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Énergie et Ressources naturelles
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GM 64220

Projet IREM P-83-21
7e rapport

GEOLOGY OF THE LAMAQUE MINE PROPERTY VAL D'OR, QUEBEC

Submitted to: André Laurin
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SUMMARY

The Lamaque Mine, located in the city of Val d'Or in Northwestern Quebec, has produced over five million ounces of gold from about 26 million tons of ore. Production has been continuous since 1935, but depleting reverves have resulted in closure of the mine in early 1985.

The rocks on the property comprise mainly Archean mafic and felsic pyroclastics and mafic crystal tuffs and flows of the Val d'Or Formation (Imreh, 1984), Upper Malartic Group. These have been intruded by intermediate to felsic plugs, six of which have been identified to date on the property, and by two generations of felsic dikes.

Penetrative planar and linear structural elements as well as the geometry of the rocks indicate at least one and possibly two phases of regional deformation. Primary compositional layering and discordances, probably representing local unconformities in the volcanic sequence, have been folded and now dip steeply south. The structural fabric is also evident in the plugs and the large shear veins.

Gold is confined to carbonate-tourmaline-quartz veins which are classed into three types: shear veins, flat veins and stringer veins. The shear veins are generally thick (up to 30 ft.) and have been traced for over 2000 feet. They are best developed in the volcanics away from the plugs in the upper parts of the mine. The shear veins have assymmetric layering and alteration, the latter being best developed in the footwall, but limited or non-existent in the hanging wall. Flat veins average about 1 ft. in thickness but extend for thousands of feet. They dip gently (10 to 20 degrees) to the west and intersect shear veins at 75 to 85 degrees. They have symmetrical banding and alteration, the

latter being equally intense and wide on both walls. They are true fracture-filled veins. Stringer veins include the masses of tension and gash veins and veinlets found predominantly in the two productive plugs. In certain portions of the plugs, these veins are so numerous that bulk mining has been possible.

Economic concentrations of gold are confined totally to the three veins classes. Gold occurs in native form and in pyrite which is the predominant sulfide. Tellurides have been identified but are rare. The gold-silver ratio is about 5.5:1.

In the upper third of the mine, most of the production was from shear veins mainly outside the plugs whereas stringer or zone ore in the plugs was the biggest contributer from 1200 to 2500 level. This drops off sharply with depth to no production below the 3400 level.

Visible hydrothermal alteration is confined to the plugs and the walls of veins. The bleaching is predominantly due to the destruction of chlorite and the introduction of silica and carbonate.

The geologic evidence favours a volcanogenic origin for the ore at Lamaque rather than a structure-related, late, hydrothermal system controlled by thrust faults. The conformable asymmetric shear veins are envisaged to be exhalative deposits formed during volcanism; the flat veins were cross-cutting feeder veins and the masses of stringer veins formed in situ within the plugs which intruded the exhalative vents. Mineralization took place over a prolonged period of hydrothermal activity beginning with early explosive volcanism and culminating with the intrusion of the plugs and late felsic dikes.

RÉSUMÉ

La Mine Lamaque, près de Val d'Or, Québec, a produit plus de 5 millions d'onces Troy d'or à partir de 26 millions de tonnes courtes de minerai. Sa production a été continue depuis 1935, mais, les réserves s'épuisant, la mine a dû être fermée dans la première moitié de 1985.

Les roches sur cette propriété minière sont archéeannes: des pyroclastites mafiques et felsiques, des tufs mafiques à cristaux et des coulées, tous de la formation de Val d'Or (Imreh, 1984) de la parite supérieure du Groupe de Malartic. Ces roches ont été injectés de cheminées intrusives felsiques (six ont été identifiées à ce jour sur la propriété) et de deux générations de dykes felsiques.

Des éléments structuraux pénétratifs tant plans que linéaires indiquent au moins une et probablement deux phases de déformation régionale. La stratification de composition chimique primaire et certaines discordances, qui représentent probablement des bris dans la séquence volcanique, ont été plissées et pentent maintenant abruptement vers le sud. Le patron structural est aussi évident dans les cheminées et dans les veines de cisaillement les plus importantes.

L'or est contenu dans des veines de carbonate-tourmaline-quartz dont on reconnaît trois espèces: veines de cisaillement, veines horizontales et réseaux de filonnets. Les veines de cisaillement sont généralement épaisses (jusqu'à 30 pieds) et on les a suivi sur plus de 2000 pieds. Elles se développent surtout dans les roches volcaniques à quelque distance des cheminées dans la partie supérieure de la mine. Les veines de cisaillement montrent un rubannement et une altération asymétrique. L'altération est présente surtout dans les épontes

inférieures; elle est très limitée ou non-existante dans les épontes supérieures. Les veines horizontales font en génral 1 pied d'épaisseur; elles ont été suivies sur plusieurs mille pieds. Elles sont légérèment pentées vers l'ouest (10 à 20°) et elles recoupent les veines de cisaillement à 75-85°. Elles ont un rubannement et une altération symétriques. Elles sont de vrais remplissages de fractures. Les réseaux de filonnets comprennent un grand nombre de veinules dans des fractures de tension; on les retrouve surtout dans les deux cheminées productives. Dans certaines parties des cheminées, ces filonnets étaient si nombreux qu'on les exploitait en vrac.

Les concentrations économiques d'or ont leur lieu dans ces trois seules espèces de veines. L'or est à l'état natif (grains libres); il peut aussi être contenu dans la pyrite qui est le sulfure minéral prédominant. On a identifié des tellurures minéraux, mais ils sont rares. Le rapport Au/Ag est de 5.5 à 1.

Dans le tiers supérieur de la mine, la plus grande partie de la production provenait des veines de cisaillement, surtout en dehors des cheminées tandis que les réseaux de filonnets dans les cheminées étaient les principales sources de minerai entre les niveaux 1200 et 2500. Il n'y a pas eu de production en bas du niveau 3400.

L'altération hydrothermale visible est restreinte aux cheminées et aux parois des veines. Le blanchissage est principalement le fait de la destruction de la chlorite et de l'introduction de silice et de carbonate.

Nos observations géologiques nous portent à favoriser une origine volcanogénique pour le minerai de Lamaque plutôt qu'une origine par système hydrothermale tardive contrôlé par des failles de chevauchement. Les veines asymétriques et conformes de cisaillement seraient des dépôts exhalatifs mis en place durant le volcanisme; les veines horizontales auraient été des veines nourricières recoupantes et les réseaux de filonnets se sont formés in situ dans les cheminées qui se sont introduites selon les évents exhalatifs. La mnéralisation a eu cours durant une période d'activité hydrothermale prolongée, commençant par du volcanisme explosif et culminant par l'injection des cheminées et des dykes felsiques tardifs.

INTRODUCTION

The largest production of gold from a single commodity deposit in Quebec has been accumulated over the past 50 years at Teck Corporation's Lamaque Mine in Val d'Or. It has yielded about five million ounces from over 25 million tons. Combined with the adjacent Sigma property, the two mines have produced 82% of the gold in the Val d'Or area.

Lamaque was the site of early geological studies mainly by Hawley (1930), Wilson (1936, 1948), and Bridger (1949). The populatiry of the structural control of the ore was firmly entrenched into investigations on the genesis of the deposit at that time and has survived to this day. Recent invertigations at Sigma (e.g. Robert et al., 1983) and Lamaque (e.g. Daigneault et al., 1983) have accepted this model and built on it. Also, past and present exploration in the area has relied heavily on the structural model as a guide.

Although the writer does not refute some of the evidence that is presented for structural control of ore, there is a lot of geologic fact which is difficult to explain by a such a model. Some of these have been referred to in recent papers (e.g. folded early veins in Robert et al., 1983) and alluded to in some of the unpublished mine reports (e.g. Bridger, 1949). In this paper, all the pertinent geological data that are available to the writer based on other investigations and on a field-oriented personal investigation both of the underground and surface exposures over a period of one year, are presented. The conclusions suggest quite a different history for the evolution of ore at Lamaque from that described in earlier papers.

ACKNOWLEDGEMENTS

The writer is indebted to Teck Corporation, particularly Dr. Norman Deevil Jr. and Mr. William Bergey for encouraging and funding this investigation and allowing its publication. Discussions with mine staff, especially Gilles Imbeau, have been very helpful. Finally drafting support and publication guidance by Dr. Guy Perrault of École Polytechnique is greatly appreciated.

HISTORY AND PRODUCTION STATISTICS

Gold was first discovered on the Lamaque property in late 1923 but it was not until April 1935 that the mine was put into production at a rate of 250 tons per day. Mill capacity was increased gradually to 2100 t.p.d. by 1953; but in 1973, the mill had to be reduced to 1800 t.p.d. due to the shortage of "zone ore" (Bédard and Imbeau, 1980). The rate has been maintained to date, partly through custom milling of ore from the Kiena Mine even though tonnage mined at Lamaque has dropped significantly.

Production decision in 1933 was based on an ore reserve of 74,495 tons grading 0.31 oz./ton. Continuous mining since then has yielded a total of over 25 million tons averaging 0.18 oz. gold/ton. Mining has been extensive from various geologic environments on the property. The bulk of the production, however, has been at the main mine where the production shaft is 3680 ft. deep and the deepest level is 3600 feet.

Production statistics based on areas, tonnage and grade are listed below.

Areas	Tons Milled	Oz./Ton	Total Ounces
Main Plug	18,306,723	0.202	3,699,005
East Plug	2,999,842	0.115	343,827
West Plug	1,644,606	0.133	219,014
"35" Zone	518,282	0.068	35,083
Northwest Zone	168,056	0.119	20,003
No. 2 Mine Flats	727,297	0.170	123,450
No. 2 Mine	139,185	0.211	30,711
No. 3 Mine	318,560	0.183	58,536
Total Production to Sept. 30, 1979	24,822,551	0.183	4,529,629

Current reserve have been nearly exhausted and as a result a decision has been made to close the mine in April 1985.

REGIONAL GEOLOGY

The Lamaque Mine property is located within Archean rocks of the upper Malartic Group of the Superior Structural Province (Fig. 1). Recent lithostratigraphic classifications in the area by Imreh (1984), place the host volcanics at Lamaque into the Val d'Or Formation (Fig. 2). The lower Malartic Group is characterized by the predominance of ultramafic and basaltic volcanics whereas the upper consists mainly of basalts, pillow andesites and mafic pyroclastics (Imreh, 1984). The Val d'Or Formation is dominated by andesitic flow breccias and pyroclastics as well as some pillowed to massive flows. The Val d'Or Formation is considered to be a facies equivalent of the ultramafic and basaltic flows and hyaloclastites of the Jacola Formation (Imreh, 1984) and represents the proximal vent facies of a major volcanic centre located in the Lamaque-Sigma area.

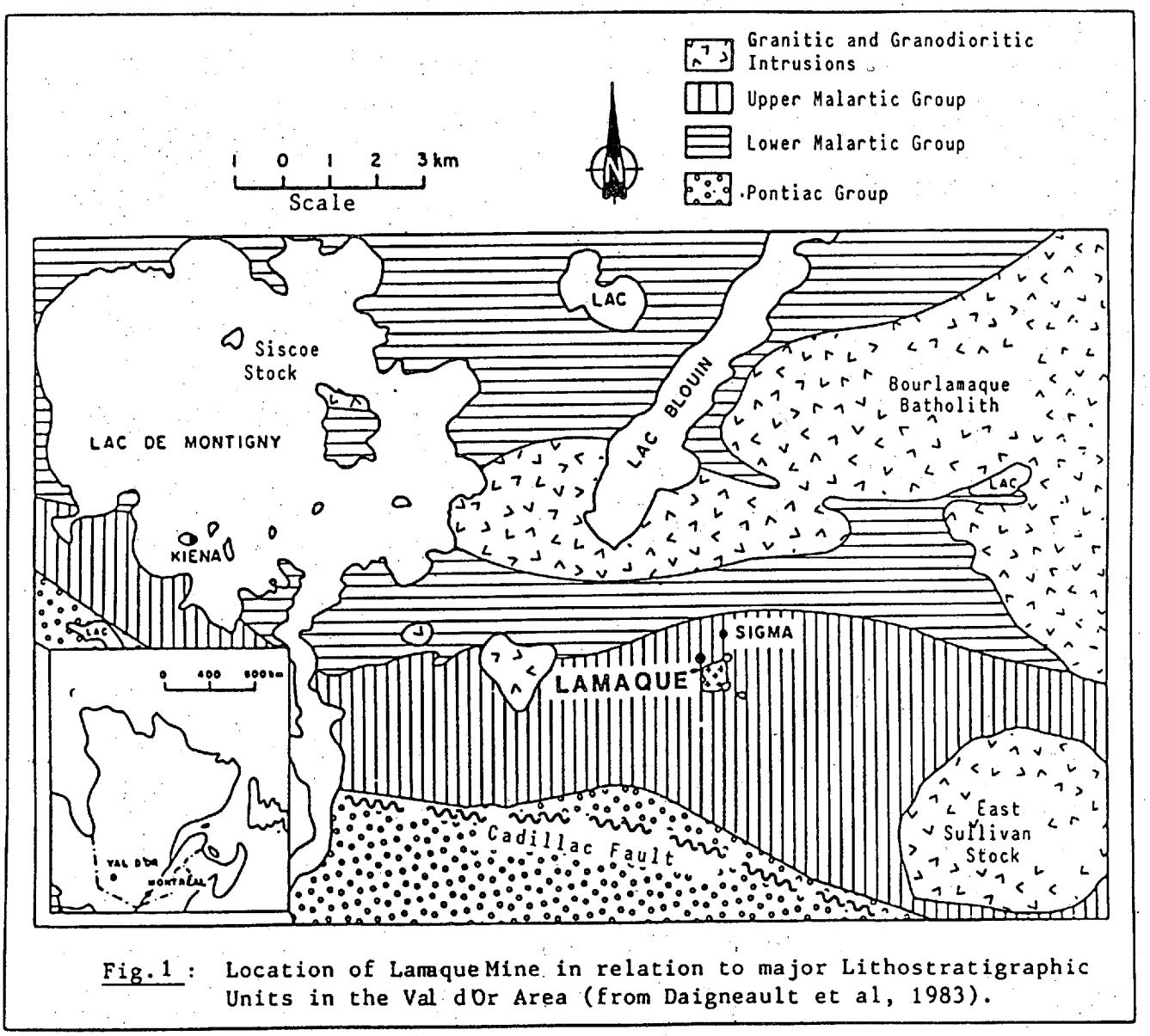


Fig. 1 : Location of Lamaque Mine in relation to major Lithostratigraphic Units in the Val d'Or Area (from Daigneault et al, 1983).

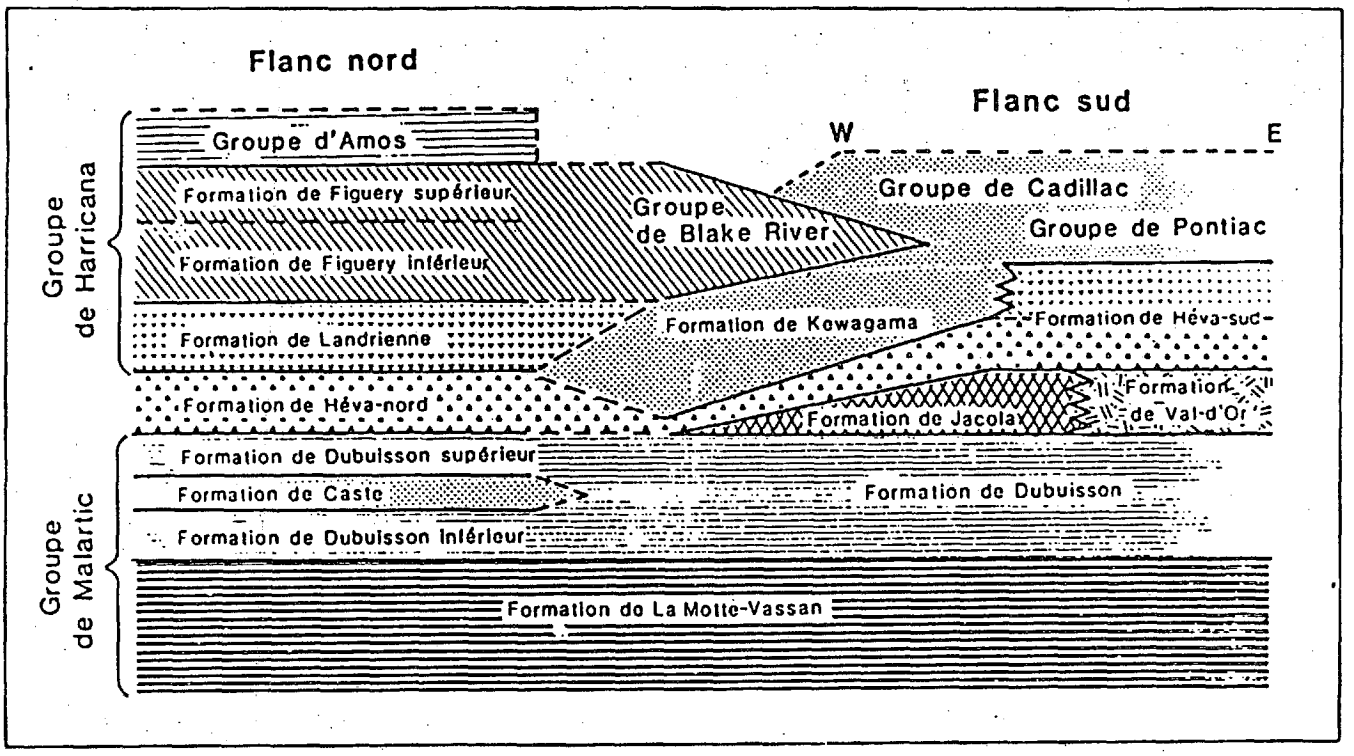


Fig. 2: Schematic Lithostratigraphic Correlation across the Flaks of the La Motte Anticline, West of Val d'Or (from Imreh, 1984).

LOCAL GEOLOGY

Most geologic descriptions of Lamaque (e.g. Dresser and Denis, 1949; Bédard and Imbeau, 1980) borrow heavily form the early works published by Wilson first in 1936 and repeated with some modifications in 1948 and partly from an unpublished geologic synthesis of Lamaque by Bridger in 1949. Over the years, a complex and cumbersome nomenclature of rock types has been developed at the mine, parts of which have crept into the recent literature. For sake of clarity, these will be avoided as much as possible in this paper. The following descriptions are based

on papers (e.g. Daigneault et al., 1983) published, on research directed by Dr. Guy Perrault at École Polytechnique in Montréal and surface and underground mapping carried out by the writer at Lamaque in 1984.

The distribution of major rock types is illustrated on the accompanying map of the main Lamaque property (back pocket). The predominant rock types are mafic and felsic pyroclastics, followed by crystal tuffs/mafic flows and intermediate to felsic intrusive plugs. Various types of porphyritic dikes also present are not shown on the map.

Pyroclastics: the northern portion of the property is almost entirely underlain by mafic pyroclastics with fragments ranging from bomb size to lapiilli to ash, but the area of biggest bomb and block sizes (average 6 to 10 inches) extends from the vicinity of No. 2 Mine to the northeast portion of the property. West of the mine the clast sizes decrease rapidly.

Mafic volcanic flows, sometimes poorly pillowed are found distributed throughout the above unit. They are thickest near the mine and thin rapidly westward, where in some outcrops they resemble dikes. According to Daigneault (1983), these flows are andesitic in composition and probably include rocks that have been called "flow breccias" at the mine. They show primary features typical of submarine mafic flows.

To the east in the vicinity of the Aumaque property, the predominant rock types are well-foliated mafic and felsic tuffs. The tuff/agglomerate unit described above is in contact to the south with a poorly-exposed sequence of carbonatized mafic tuff which grades

southward at the Aumaque property line into a carbonatized and sericitized felsic tuff. Intercalated within this unit are pyritic tourmaline-carbonate-chert exhalites which contain a large component of ash material (25 to 75%). The conformable ore zones at the Aumaque (estimated at 180,000 tons of 0.25 oz. Au/ton) are at the base of the felsic tuff and may represent an exhalative-type stratabound deposit.

Southward from the Aumaque shaft is a sequence of well-foliated to massive mafic tuffs with some intercalated mafic flows and/or crystal tuffs. This unit is predominantly chloritic and carbonate alteration is limited.

The southernmost member is a strongly-carbonatized, sericitic, well-foliated felsic tuff which is poorly exposed in low outcrops east of the No. 4 plug. It is similar to the Aumaque felsic tuff.

Crystal Tuff/Mafic Flow ("DPC"): a large body of mafic rock well-exposed in outcrops east of the main mine and in various parts of the underground workings is refered to in mine terminology as "diorite porphyry type C" (or DPC). A similar rock is identified at the Sigma Mine where it is called "C-porphyry". At Lamaque this rock has always been treated as intrusive, mainly because of its partly developed porphyritic texture and massive appearence. At Sigma, it is considered to be a "stock-feeder dyke complex with associated porphyritic flows" (Sigma Staff, 1980). The phenocrysts of intensely altered plagioclase (now mainly albite and epidote/clinozoisite) are about 1 to 3 mm in size and vary from 30 to 40%. The matrix is secondary albite and chlorite (Sigma Staff, 1980; Daigneault, 1983). Based on thin section studies of

"DPC" in the No. 2 mine of Lamaque, Daigneault (1983) concluded that the textures suggested a hypabyssal level of intrusion. The DPC at Lamaque is andesitic in composition and chemically similar to the mafic tuff/ agglomerate (Daigneault, 1983).

At the Lamaque Mine, massive, mafic rocks with varying sizes and amounts of plagioclase phenocrysts are frequently encountered and most have been classed as "DPC". However, Daigneault (1983), in his thesis research which dealt mainly with the No. 2 Mine area, made a distintion between rocks he considered to be hypabyssal and many other similar rocks which to the nake eye resemble "DPC", but under the microscope are in fact crystal tuffs. The textural and primary sedimentary features in these rocks as described by Daigneault (p. 45) are convincing evidence to his conclusion. Bridger (1949) and others have pointed out the close spatial association of "DPC dykes" and gold mineralization. The importance is also well-recognized at the Sigma. According to Bridger, a conformable unit of "DPC" follows the No. 18 and No. 3 shear veins and these veins are best developed where "DPC" is present. Many, if not most of these dikes could be crystal tuffs.

The writer does not negate the possibility of portions of "DPC" type rock being intrusive as in the case underground at the No. 2 Mine and on the nearby Sigma ground; however, sufficient evidence also exists from surface to suggest that large parts are crystal tuffs or flows. A good example is a thick (1200 ft.) north-south section of "DPC" outcrops east of the main mine. Here individual units, varying in thickness from 100 to 250 feet can be readily identified by quartz grain

and/or feldspar content, weathering features and textures. Each unit is separated by a 20 to 75 ft. wide zone of foliated, rusty-weathering tuff which is usually pyritic and contains concordant lenses and stringers of quartz. When mapped out, these units are found to trend east-southeast and dip steeply.

Between the main plug and No. 2 Mine good outcrop exposures show "DPC" and mafic pyroclastics in a typical facies change relationship (see map, inside back cover). Although too small to be shown on the map, many other similar massive members in the tuff/agglomerate unit may be crystal tuffs or flows of the "DPC" type.

Careful examination of contact relations failed to turn up any cross-cutting features between the "DPC" and mafic tuff/agglomerate, which should exist if this large mass of rock was truly intrusive. The only exceptions were two narrow (10 to 40 ft.) mafic feeder dykes, one exposed northeast of the Main Mine and another west of No. 2 Mine.

Intermediate to Felsic Intrusives: the diorite/granodiorite plugs and associated porphyritic dikes have received much attention because of their close spatial relation to ore. Recently, Daigneault (1983) has studied the six plugs at Lamaque in thin section and has analyzed them for major and minor elements. Results are summarized in Daigneault et al. (1983). The six plugs, shown on the main map, are known as west, main, east, No. 5, No. 4, and No. 3 plugs. Compositionally, they vary from diorite to tonalite and intense alteration is an important component.

The main plug (fig. 3) is the only composite body, being zoned from an outer diorite border, through a partialy preserved quartz diorite into a tonalite core. It measures 800 feet east-west and 350 feet north-west and has been traced to a depth of 5000 feet. The east plug, located at the east end of the Main Mine, is about half the areal size of the main plug. It is highly differentiated (SiO_2:70%) and consists only of tonalite and associated alterations. Together the east and main plug areas hosted about 90% of the ore produced at Lamaque. Both east and main plugs plunge about 70 degrees to the northeast.

Plug numbers 3, 4 and 5 are more mafic (dioritic) and larger than the main and east plugs. Although each is mineralized, only a small amount (58,536 oz.) was mined from the No. 3 and some proven reserves have been outlined at No. 4.

The west plug, which forms the west end of the Main Mine in the upper levels, is an irregular subvertical zone of tonalitic material and extensive alteration (bleaching).

None of the plugs are exposed on surface, although in the early days, outcrops of the main plug were present in the vicinity of the initial discovery of gold.

According to analyses by Daigneault et al. (1983), the main, east and west plugs and the felsic intrusive dikes (described in the next section) have a calc-alkaline affinity while the No. 4 is tholeiitic. Plug No. 5 has chemical characteristics of both.

Felsic dikes: two types of dikes, both porphyritic have been identified at Lamaque. A folded quartz-feldspar porphyry dike is mapped in the upper levels of the mine. These dikes consist of feldspar phenocrysts

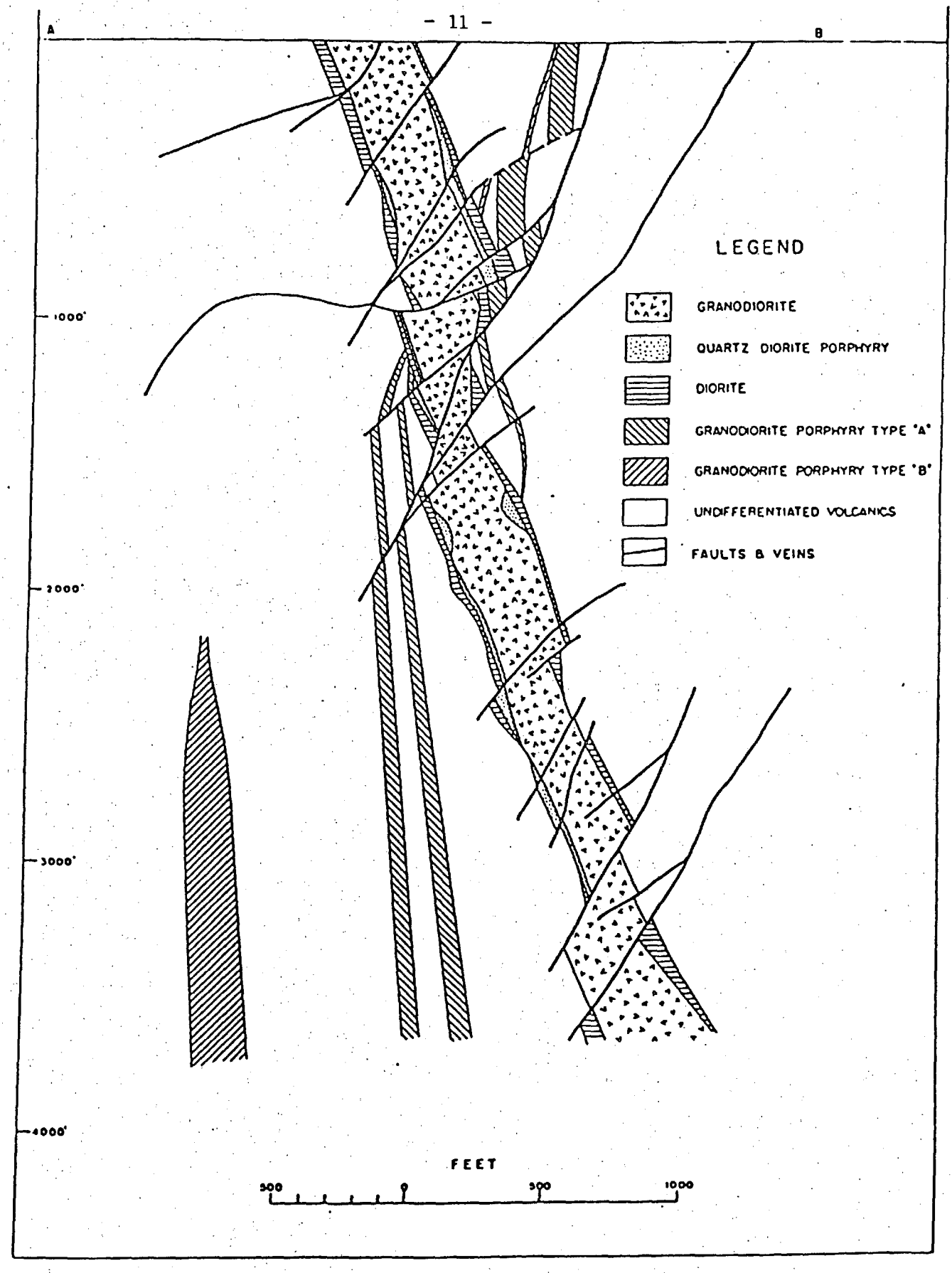


Fig. 3: South-North Section through Main Plug, Lamaque Mine (modified after Wilson, 1948).

of 2 to 5 mm in a matrix of microcrystaline quartz. They are common in the plug areas not only at Lamaque but elsewhere in the region (Daigneault et al., 1983). They are not spatially related to ore at Lamaque.

The other type, which is a feldspar porphyry is common as dikes in the north part of Lamaque property. They are relatively undeformed and show important associations to ore at No. 2 Mine and at Sigma ("G" type). They range from 5 to 25 ft. in thickness, trend east-west and dip steeply south, and have been followed up to 5000 feet along strike at Sigma (Sigma Staff, 1980).

STRUCTURE

Regional structures in the Val d'Or - Malartic area have been described in the early days mainly by G.S.C. (Gunning and Ambrose, 1940; Norman, 1941, 1943) and more recently by Bouchard (1979) and Imreh (1984) of the Provincial Survey. The major and minor structures evident in the Val d'Or area are typical of most Archean volcanic terranes where evidence of several phases of deformation can be found (see Bouchard, 1979). Bridger (1949) presents the most comrehensive structural synthesis of Lamaque, although he deals mainly with brittle deformation and the application of the strain ellipsoid in an attempt to explain the known vein systems. Similar studies have been done recently by Robert et al. (1983) at Sigma and Daigneault et al. (1984), at Lamaque.

No comprehensive recording of all structural elements and their interpretation has been done at Lamaque and although many were observed and measured during the course of mapping by the writer, the data is far from complete. These observations, however, suggest that the volcanics and intrusive plugs have been affected by at least one phase of penetrative deformation and probably by two. This is evident in the geometry of the rocks and the planar and linear elements found in the rocks on the property.

Primary Compositional Layering: no distinct marker horizon exists within the volcanic package which could be used to describe the geometry of the lenticular volcanic units on the property: only contacts between units which appeared to be primary could be used. Measurement of these primary elements indicate a generally steeply-dipping to moderately southward-dipping, east-west trending sequence of volcanic tuffs and flows. Detailed work in the mine area revealed abrupt angular discordances in the sequence; these discordances or unconformities are occupied by the main shear veins which outcrop on surface in the original discovery area (see map).

Although not evident from surface mapping, a local fold (described as a "drag fold" by Bridger, 1949), is delineated underground by shear veins 1 and 13 (Fig. 4). This fold which plunges east at about 20° dies out downward and may do the same above the 300 level.

Structural Elements: penetrative foliation is the most dominant planar element, particularly in the tuffs, where in places the movement has been intense enough to form shear zones. Such zones of concentrated

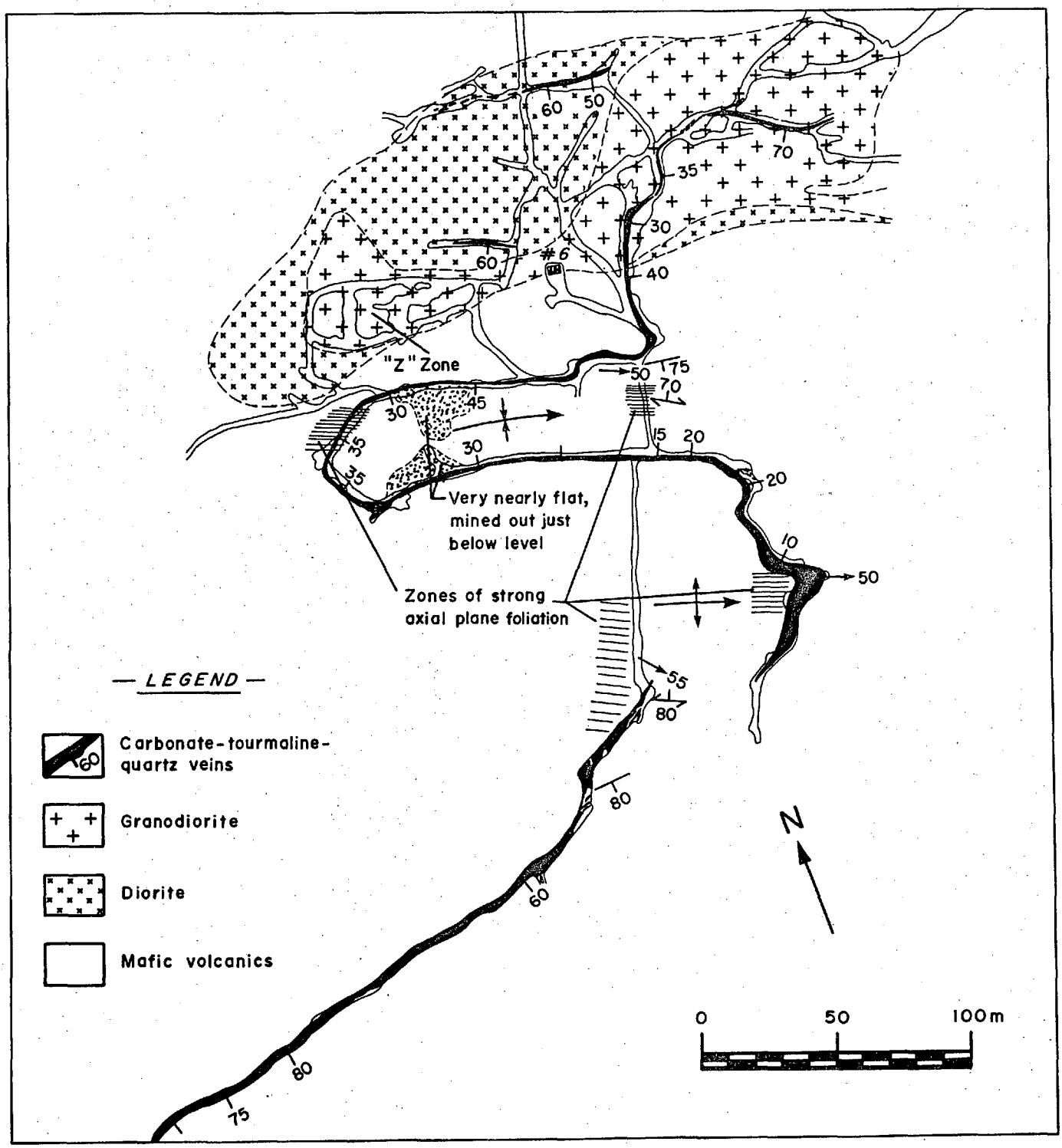


Fig. 4: Geologic Plan of 950 Level of Lamaque Mine Illustrating a Thightly folded portion of Shear Vein 13V and its Relation to the Main Granodiorite Plug.

shear are most evident in sequences where more competent and massive units of volcanics, such as crystal tuffs and mafic flows predominate. Because of this physical anisotropy in the volcanic pile, most of the movement associated with folding took place in the tuffaceous units. The "DPC" outcrop area east of the mine is a good example.

In the mafic tuff/agglomerate, the foliation is so pronounced, that in most places the axis of elongation of bombs has been transformed into the plane of foliation, thus producing a false layering direction. In the northwest part of the property, previous mapping has confused this with primary layering and resulted in many of the volcanic flows and crystal tuffs to be classified as dikes.

Penetrative foliation is less obvious in the more massive volcanic members, but a subtle alignment of phyllosilicates is evident on weathered surfaces. In the plugs, the most prominent planar elements are a fracture cleavage and a penetrative (often cross-cutting) foliation in shear zones. In the large shear veins, particularly near the noses of folds, a penetrative foliation cuts the enclosing tuffaceous material and a fracture cleavage is evident in the quartz-tourmaline material.

Lineations are not obvious on most outcrops but underground in the upper levels of the Main Mine, intersecting planar features and mineral lineations, especially in the vicinity of the "drag fold" southwest of the main plug, are common (Fig. 4). These lineations vary from 085°/50° to 120°/70° and average about 100°/59°.

Faults and Unconformities: mineralization controlled by faults is the general description of the Lamaque deposit (Fig. 3). The offset of the main plug contacts along southerly-dipping thrust faults, most of which contain the "shear veins" is well documented (Wilson, 1948). Displacement on these, as measured at the plug contacts, is in the order of tens of feet, but their overall displacement and extent beyond the mine area is not known. A total of eight major thrust faults are recorded in the main plug.

Although alluded to in some reports (e.g. Bridger, 1949), no publications point out the fact that these thrust faults are folded. Observations made on levels from 300 to 1800 levels of the main mine indicate these shears to be folded with the enclosing rocks and the sheared rock and vein material in them to contain the same structural fabric as the host volcanics. This fact is alluded to by Bridger (1949) who wrote: "A foliation is often developed within the fault planes" and that it is cross-cutting in some areas and parallel in others (p. 14).

Another important feature, which has not been documented in the past is the presence of structural discordances in the volcanic sequence. The best example on surface is in the No. 3 vein pit where volcanic flows and interflow tuffs on the north side strike into the east-trending No. 3 vein at a sharp angle whereas the flows and tuffs on the south side of the vein appear to trend with it. Similarly, No. 1 Vein which outcrops on surface makes an angular discordance with the volcanics to the north, but the volcanics on the south, based on observations underground appear to be conformable with No. 1 Vein. Similarly,

if the interpretation of the "DPC" rocks to the east is correct, there appears to be an easterly-trending discordance cutting through the area which parallels and may host the A (α) Vein and C (Float) Vein.

These structural discordances resemble local unconformities which are common in an explosive submarine volcanic environment. It is interesting to note that the vein-bearing "thrust faults" of the Main Mine occupy some of these structures. Underground mapping to further define and delineate these features is difficult due to access problems and dirt covered drifts. The extent and geometry of these discordances would shed new light on the genesis of mineralization at Lamaque.

Stratigraphic tops: although the volcanic sequence in the Lamaque - Sigma area is generally accepted to be facing south (Norman, 1943; Bridger, 1949), conclusive evidence for this is difficult to find. During the current surface mapping no firm features were encountered to substantiate this; however, underground, especially in the No. 2 mine area, flows described by Daigneault (1983) appear to confirm this statement. The physical disposition of the angular discordances, if they are unconformities, also support this view.

METAMORPHISM

The rocks of the Val d'Or area show evidence of regional metamorphism and contact metamorphism related to the intrusion of late batholiths (e.g. Bourlamaque Batholith). The regional grade is lower greenschist (sericite, epidote, chlorite), but south of the Cadillac Fault, the metamorphism increases progressively with the first

appearance of staurolite at 3 to 5 km to the south. Contact metamorphic aureoles are delineated by staurolite, amphibole or amphibole and garnet (Imreh, 1984).

At Lamaque, chlorite is the predominant mafic mineral, although biotite has been recorded in places and at a depth of about 3100 feet, biotite becomes prominent in the main plug (Daigneault, 1983). In the dioritic phase, hornblende becomes the dominant mafic mineral at a depth of about 5000 ft. No contact metamorphic aureoles have been recognized around any of the plugs. A study of mineral assemblages and major element variations immediately outside the main plug by Cargill (1967) revealed a surprising lack of any chemical or mineralogical change in the host volcanics.

VEINS

An economically important rock type, consisting of varying amounts of quartz, tourmaline, and carbonate (ankerite, calcite, ferrodolomite), but in which quartz predominates, occurs in systems of veins of which there are many at Lamaque. At the Main Mine alone to a depth of 3600 feet, a total of 58 "lesser veins" and eight major shear veins (e.g. IV, 13V) have been documented (Bédard and Imbeau, 1980). In addition to these, there are countless numbers of flat veins (Fig. 5) and stringer-gash veins. In general, however, the veins can be classed into three types: "shear" veins, flat veins and stringer veins.

Shear Veins: the original discovery and most of the upper level mining to about 1200 feet was in long, wide (up to 30 ft.) veins which could be

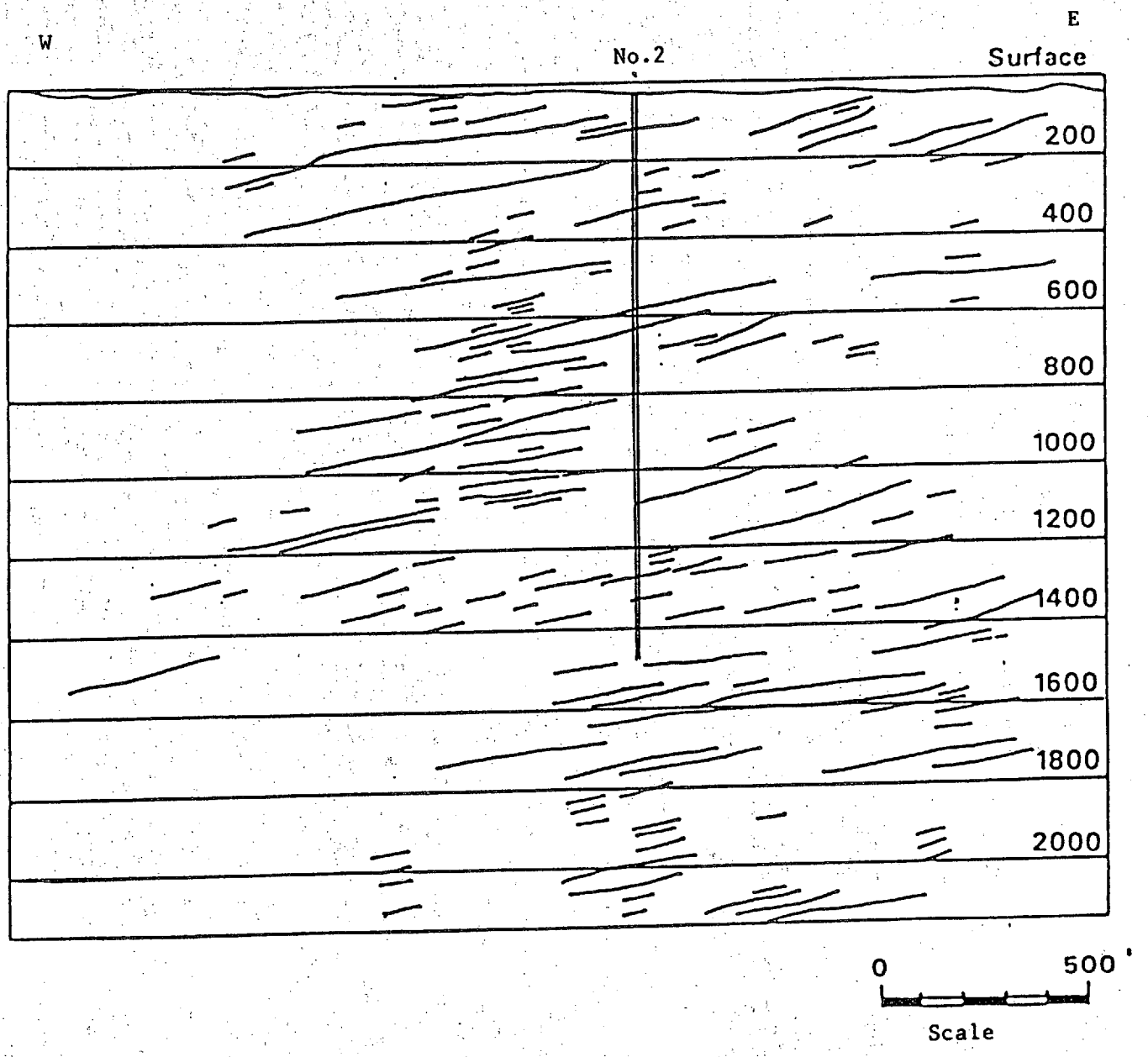


Fig. 5: East-West section through No. 2 Mine shaft showing distribution and orientation of flt veins.

followed for over 2000 feet in length and to depths of up to 1000 feet or more. These veins are found throughout the mine, but are most prominent above 2000 level.

The shear veins are predominantly quartz; however, in many parts they consist of massive banded tourmaline with ankerite and layers of quartz. These veins are sandwiched in volcanic rocks, often with a "DPC type" flow nearby in one wall; typically the veins grade lit par lit, in both walls, into a layered rock of alternating bands each dominated by either ankerite, quartz or mafic minerals (mainly chlorite and tourmaline). This wall rock varies in thickness from a few inches to a few feet and is the "shear" that is generally followed when a vein pinches. Where shear veins occur in mafic volcanic rocks, this rock type strongly resembles an interflow tuff unit with carbonate and quartz (chert).

The nature of shear veins occupying the thrust faults described earlier was examined in several places as they pass into the main plug. In theory, the structural model dictates that these veins should open-up and be best developed in the incompetent plug material as the thrust faults pass through it. This, however, is not the case. Veins such as 1V and 13V, which were traced and mined for over 2000 feet in volcanics between main and west plugs become dispersed and less prominent in the plug (see Fig. 4). Also the enclosing tuffaceous material appears to accompany them into the plug. Examination of geology plans and of the veins tehmselves show none of the major shear veins, supposedly occupying thrust fauts in a dilatent zone created by the main plug, as

actually being very strong and prominent as fractured-filled bodies. The vein material can be traced through the plug in most cases; however, the makeup of the "vein" is not that of a simple fracture-filled fault.

Although the shear veins reach thicknesses of over 30 feet and average over six feet, the extent of wall rock alteration (described later) is small, particularly in the hanging wall, compared to the proportion seen in the flat veins. It is interesting to note that wall rock alteration is most extensive in the footwall where the "shears" contain vein material. Barren "shears zones" have no wall rock alteration (Bridger, 1949). In the footwall of 13V and 1V, zones of bleaching and alteration, accompanied by pipe-like and irregular zones of brecciation are common in the west part of the mine. Blocks of footwall volcanics caught up in these zones show zoned alteration and the matrix in places is filled with quartz, auriferous pyrite and black tourmaline.

This asymmetry (Fig. 6) in wall rock alteration is also reflected in the shear veins themselves. The veins show asymmetric layering of quartz, tourmaline and carbonate with varying amounts of chlorite. Often one side of the vein is nearly massive tourmaline which grades into quartz-tourmaline and finally quartz on the other side. The main massive part of the vein always grades into the tuffaceous (shear) material of the walls through a series of quartz, carbonate, and tourmaline layers. Sutures or stylolites (Grabau, 1913) are common along thin layers or planes of separation within the vein material.

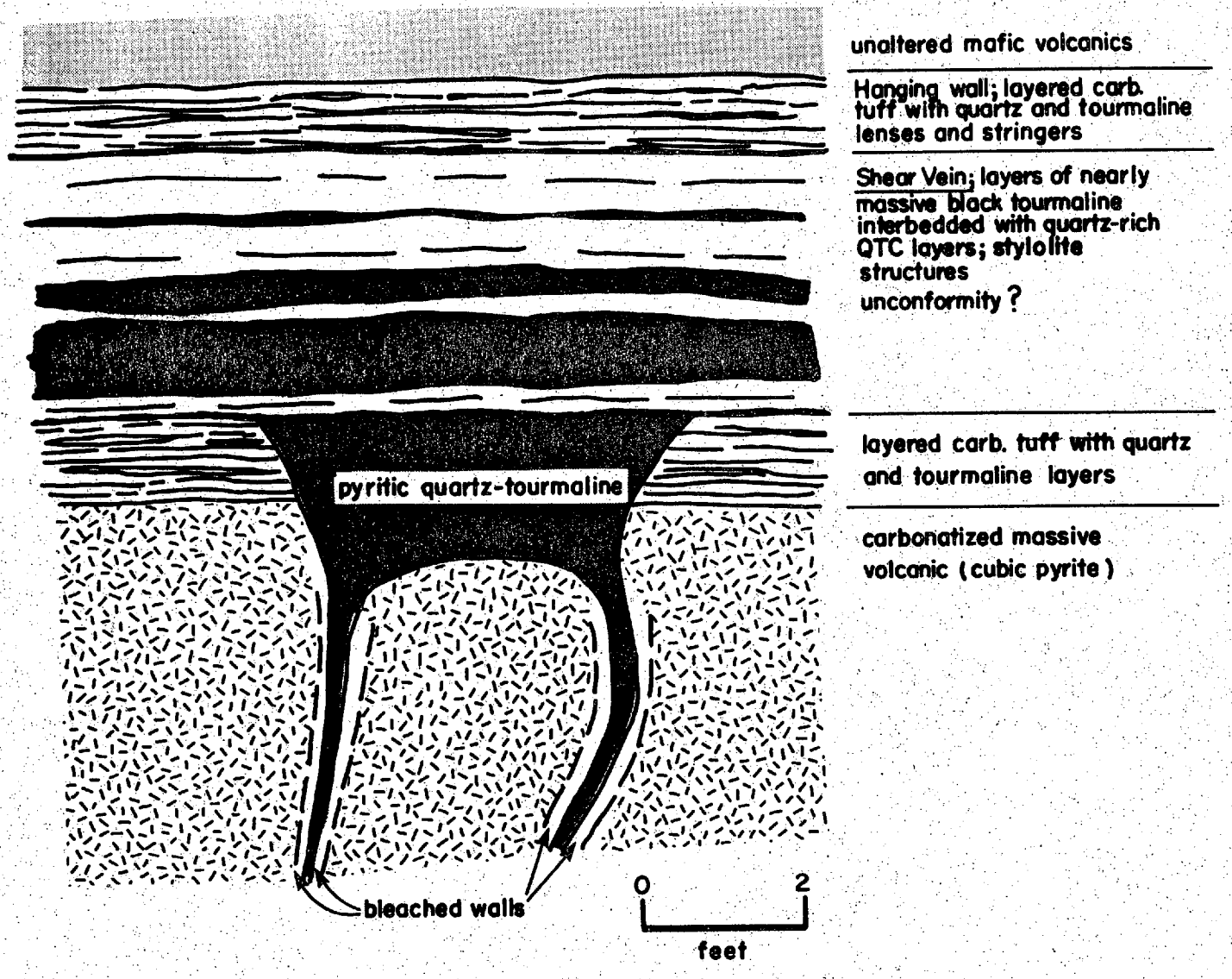


Fig. 6: Sketch of a section of 13V on 700 level Lamaque Mine showing asymmetrical depositional features and contract relations. The cross-cutting pyritic quartz-tourmaline veins have distinctly bleached walls in a moderately carbonatized mafic volcanic. The veins join a mass of quartz-tourmaline which is truncated by layers of quartz and tourmaline of the "shear veins".

Measurements made on several levels in the mine indicate the shear veins to be conformable with the layering in the tuffaceous walls, and in some places where such measurements could be made, conformable with some of the enclosing volcanic units. The drag fold described earlier, is a good example of how shear veins 1V and 13V and probably 39V have been folded. Measurements in crosscuts through the fold axis indicate the volcanic units to have been folded in a similar manner (Fig. 4). Also, at the noses of these folds, it is evident that the main foliation cuts across the layering in the enclosing tuff. Therefore, if the shear veins were truly deposited in thrust faults, then these structures must predate regional deformation.

Fracturing of the shear veins along directions of the main penetrative foliation are common, especially in fold nose areas, and in places some displacement of the veins have occurred due to movement on these planes. Along the flanks of folds, the foliaton coincides with the vein and enclosing tuff. Here movement has been confined mostly to slip surfaces at the contacts of the massive portions of the veins.

Flat Veins: sub-horizontal fracture-filled veins which vary form ½ inch to 5 feet but average less than 1 foot, predominate in the No. 2 Mine but are less common at the Main Mine. At No. 2 and Sigma, these veins trend north to northeast and dip 10 to 20 degrees northwest (Bédard and Imbeau, 1980). They intersect shear veins at 75° to 85° and generally cross-cut or stop at them; however, shear veins cutting flat veins have been recorded in places (Robert et al., 1983).

The flat veins have symmetrical distribution of banding or ribbon patterns of quartz, tourmaline and carbonate and a wide zone of visible alteration equally intense on both walls. Commonly this wallrock alteration is as thick as the vein itself.

Flat veins cross-cut all major rock types and are obviously true, fracture-filled veins. Although they continue along strike or down dip for hundreds of teet, they are locally disrupted by faults and have deformational features (well-described by Daigneault, 1983). Work by White (1943) and Ritter (1971) mainly on shear veins at the Main Mine and by Daigneault (1983) on flat veins at No. 2 Mine have recognized cataclastic and undeformed quartz. Economic gold enrichments are generally found in the former type.

Stringer Veins: this group describes the masses of tension and gash veins and veinlets found predominantly in the main and east plugs. In particular portions of the plugs, these veins are so numerous that bulk mining, of what is called "zone ore" was carried out (see later section). In places shear veins on entering the plug "horse tail" into stringer zones.

MINERALIZATION

Economic concentrations of gold are confined totally to the three vein classes described above. Gold occurs mainly in the native state, generally in small grains, patches or irregular sheets. It is also tied up with pyrite, particularly in wall rock near veins and in a few places the gold tellurides petzite, calaverite, krennerite, and

tellurbismuth have been identified (Bédard and Imbeau, 1980). Sulfides mainly in the form of pyrite with lesser amounts of pyrrhotite and chalcopyrite constitute only a few percent of the veins and country rock. Gold-silver ratios average 5.5:1 with no noticeable change in finness with depth (Fitzgerald et al., 1967).

The contribution of scheelite was tested by the writer on most levels to 2500 feet in the Main Mine. It is virtually non-existent in the shear veins, but can be found commonly in subhedral crystals and irregular blobs mainly in flat veins and at times in stringer veins. Scheelite is also common in the flat veins of the No. 2 Mine.

DISTRIBUTION OF ORE

In the shear veins, assay plans reveal an irregular, patchy distribution of economic concentrations (>0.15 oz. Au/ton) of gold both along strike and down dip of these large irregular bodies. No statistical data exists to demonstrate any regular pattern and there is no obvious relationship between gold content and proximity to plugs. Large sections of these veins, where all the visible vein characteristics are present are devoid of economic gold mineralization. Similar patterns exist in the flat veins of No. 2 Mine.

Although it is generally quoted that the bulk of the ore (>70%) has come from the plugs, the assumption has been make that it was in the plugs where the large shear veins were most productive. This is misleading. The bulk of ore mined in the plugs has been from stringer and gash veins in zones along with more "regular" "shear-like" veins generally along the plug contacts or in the diorite.

An interesting statistic exists with respect to plug ore versus shear vein ore. In the upper third of the mine, the bulk of mine production was from shear veins largely outside the plugs (Fig. 7). Plug ore, mainly stringer and gash vein type (zone ore) was the biggest contributor from about 1200 level to 2500 level with a peak at about 1800 level. This drops off sharply with depth to no production below 3400 level. Exploration drilling to the 5000 feet level in the main plug has failed to delineate any economic mineralization.

ALTERATION

No obvious large-scale alteration (e.g. carbonatization, chloritization, sericitization, etc.), typical of some major gold areas such as Timmins, Larder Lake-Virginiatown, Malartic, etc. exist in the immediate Lamaque-Sigma area. The volcanic sequence is very much the same as any unmineralized mafic section. However, at the east end of the property, alteration assemblages of ankeritic carbonate and sericite are common in the tuffs. These alteration zones appear to be stratabound and can be traced in outcrops for several miles into Louvicourt Township. They may be time-equivalent to exhalative activity at Lamaque and Sigma.

At the Lamaque Mine, visible hydrothermal alteration is confined to the plugs, to walls of flat veins and to irregular, cross-cutting zones usually in the footwalls of shear veins.

Alteration associated mainly with flat veins have been well documented at Lamaque (Daigneault, 1983) and Sigma (Robert et al., 1983). Both visible and cryptic zones of alteration have been

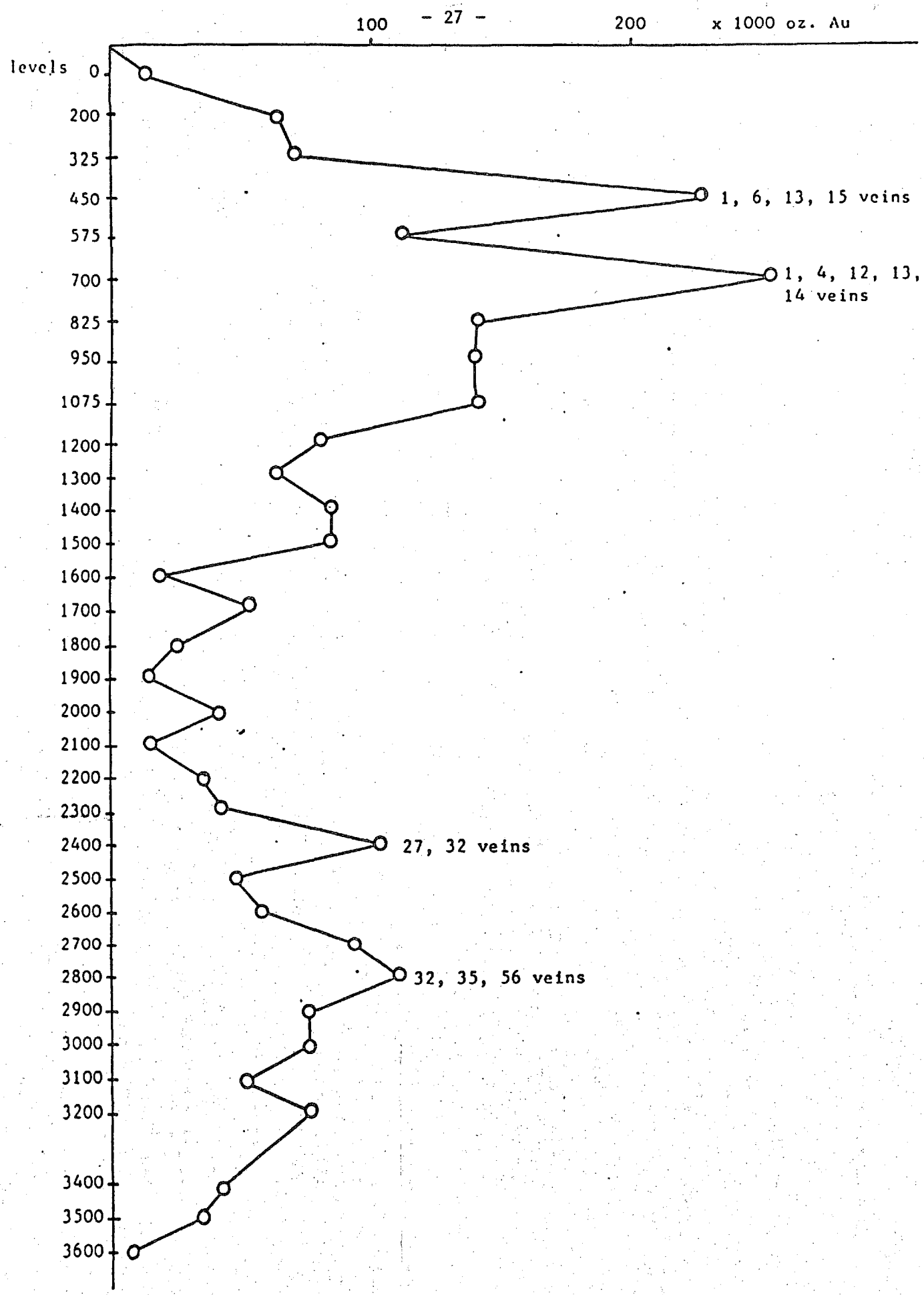


Fig. 7: Non-Plug (mainly "shear vein") Production in Ounces per level, Lamaque Mine.

identified. In the visible zone, bleaching, marked by the destruction of chlorite is the most obvious. In thin sections of these rocks, plagioclases appear to be altered in places to sericite or paragnonite, but most commonly are replaced by albite. Varying amounts of carbonates (calcite and some ferrodolomite), tourmaline, apatite, rutile, sphene, and pyrite are also present (Daigneault, 1983). The result is a light-brown to buff colored rock in which original textures are preserved.

Major and trace element variations across wallrock alteration zones in various country rocks have been documented by Daigneault (1983). In general, there is an enrichment in TiO_2, P_2O_5, CaO, Na_2O, Rare Earths, Y, Zr, Nb, Ta, Hf, U, and Th and a depletion in SiO_2, Al_2O_3, K_2O, MgO, Fe_2O_3, Rb, and Sc, compared to original compositions of the rocks. Certain trace element enrichments (Sr, Y, Zn, Nb) favour the hypothesis that the mineralizing fluids were late magmatic (Daigneault, 1983).

Visibly, the alteration commonly associated with the shear veins and that found in irregular zones measuring hundreds of feet in size in the plugs, particularly the west plug, are similar to the bleached wall rocks of the flat veins. According to Bridger (1949), the alteration with the shear veins "takes the form of bleaching, which is caused by replacement of the original minerals to mixtures of albite, carbonate and quartz with some pyrite and tiny needles of tourmaline" (p. 14).

Irregular zones of bleaching (alteration) of varying size (tens to hundreds of feet) are known from mining and drilling in the mine area. These are cross-cutting, and take on crudely pipe-like shapes.

There appears to be a complete range of alteration pipes or vertical irregular zones which vary from weakly altered to intrusive-looking bodies such as the compositionally-zoned main plug. The west plug, which is made up of about equal quantities of altered (bleached) rock and tonalite could be considered to be an intermediate example. These zones of alteration probably represent fossil hydrothermal vents and plumbing systems which transported the solutions that gave rise to the mineralization at Lamaque. Some fossil vents are now occupied by intrusive material or volcanic necks as suggested by Fitzgerald (1965). Could possibly the plugs as we see them today, be the end product of intensive hydrothermal activity, with very little or no magmatic component?

INTERPRETATION

The volcanic section is one which typified submarine volcanism in a volcanic vent environment. Unconformities in the section suggest much tectonic activity and tilting and probably destruction by explosive activity and submarine erosion. The association of at least some shear veins with the unconformities, the non-vein characteristics of the shear veins as described above and the fact that the shear veins have been deformed equally with the enclosing volcanics suggest they formed during volcanism, prior to regional deformation and probably prior to formation of the plugs. The plugs and related alterations predate regional deformation and probably represent the latter stages of volcanic activity in the area. Various deformation characteristics of flat veins suggest a long history of formation from pre-plug times through to the late stages of deformation.

GENETIC MODELS

The geologic evidence and the interpretation do not support the generally accepted structural model of ore concentration through brittle deformation (faulting) of a passive sequence of volcanic rocks and intrusive plugs. The timing constraints imposed by the structural evidence do not allow it. The shear veins which are supposed to follow thrust faults that crosscut everything, including deformed volcanics, show all deformation of the enclosing rocks. If the shear veins are fault controlled then the faults and veins had to form after volcanism and plug intrusion, but before regional deformation. This is unlikely.

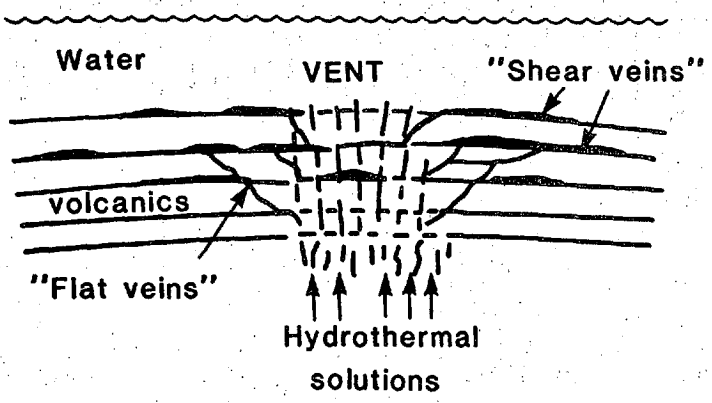
The structural model leaves unexplained many pertinent features described above:

1. the setting of the host rocks being proximal to a volcanic vent (Fitzgerald, 1965; Imreh, 1984);
2. the asymetrical, conformable nature of the shear veins and the location of some, if not many of them along unconformities;
3. the distribution of ore between plugs and shear veins with depth;
4. the chemical similarities between alterations associated with walls of flat veins, footwalls of shear veins and zones in and around plugs;
5. the geometric relations between shear veins and flat veins (75° to 85° to each other) and the failure to fit these vein orientations into any simple stress ellipsoid (Bridger, 1949);
6. the asymmetry and general lack of intense alteration in walls, especially the hanging wall of shear veins as compared to alteration associated with flat veins.

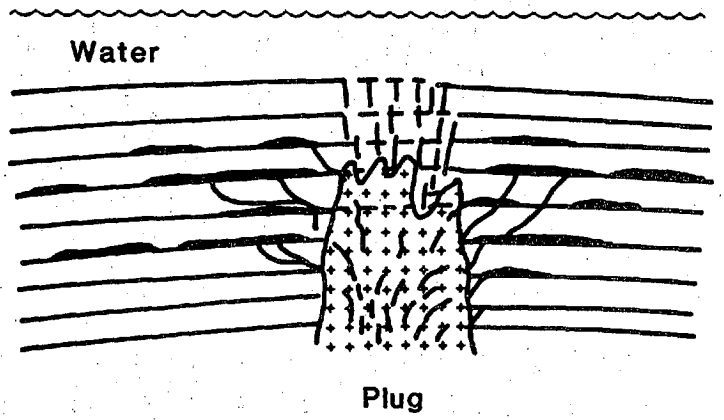
The geologic evidence could be better explained by a volcanogenic model. The shear veins could represent deposits of borates (colemanite), silica and carbonate which were chemically deposited in a volcanic vent area (caldera?) at repeated times of relative quiescence but of active hydrothermal exhalative activity. Chemical conditions were such that gold was transported and deposited. The shears at Lamaque could simply represent interflow tuff-exhalite units deposited on irregular volcanic surfaces (Fig. 8). Thickest exhalative deposits were formed in topographic depressions. Testing of interflow tuffs probably time-equivalent to the shear veins, in un-mineralized areas of the mine and in the "DPC" area to the east indicate high levels (500-1000 ppb) of gold and associated trace elements. Veins now flat would have been near vertical during volcanism and they and the breccia alteration pipes below the shears could have acted as feeder veins (Fig. 8).

Through a prolonged period of exhalative activity interupted periodically by explosive volcanism and deposition of crystal tuffs and minor flows, a series of shear veins were deposited in a restricted area around the vent. Volcanic activity culminated with the intrusion of the plugs into the vents to shallow levels below the surface. Hydrothermal activity continued well after and as a result flat veins extend relatively undeformed high up into the pile and many of the stringer ore zones and other veins at depth in the main and east plug formed at this time.

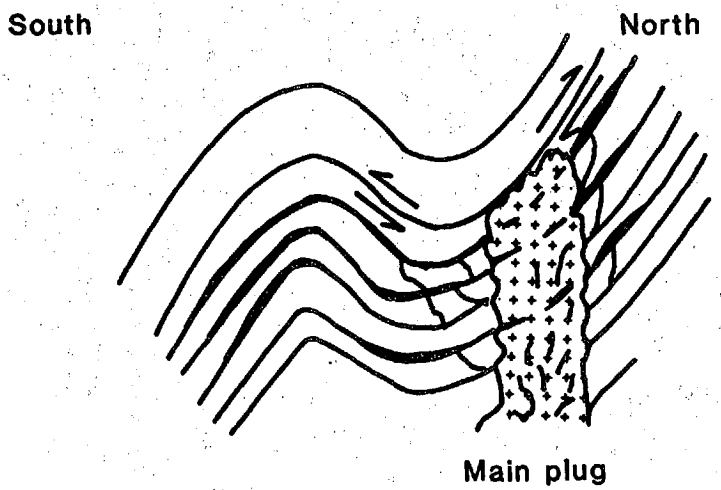
Deformation probably began when the volcanic pile became unstable, possibly before all extrusive activity was complete, and continued well after. The rocks were tightly folded, with much of the



I: Exhalative Phase. Deposition of some stratabound gold mineralization as well as feeder veins in and near exhalative vent.



II: Intrusive Phase. Invasion of vent by intense alteration and intrusion. Formation of vein zones in plug and additional veins in country rocks.



III: Deformation Phase. Penetrative folding of rocks including plug and veins about easterly-plunging fold axes. Accompanied by vein remobilization, some new vein formation and intrusion of late felsic dikes (not shown).

Fig. 8: Sketches of a possible Sequence of Ore Formation and Main Plug Intrusion, Lamaque Mine.

movement taken up along interflow tuff units and shear veins. The main plug being on the north side of a local syncline-anticline pair, was broken up and sheared along planes directed from the interflow tuffs. The movement along these surfaces, transposed the plug into sub-vertical position (70°NNE) which may have intruded a partly deformed or tilted volcanic sequence.

Late, relatively undeformed veins and feldspar porphyry dikes mark the end of felsic intrusive activity and hydrothermal activity.

During deformation, breaking up and remobilizing of solutions in the pre-existing quartz veins may account for the two types of quartz (deformed and undeformed). With this model, it is difficult to explain how the shear veins could pass through the plug if they in fact formed before it, even though we know that these veins change character and become less prominent in the plug. Part of the difficulty may lie in the lack of understanging of how the plugs really formed. Are they the end result of extensive hydrothermal activity or are they really magmatic? (A sharp contact with no apparent chemical or mineralogical aureole supports a hydrothermal origin.) Could it be possible that the shears and associated veins through the plug reflect relict features in a "granitized" rock? These are perplexing questions.

CONCLUSIONS

Although the evidence is not conclusive, this synthesis suggests that gold was deposited as exhalative stratabound deposits, and as true veins during a prolonged period of Archean mafic volcanism, hydrothermal activity and felsic intrusion. The ore-forming activity was confined to a major volcanic centre in the Lamaque-Sigma area.

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