jardine, 1966, p. 45) to grade into fractured rock, which in turn, grades into relatively undisturbed rock. In some cases chaotic breccia appears to extend from bedded sediments through the pebble fragmental and right up to the sulphide footwall.

In addition to the cross-cutting chaotic breccia phase, some rubbly zones, such as exposed in 39-L-14 Sub A, are probably slump deposits.

SOUTHWEST BRECCIA

Near the southwest margin of ore, there is a cross-cutting zone of fragments and contorted sediments which transects the main sulphide body and merges with a stratifrom fragmental unit in the hanging wall (Fig. 8). This zone, which was named the Southwest Breccia by Owens (1960) transects about 45 m of stratigraphy. The discordant part of the southwest breccia has a flattened ellipsoidal shape in plan. The long axes trends N-S about 250 m; the short axis is 16 m (Fig. 2).

Owens(op. cit.) has observed that fragments within the Southwest Breccia vary from angular to subrounded and consist of fine-grained sedimentary rocks, as well as tourmalinite. Intense alteration, primarily chloritization, and the presence of sulphide stringer zones, tend to mask primary features in the Southwest Breccia.

GENESIS

In basins flanking mobile belts, rapid accumulation of fine grained sediment is a common phenomena. In some of these accumulating piles, clays form an impermeable seal which prevents escape of pore fluid. Continued accumulation of sediment, increases in temperature (Bradley, 1975) and other processes, such as methane generation by anaerobic bacteria (Hedberg, 1974) result in pore pressures which greatly exceed normal hydrostatic pressures. Subsequent abrupt pressure release, commonly generated by tectonic adjustments causing earthquakes, result in sedimentary diapirism or the extrusive equivalent mud volcanism (Higgins and Saunders, 1974).

Most of the Lower Aldridge Formation, the footwall succession at Sullivan, is fine-grained argillaceous sediments, which accumulated in a basinal setting. Carbonaceous detritus and iron sulphides are ubiquitous in these sediments. Evidence of higher than normal thermal activity is indicated by alteration phases associated with the Sullivan deposit.

The cross-cutting pebble fragmental bodies south of 10,000 N probably formed by some form of pressure release phenomena. Microfaults and sedimentary dykets in associated sediments are indicative of tensional stress which may have been the triggering mechanism. A well developed clast fabric in some of these bodies indicates that at least locally fragments moved freely, assuming an orientation imposed by flow. The presence of clasts within plastically deformed clasts suggests a pulsating origin for the energy mechanism which formed these fragmental dykes.

Some fragmental dykes probably vented at the sediment water interface. Evidence of this are slump sheets in the footwall such as that exposed at 39-L-14 Sub A.

GENESIS (Cont'd)

North of 10,000 N and west of the transition zone, parts of the base of the footwall fragmental complex are characterized by cross-cutting fragmental dykes similar to those which occur as isolated bodies to the south. In this basal zone there are also large blocks of bedded sedimentary rocks, some of which are disoriented. These were probably formed by anastomosing networks of fragmental dykes. The body of the western pebble fragmental is attributed to the amalgamation of networks of these sedimentary dykes. The fact that at some localities the fragmental is in contact with the sulphide footwall, whereas elesewhere there is interbedded sediment, is evidence for a period of inactivity and sedimentation, followed by one of rejuvenation of the fragmental forming process.

Zones of chaotic breccia, which are commonly intimately associated with the pebble fragmental, are interpreted to represent a juvenile stage of the same process which formed this more mature body.

East of the transition zone, the pebble fragmental is a sheet-like body which tapers in thickness to the northeast. West of the transition zone it merges with the more irregular western pebble fragmental. Undisturbed beds occur both above and below the eastern pebble fragmental. These relationships, coupled with the internal textures in this unit, indicate that it probably formed as slump deposit. A narrow reworked zone at the base, and a wider reworked zone at the top of this otherwise intact massive fragmental, are attributed to zones of mixing related to turbulence or interface in stability (Hampton, 1972) which formed during slumping. Subsequent to slumping, there were probably several episodic periods of reworking at the top as indicated by clast stratification, interbedded sediment and a well developed clast fabric.

GENESIS (Cont'd)

Immediately east of the transition zone, there is up to 15 m of bedded sediment between the top of the fragmental sheet and the sulphide footwall (Fig. 5). The thickness of this interval of sediment gradually decreases to the northwest until sulphide rests directly on fragmental. Southeast and northwest of the transition zone, the thickness of this zone also gradually decreases. These relationships have at least two implications. The first is that after emplacement of the slump sheet, there was probably some subsidence of the western fragmental complex. This is supported by the northeast tapering wedge of sediment between the fragmental unit and the sulphide footwall. The second implication of these relationships is that a tapering trough-like depression was responsible for the localization of slumping. Isopach maps of other hanging wall units also support this hypothesis.

The Southwest Breccia complex probably represents a late-stage post-ore fragmentation event similar to process which were common in the footwall.

In summary, the following simplified history is envisaged for the formation of fragmental rocks associated with the Sullivan deposit.

1. Rapid deposition of most of the Lower Aldridge Formation, a sequence of predominantly fine-grained sediments, in a basinal setting. Sealing of this sediment pile, and development of pore overpressure. Contribution factors may have included additional sedimentation, an increase in thermal gradient and methane generation by anaerobic bacteria.

2. Initiation of a tensional stress regime, perhaps related to some incipient zones of crustal weakness (Fig. 9.1).

GENESIS (Cont'd)

3. Pore pressure release and the formation of cross-cutting fragmental dykes. Some of these probably vented at the sediment water interface forming local slump deposits (Fig. 9.2).

4. Growth and amalgamation of fragmental dykes into the western fragmental complex. A large mound of variably fragmented sediment formed at the sediment water interface and subsequently slumped into a trough-like depression which lay to the northeast (Fig. 9.3).

5. A period of subsidence of the core zone of the fragmental complex. This was followed by a period of relative inactivity of the fragmental complex, coupled with turbiditic sedimentation (Fig 9.4).

6. Rejuvenation of the core zone of the fragmental complex including the develepement of new zones of fragmentation which reached the sediment water interface. This was followed rapidly by the introduction of metal-rich brines into the system (Fig. 9.5).

7. A post-ore stage of fragmentation resulting in formation of the Southwest Breccia.

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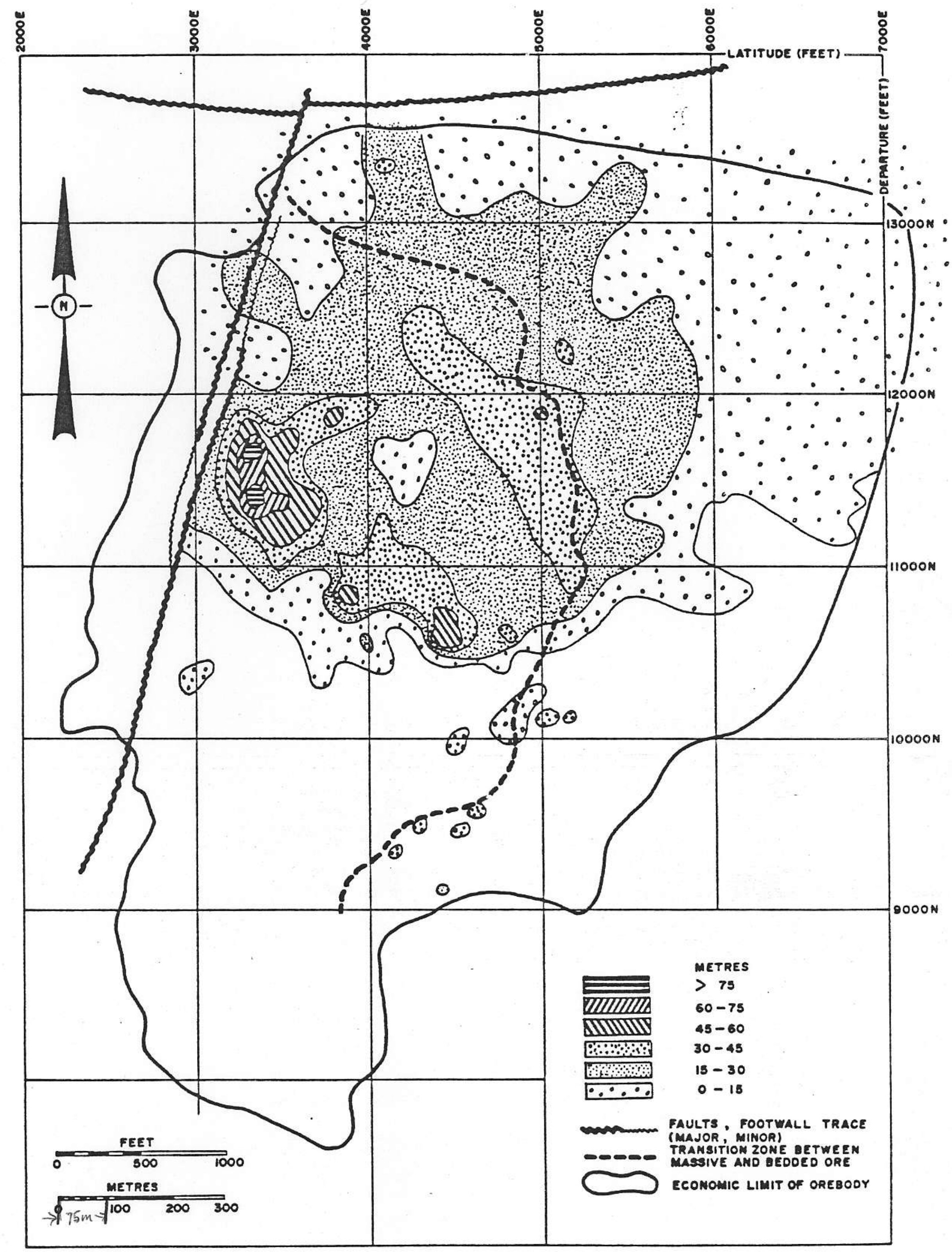

Figure 1. Isopach map of footwall pebble fragmental

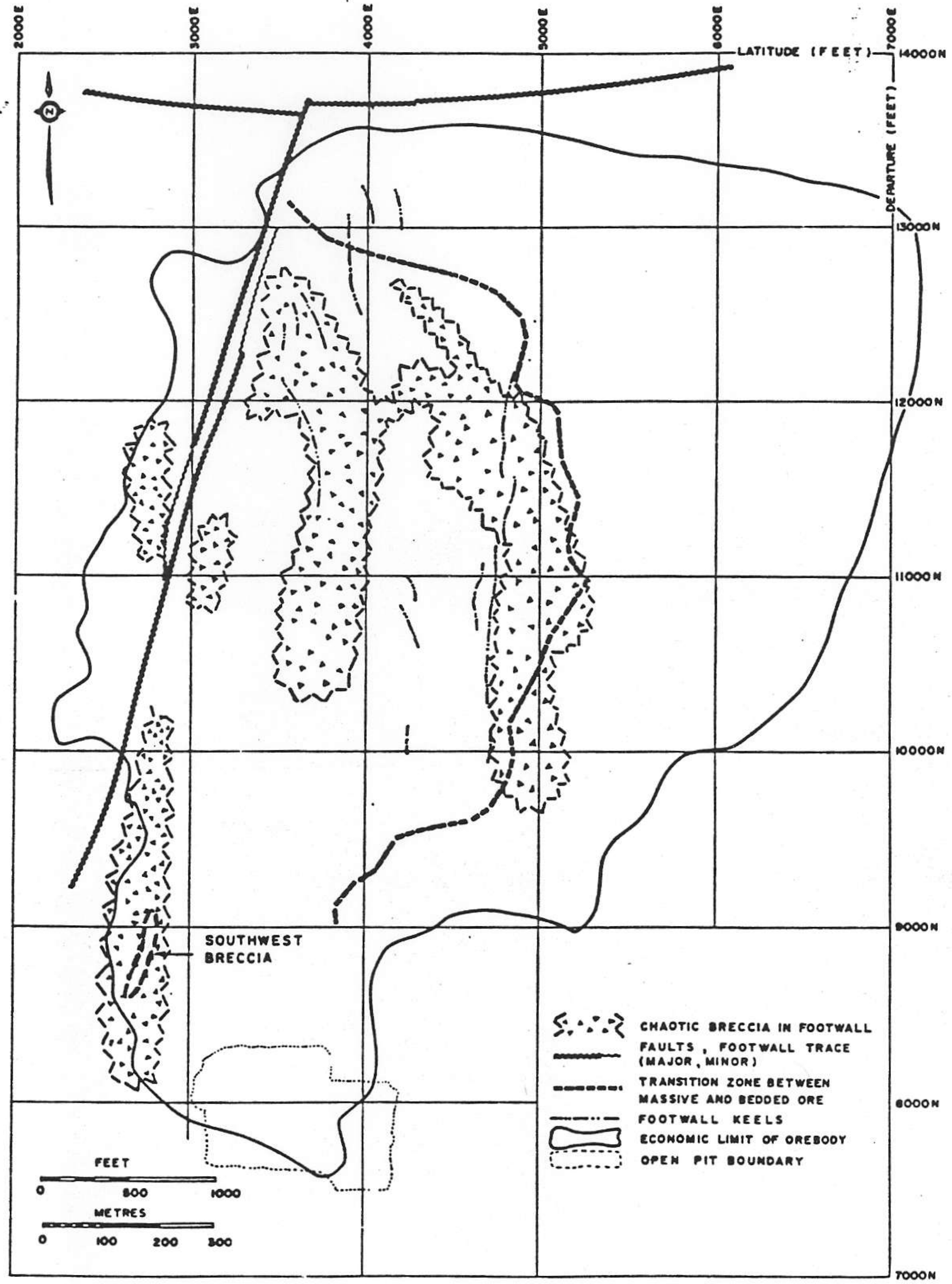

Figure 2. Distribution of chaotic breccia in the footwall and the Southwest Breccia in the hanging wall of the Sullivan orebody.

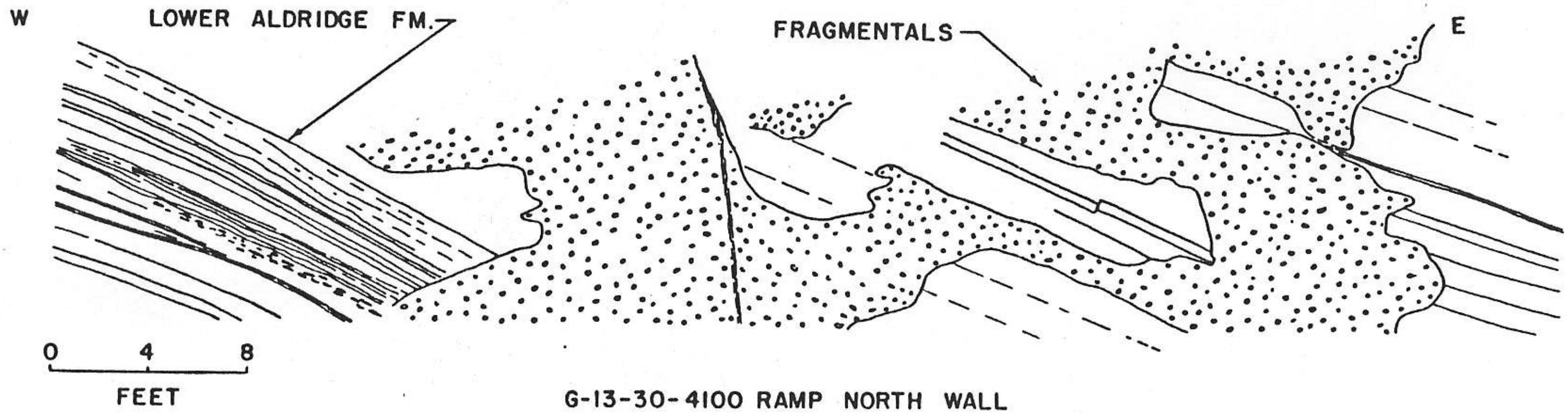

Figure 3. Fragmental dyke in G-13-30 block along the north wall of the 4100 Ramp.

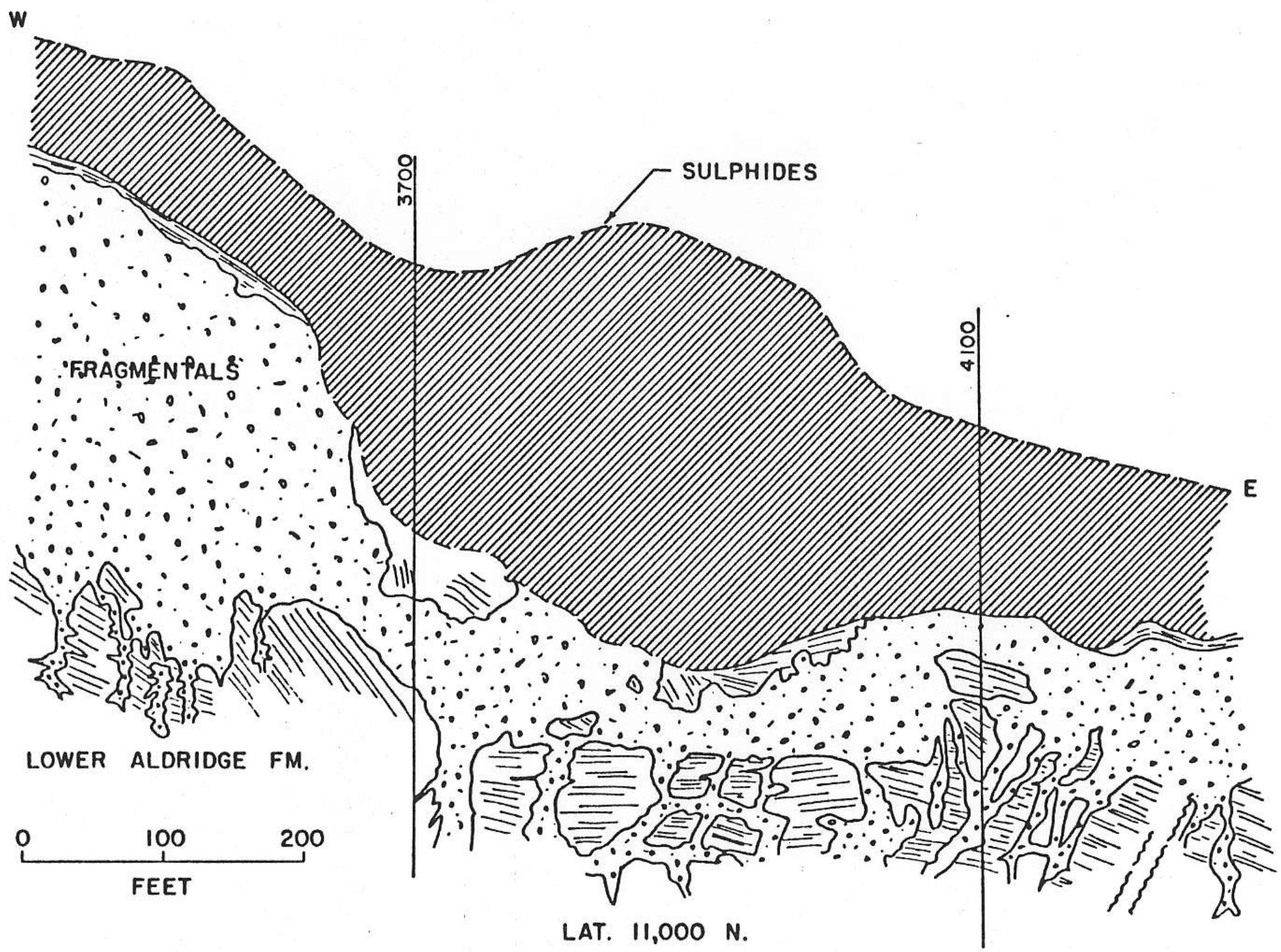

Figure 4. E-W cross-section along a portion of the 1,000 N latitude. This figure illustrates the nature of the pebble fragmental west of the transition zone.

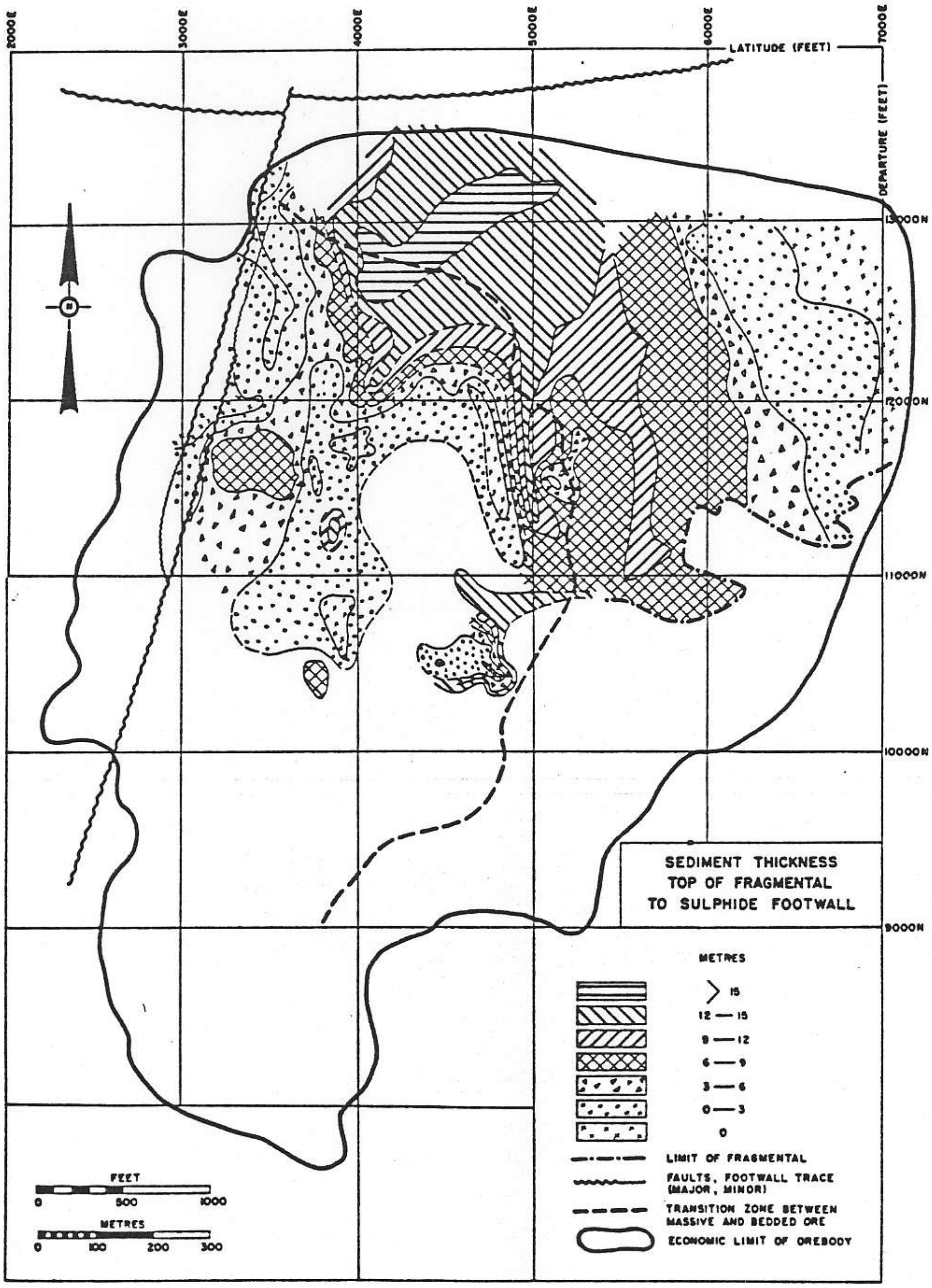

Figure 5. Isopach map of the thickness of bedded sediment between the top of the pebble fragmental and sulphide footwall of the Sullivan orebody.

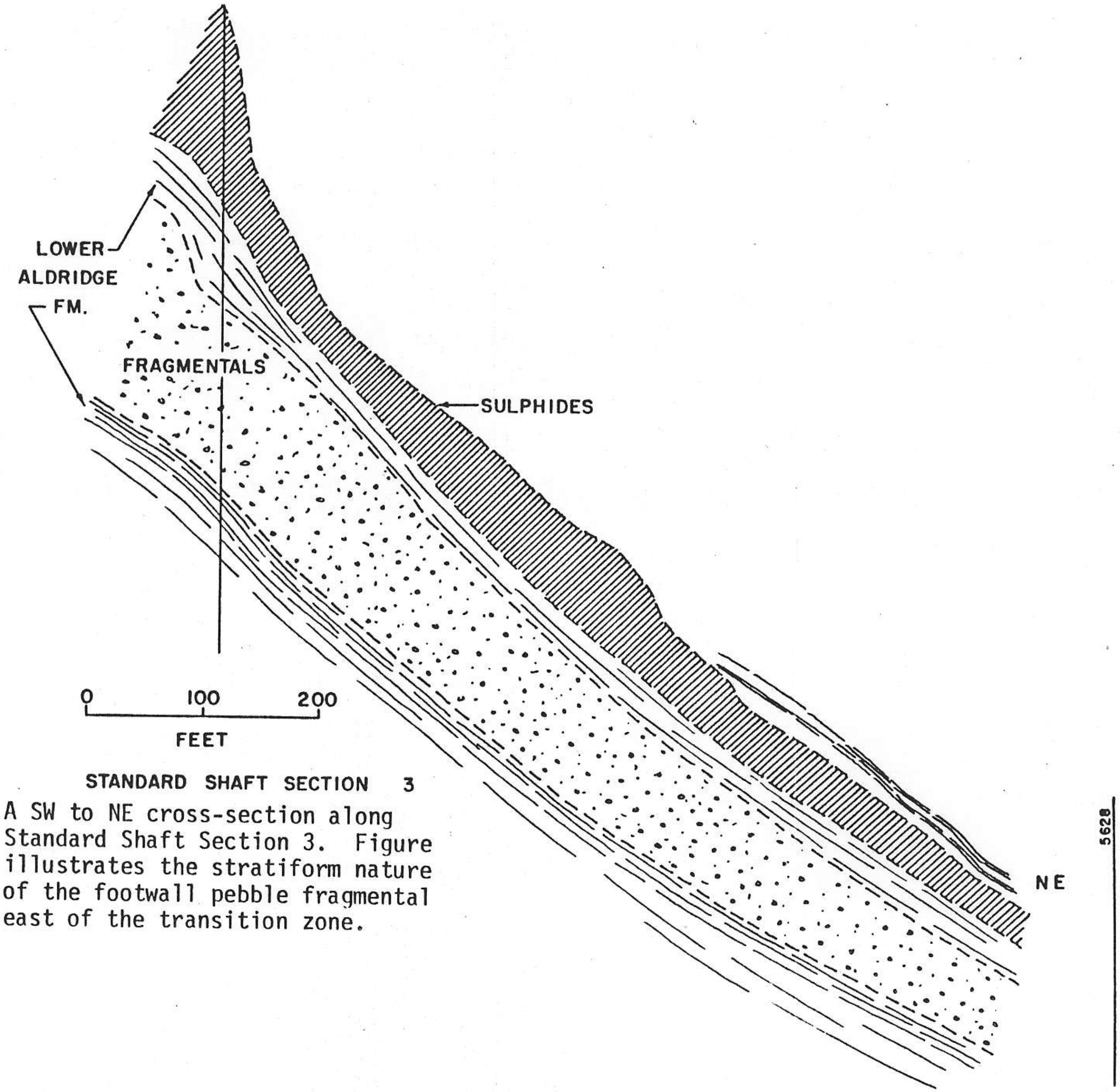

Figure 6. A SW to NE cross-section along Standard Shaft Section 3. Figure illustrates the stratiform nature of the footwall pebble fragmental east of the transition zone.

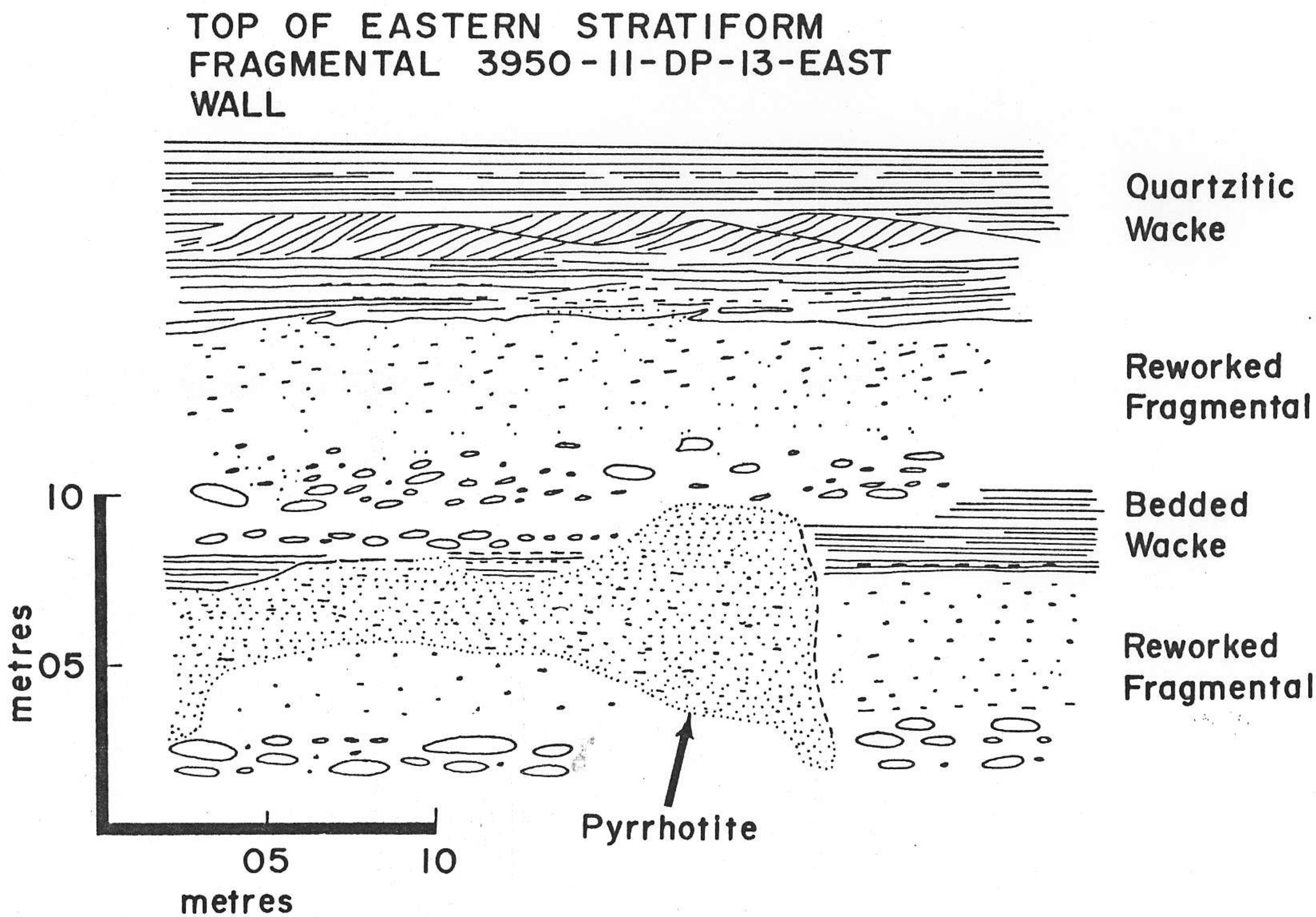

Figure 7. Detailed map of the top of the eastern stratiform fragmental 3950-11-DP-13 eastwall.

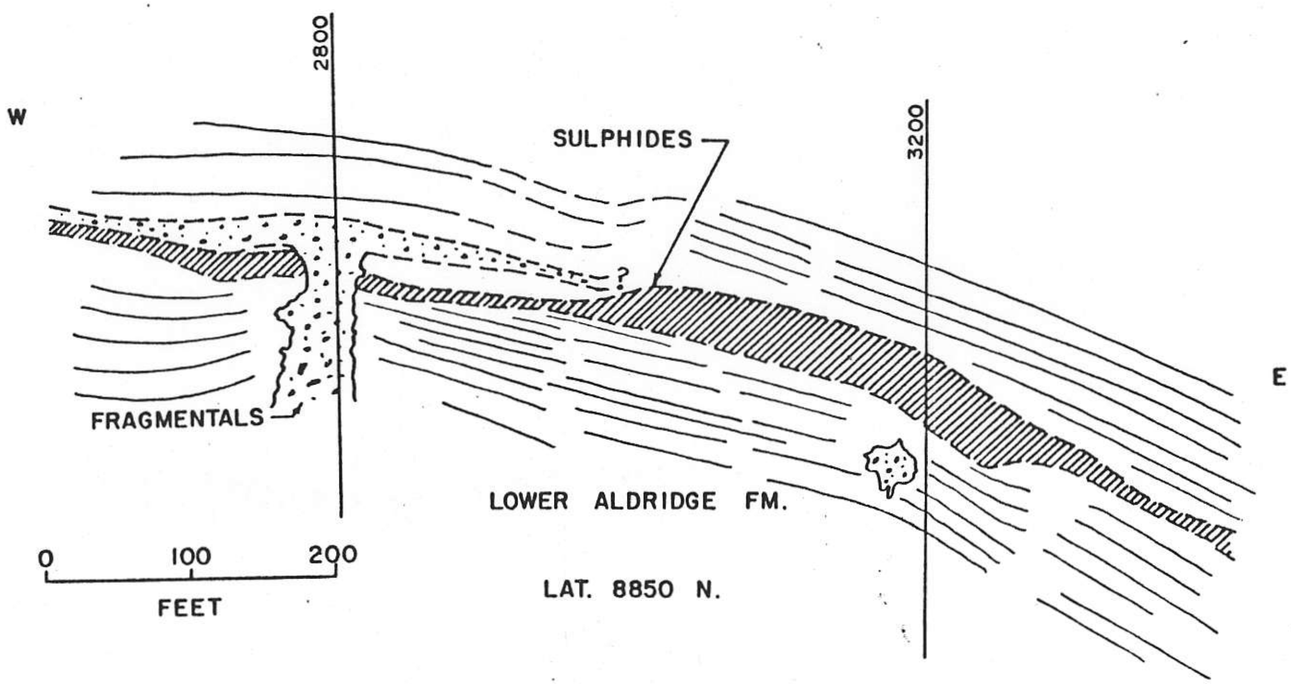

Figure 8. E-W cross-section along a portion of the 8850 N latitude.
This figure illustrates the cross-cutting nature of the Southwest Breccia.

1. INITIATION OF TENSION (Related to zones of crustal weakness)

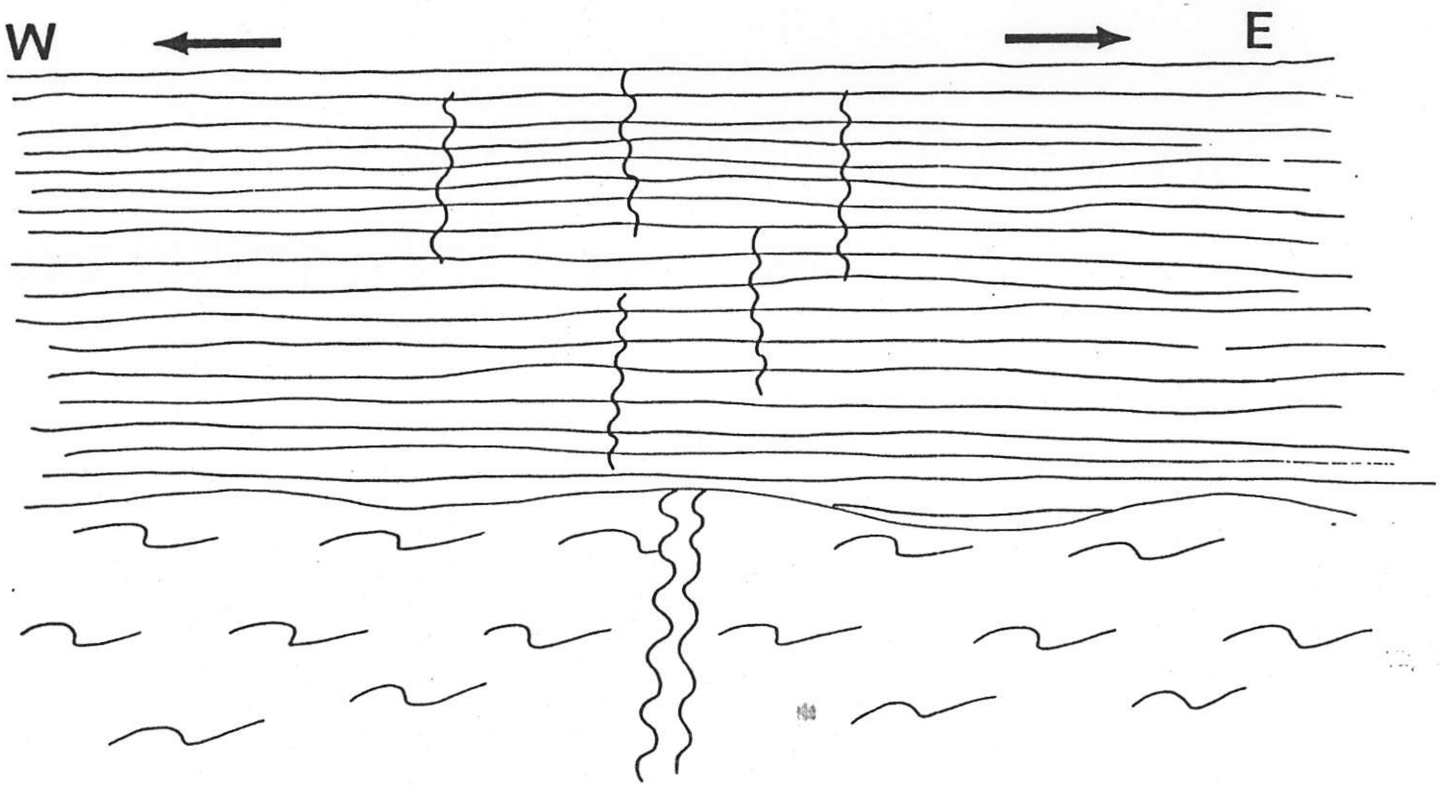

Fig. 9.1

2. PRESSURE RELEASE (First cross-cutting fragmentals; some venting and slumping)

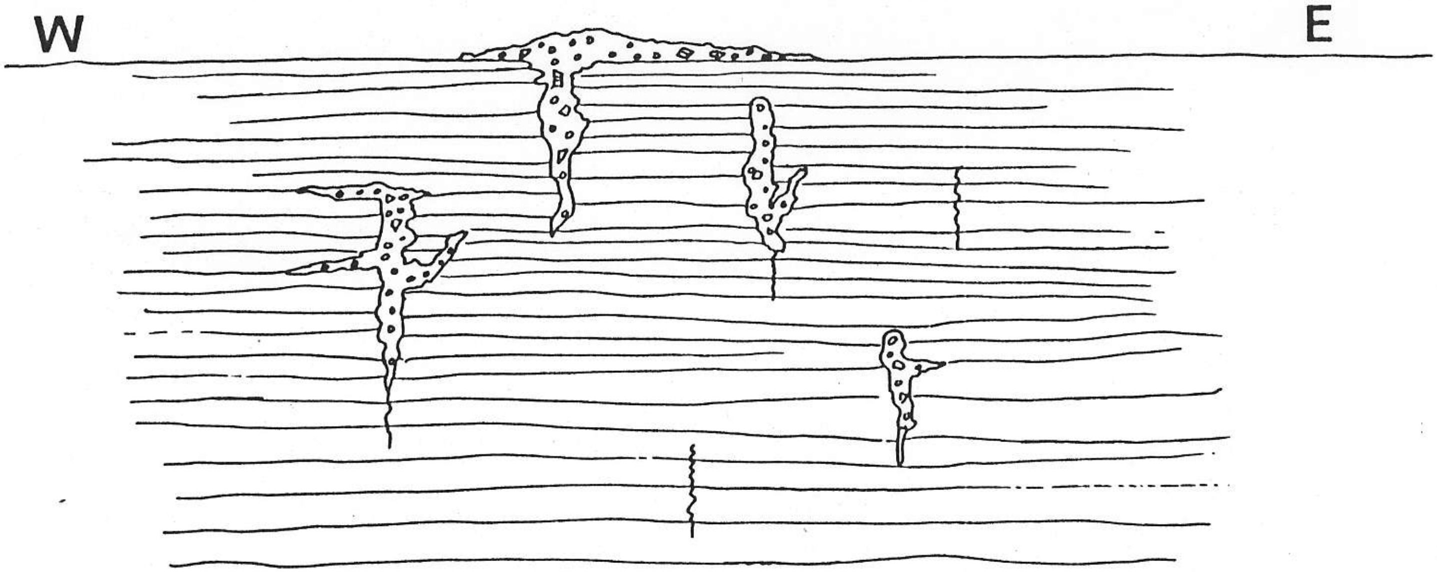

Fig. 9.2

3. AMALGAMATION (Growth of fragmental large slump to northeast)

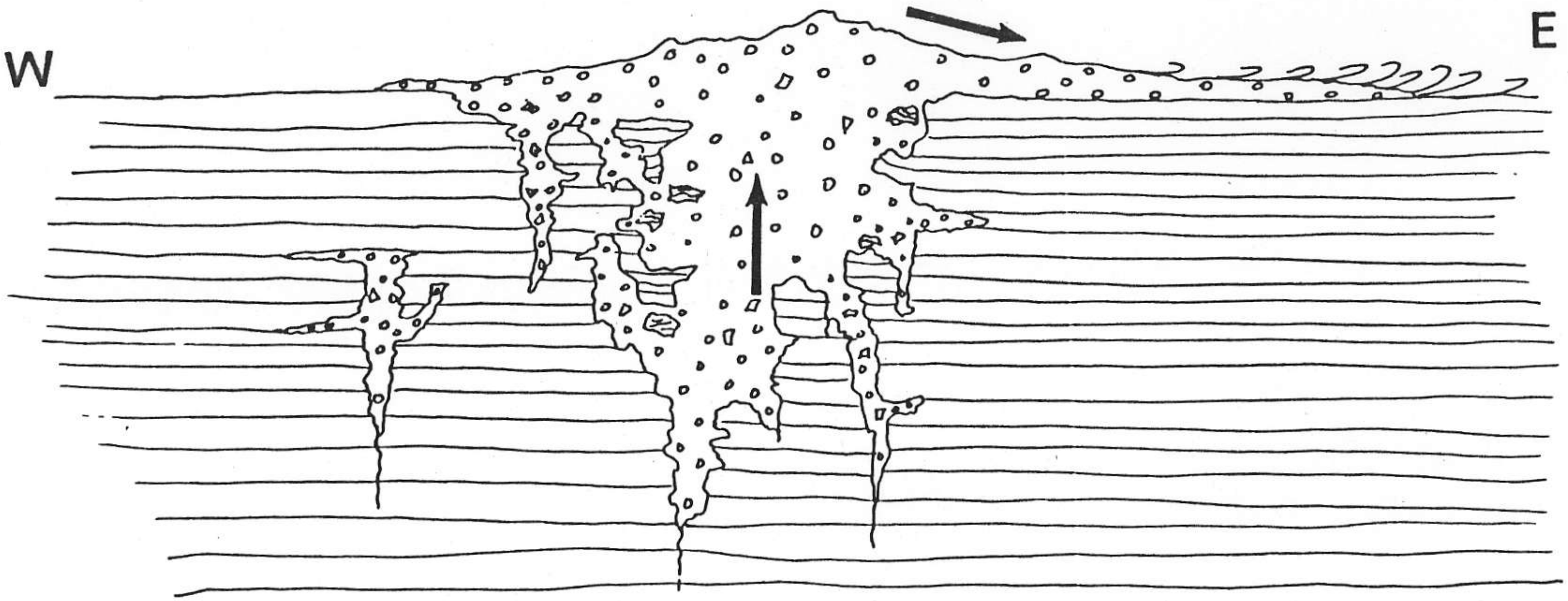

Fig. 9.3

4. SUBSIDENCE; SEDIMENTATION

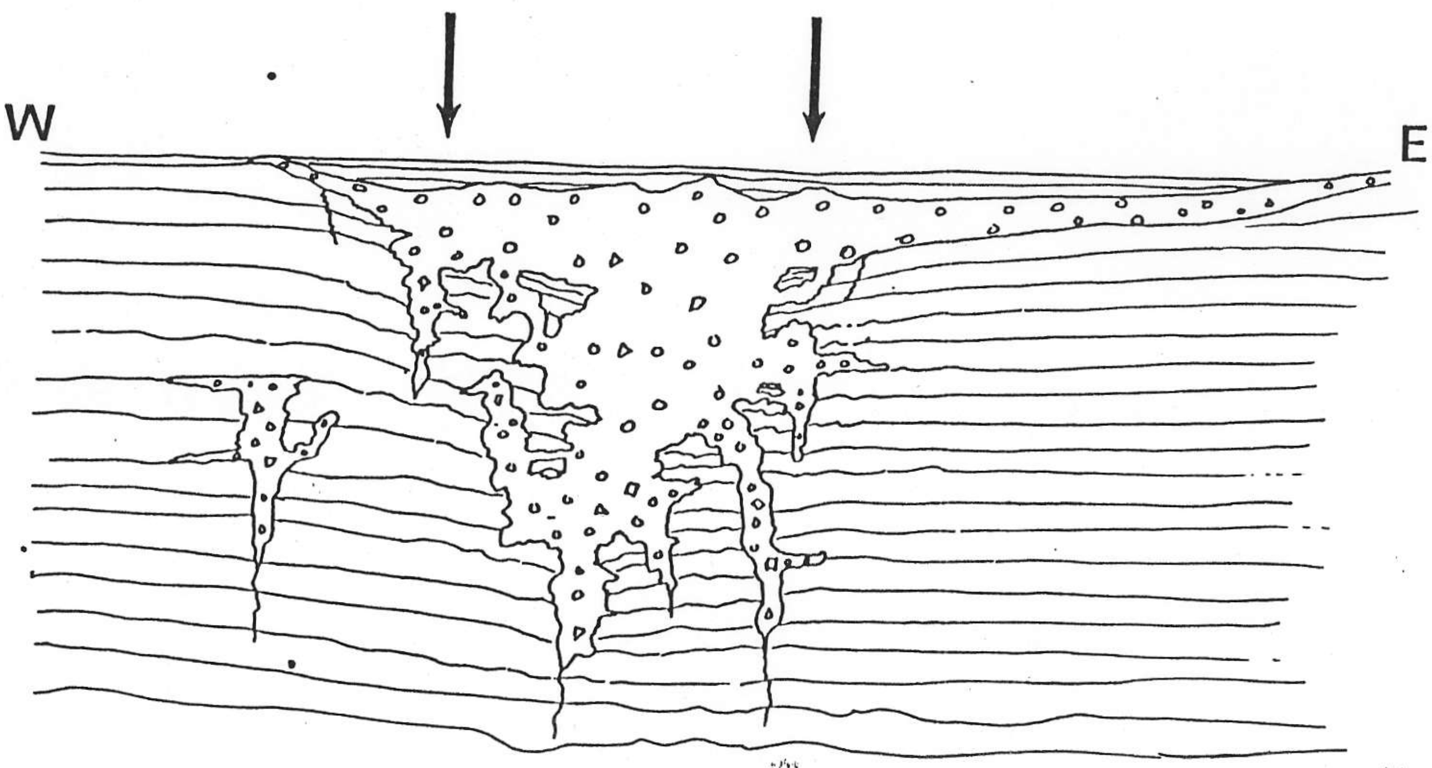

Fig. 9.4

5. REJUVENATION (Final phase of footwall fragmental formation; metal-rich hydrothermal solutions begin to enter sub-basin)

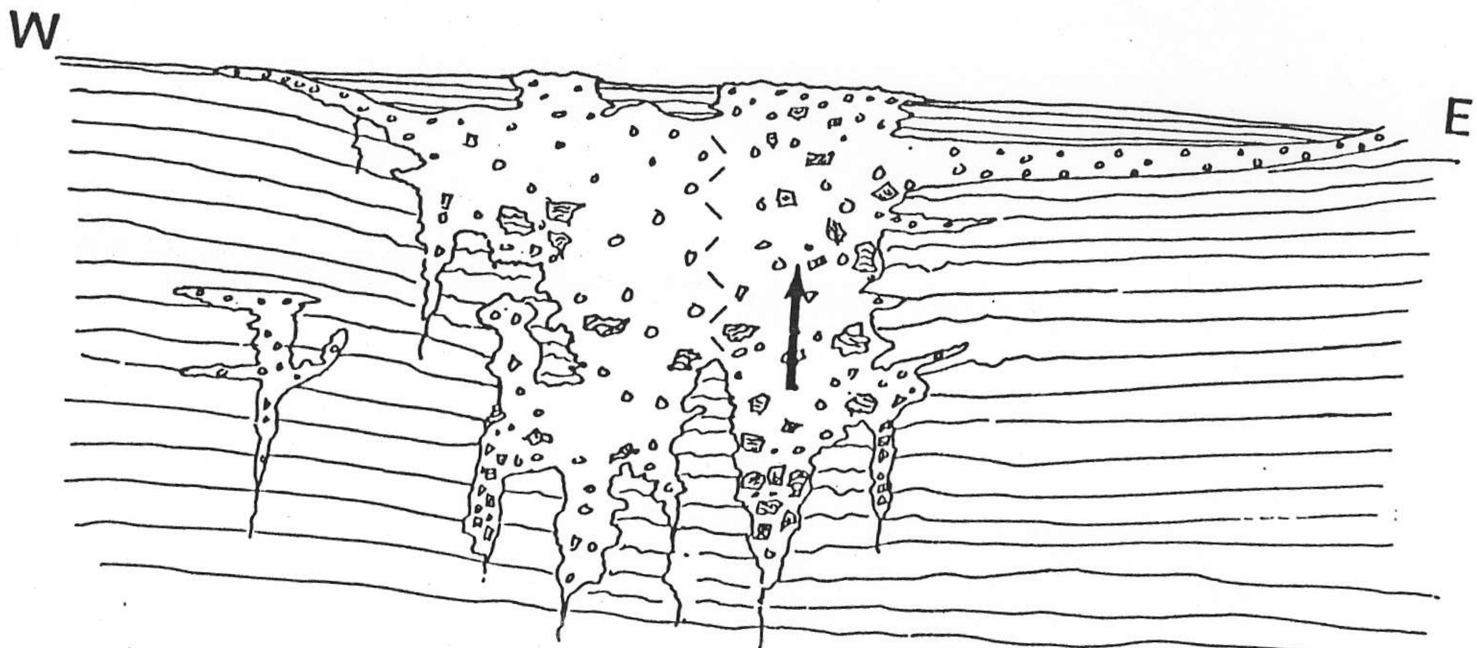

Fig. 9.5