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Highland Valley 176

Petrochemistry

3 spaces

The order of intrusion derived from discussions in the preceeding sections for plutonic rocks exposed at the Bethlehem mine began with emplacement of the Guichon granodiorite and was probably followed in the order: (1) Bethlehem granodiorite and leucophase, and possibly Bethlehem porphyry; (2) porphyritic quartz latite; (3) prebreccia dacite porphyry, occurring as breccia clasts and ~~in one~~ as a pluton south of the East Jersey zone; (4) breccia; (5) granodiorite; (6) granite; (7) postbreccia dacite porphyry; and (8) pink-stained dacite porphyry. The Bethlehem porphyry may be younger, but has been incorporated with Bethlehem granodiorite and related rocks because of similarities in texture~~s~~, mineralogy, and chemistry. The granodiorite unit has compositional affinities to both porphyritic quartz latite and granite; however, it is not recognized among clasts in the breccias and is therefore assigned a postbreccia age. Nearly all of the exposed dacite porphyry intrusions appear to be members of the postbreccia suite. Prebreccia dacite porphyries have almost identical equivalents among this later suite, and consequently their mineralogical and chemical variations are discussed as part of the postbreccia group. As described earlier, the quantitatively miniscule aplites have multiple, in part uncertain, ages. The potassium feldspar-rich aplites have chemical and mineralogical trends much like the granite, whereas the potassium feldspar-poor, plagioclase-quartz aplites have components of the trends of both the granite and the more leucocratic dacite porphyries. As a result, the aplites are not characterized separately.

- Gu
- Bm + Bm Ppy
- Ppytic Qtz Latite
- Dacite Ppy
- Bx
- Later dacite ppy
- Pink dacite Ppy

lesson?

stock Ppytic Qtz latite = "Bm Granite"?

*aplite of several generations (two types - Kspar poor + Kspar-rich)

dacite ppy post Bx

Mineralogical Variations. Temporal variations in the amounts and proportions of igneous minerals are portrayed in Figures 32, 37, and 38. The QAP diagram of Figure 32 shows two, largely separate clusters of rocks. The first group is comprised of potassium feldspar-bearing units that show a marked increase of quartz and potassium feldspar relative to plagioclase, following the sequence of intrusion. The second is a potassium feldspar-deficient group dominated by the dacite porphyries, and represents a major hiatus in this trend. The resultant bimodal distribution closely resembles that of plutonic suites associated with volcanic arc porphyry copper mineralization in the northern Caribbean (Kesler and others, 1975) and Panama (Kesler and others, 1977).

Bimodal Suite – K-rich trend K-poor trend (* see Kesler et al 1977)

Late-stage emplacement of potassium feldspar-poor porphyries is complicated by the early hydrothermal alteration of this mineral to secondary plagioclase and clay minerals, near the copper orebodies. In an attempt to avoid this problem, most of the analyzed samples are from relatively weakly altered dacite porphyry dikes that intrude rocks displaying stable primary potassium feldspar. Moreover, the contacts between ~~the~~ these dikes and ~~these~~ their wallrocks were closely scrutinized for similar alteration effects to determine if ~~to preclude that~~ fluids indigeneous to the dacites ~~may~~ might have destroyed preexisting potassium feldspar in the dikes. Wallrock at the contacts does not appear to have undergone this kind of alteration. Consequently, except for the pink-stained dacite porphyry which is substantially altered throughout, the potassium feldspar contents of the dacite porphyries are believed to largely reflect the content in the magma.

The dual populations of the QAP diagram are generally maintained on

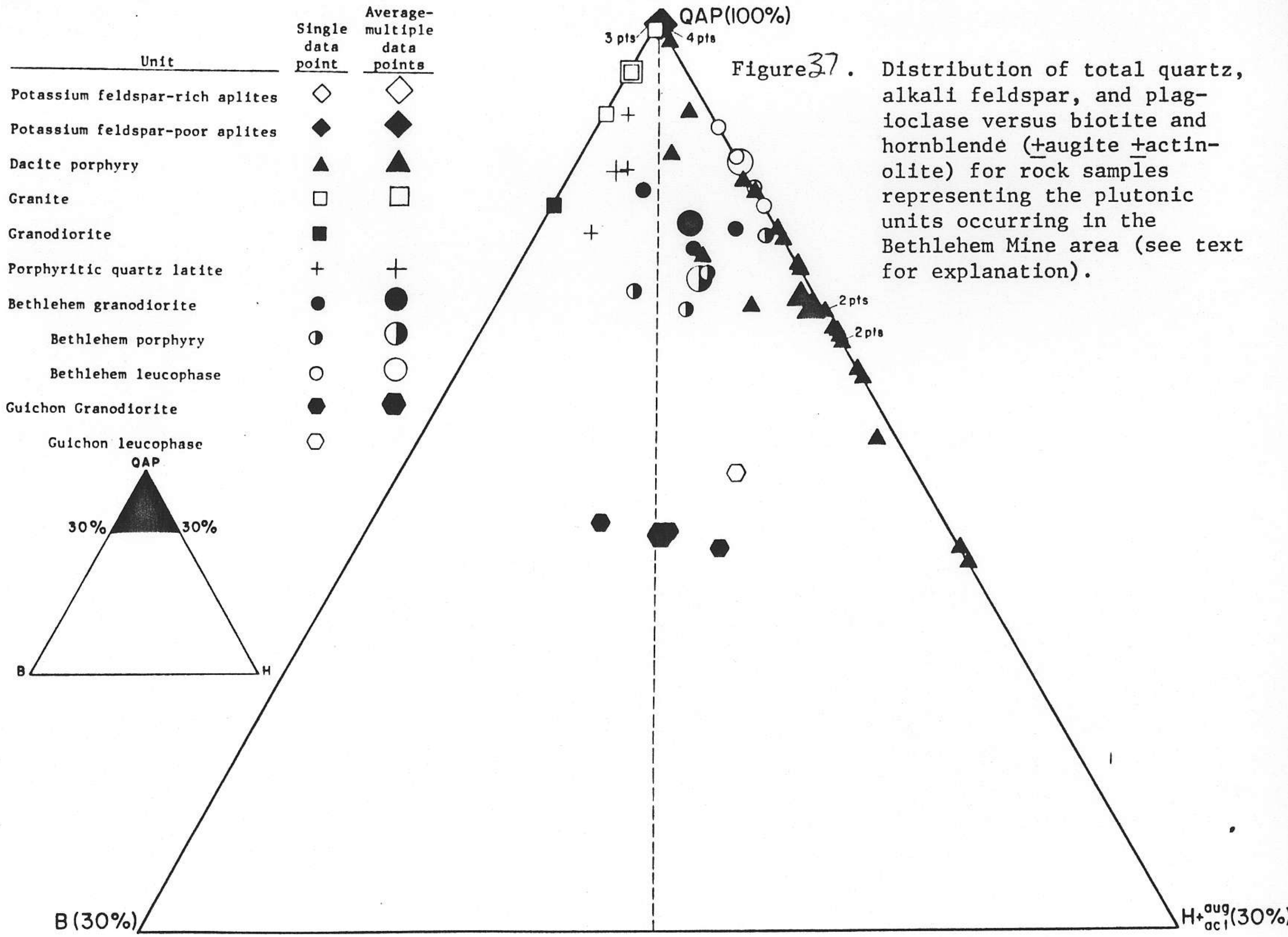

Figure 37. Distribution of total quartz, alkali feldspar, and plagioclase versus biotite and hornblende (±augite ±actinolite) for rock samples representing the plutonic units occurring in the Bethlehem Mine area (see text for explanation).

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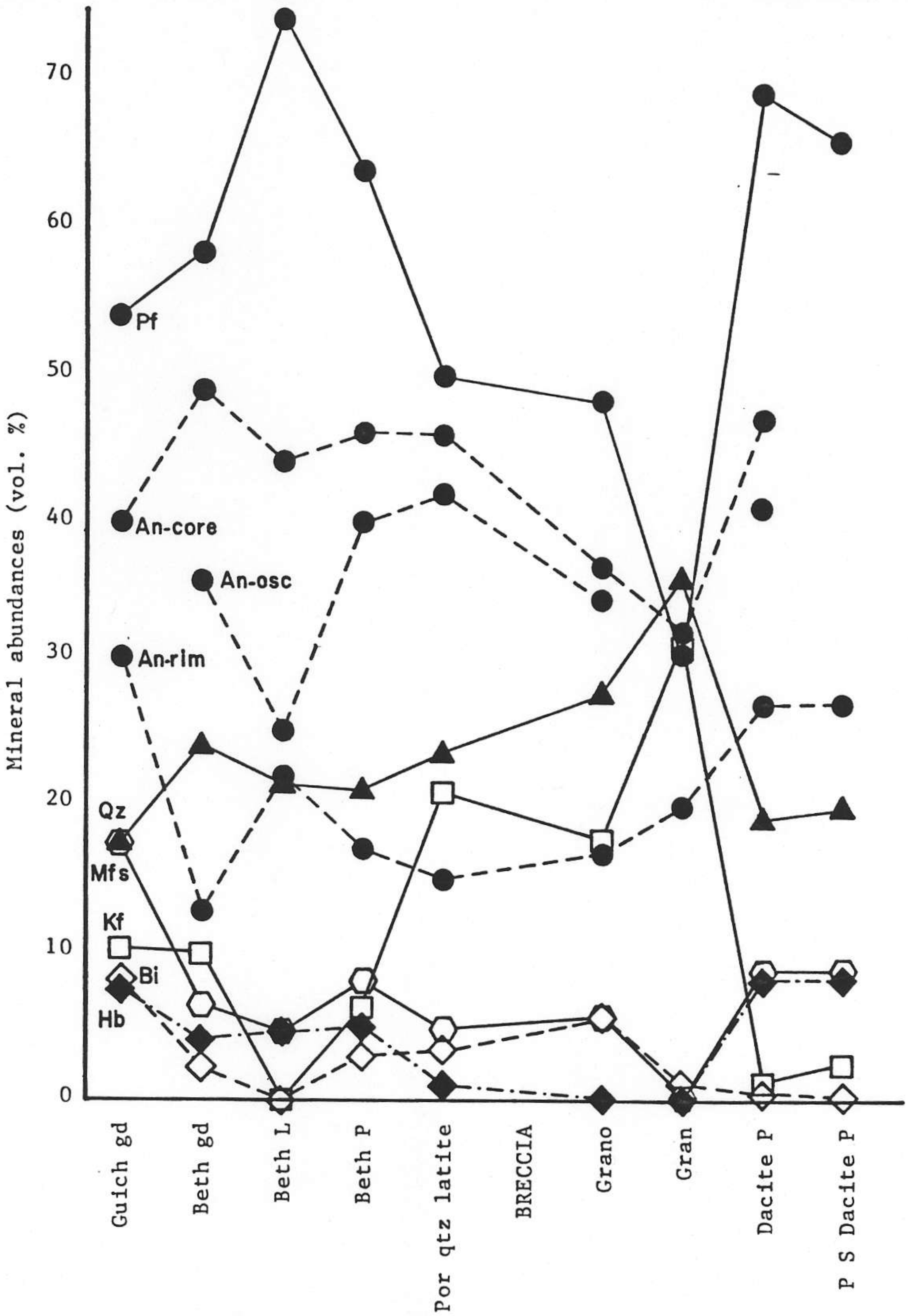

Figure 38. Plot of mineral abundances and plagioclase compositions versus order of intrusion of Bethlehem plutonic suite. Pf-plagioclase; An-anorthite content of plagioclase cores, most calcic oscillatory (osc) zones, and rims; Qz-quartz; Mfs-total mafic minerals, including magnetite; Kf-potassium feldspar; Bi-biotite; Hb-hornblende (±actinolite).

the QAP-B-H illustration in Figure 37. The potassium feldspar-rich group evolves from rocks having nearly equal proporations of biotite and hornblende, through biotite-dominant units, to the granodiorite and granite, in which biotite is the sole ferromagnesian silicate. This progression is reversed with emplacement of the hornblende-rich dacite porphyries.

kspar-rich series
Bio ≃ Hb → only bio
kspar-poor - Hb dominates

Changes in the absolute abundances of primary igneous minerals with the approximate temporal order of intrusion of the plutonic rocks at Bethlehem are displayed graphically in Figure 38. In general, with decreasing age and increasing differentiation (1) plagioclase and the anorthite content of its cores, total mafic minerals (including magnetite), and hornblende all decrease; (2) quartz and potassium feldspar increase; and (3) biotite and the anorthite content of plagioclase rims and oscillatory zones remain roughly constant. Intrusion of the late-stage dacite porphyries has caused major reversals of trends for groups (1) and (2). Additionally, biotite almost disappears, and the anorthite contents of rims and oscillatory zones of plagioclase increase significantly. Bethlehem leucophase sporadically causes marked hiatuses in these mineralogical trends.

Major Oxide Variations. Increasing differentiation of the Behtlehem host rocks with decreasing age is expressed by progressive increases in their average Larsen differentiation indexes and concommitant decreases in average bulk rock densities (Figure 39). These trends, like those of the mineralogical variations described previously ~~above~~, undergo major reversals upon emplacement of the dacite porphyries.

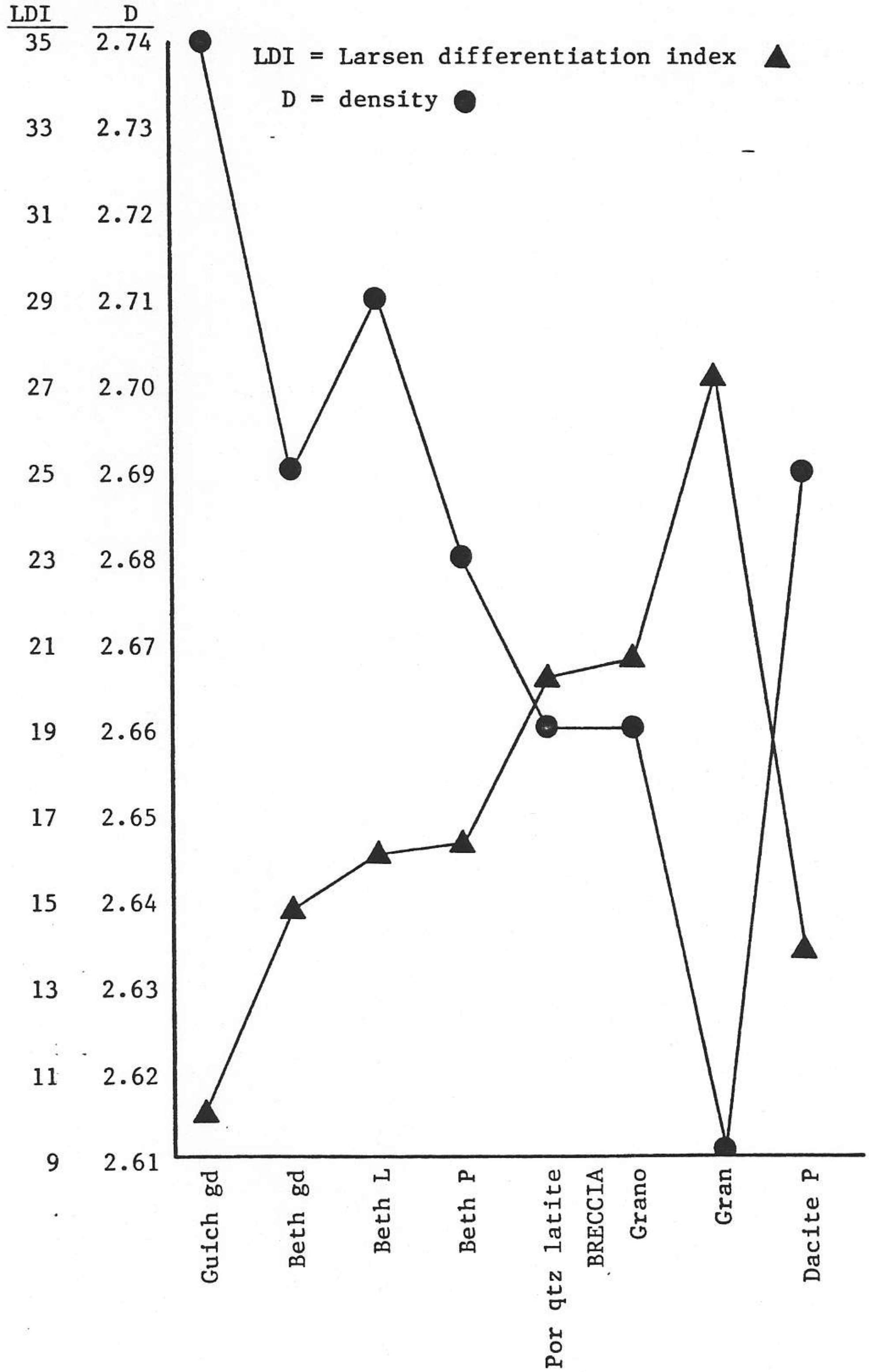

Figure 39. Plot of Larsen differentiation index (LDI) and density (D) versus order of intrusion of Bethlehem plutonic suite.

The ratios of alkalis to silica in rocks from the mine area (Figure 40) are comparable to those for the batholith (cf. Figure 17) and reflect its subalkaline composition. The granite and aplites, however, are more highly fractionated and contain more alkalis and silica than even most of Northcote's (1969) Witches Brook Phase (Olade, 1974, 1976). Rock units of the mine also display the same unexpectedly weak positive correlation (sr=0.420) between alkalis and silica that characterize magmatic differentiation in the batholith. The minimum statistically significant Spearman rank correlation coefficient at the 0.025t-probability level for the Bethlehem plutonic suite is equal to 0.265.

A progressive enrichment of alkalis relative to iron and magnesium is demonstrated by the AFM diagram of Figure 41. This line of descent approximately follows the temporal sequence of emplacement from early Guichon granodiorite to the late granite unit, but with a regression to more iron- and magnesium-rich rocks upon intrusion of the dacite porphyry. The alkali enrichment trend closely approximates the calc-alkaline trend of the batholith (cf. Figure 18). However, the Peacock index is about 64 and suggests an even more calcic magma. This is consistent with the relatively high anorthite content of plagioclase in the Bethlehem plutonic rocks, and probably also with the basic compositions of the late-stage dacite porphyries.

Peacock Index=64

The erratic, magnesium-deficient dacite porphyry sample occurring above the calc-alkaline trend line (number 52, Tables 18 and 20) in Figure 41 contains about 10 percent mafic minerals including 7 percent secondary amphibole. The unexpectedly low MgO analysis (see Table 20) may result from analytical errors or may reflect the presence of inordinately iron-rich actinolite. The

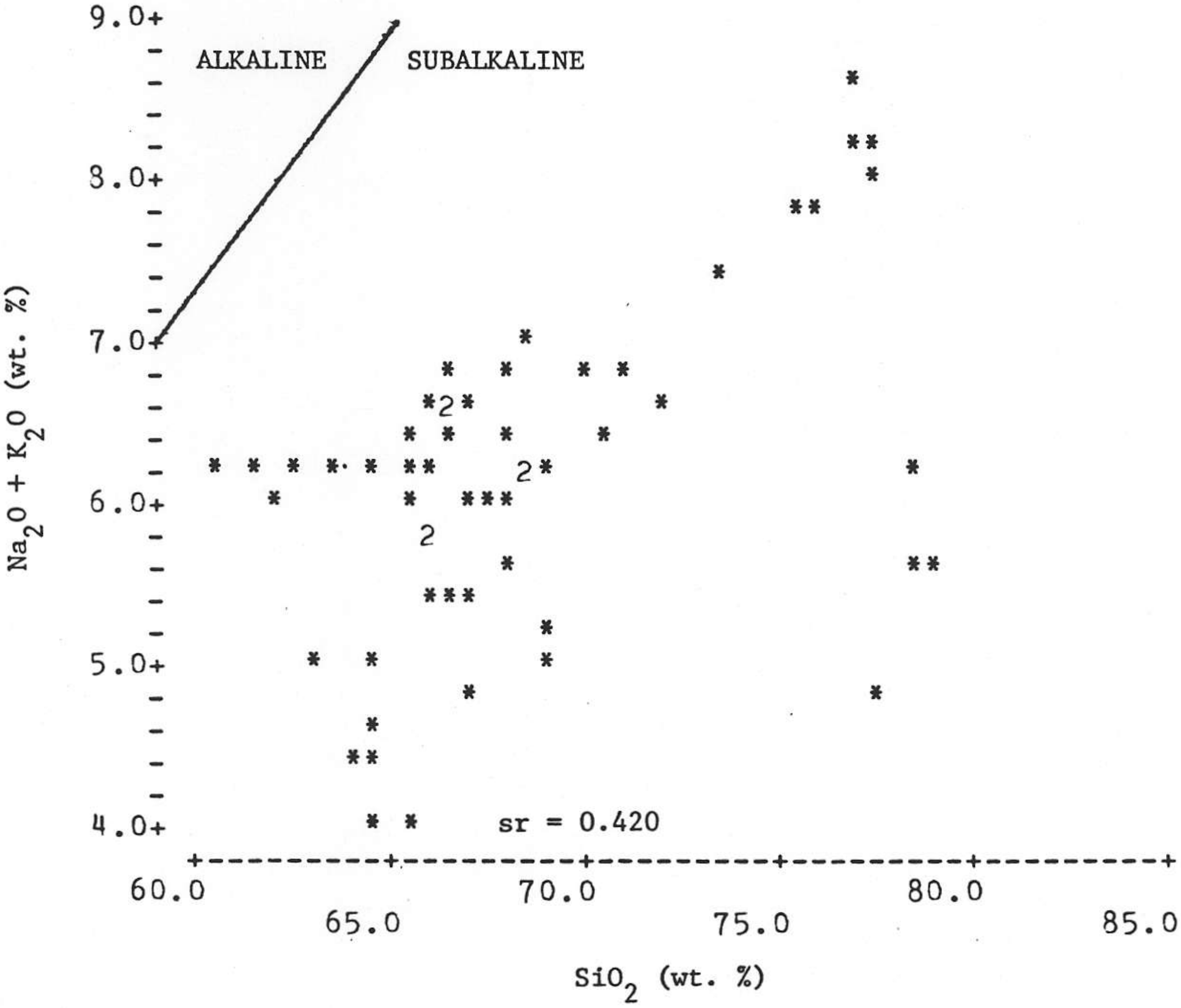

Figure 40. Alkalis-silica plot for plutonic rocks from the Bethlehem mine. Numerical plots indicate number of coincident data points.

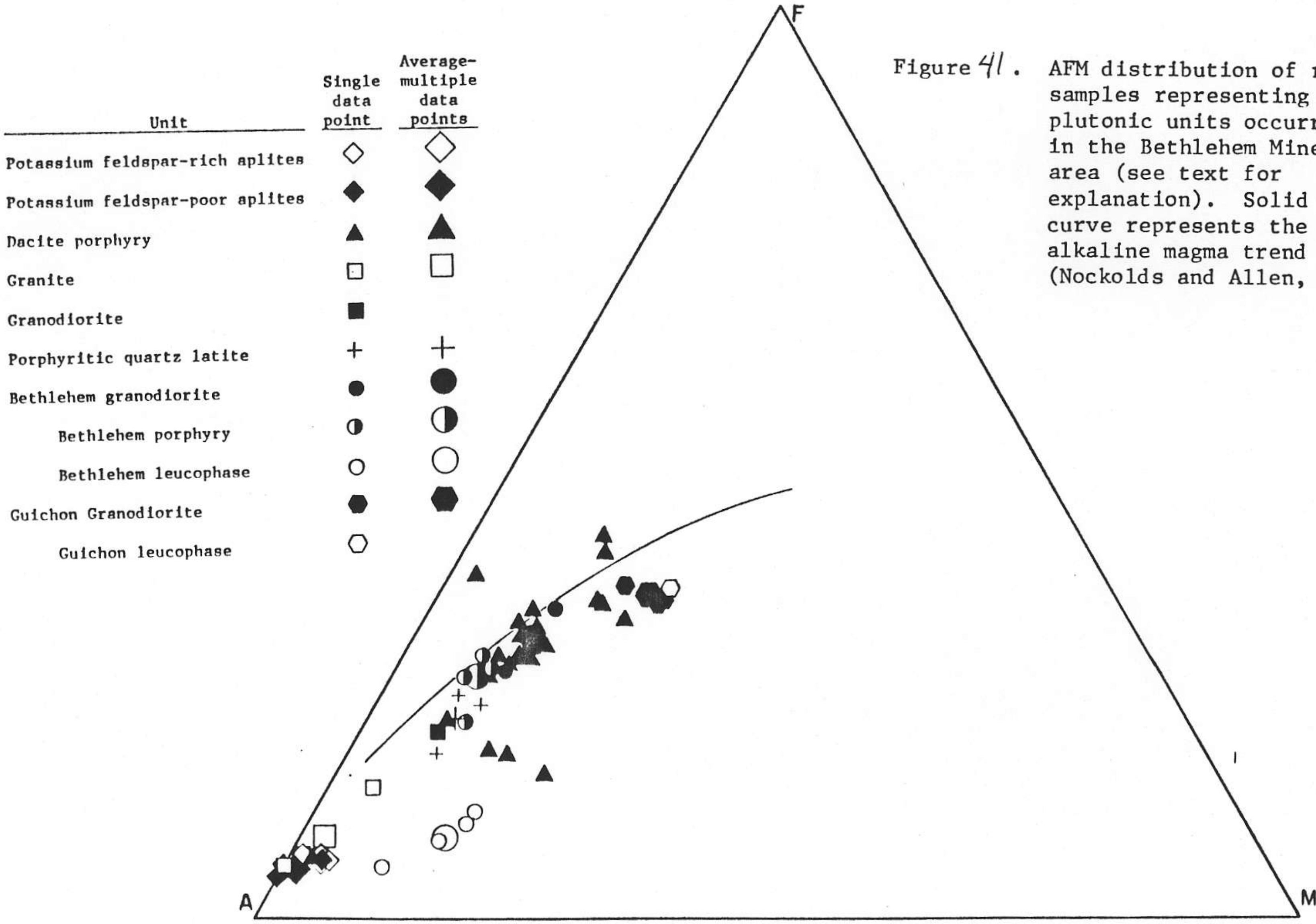

Figure 41. AFM distribution of rock samples representing the plutonic units occurring in the Bethlehem Mine area (see text for explanation). Solid curve represents the calc-alkaline magma trend (Nockolds and Allen, 1953).

abundance of more common magnesium-rich actinolite and rarely tremolite(?) replacing hornblende in the Bethlehem leucophase unit probably accounts for the relatively high magnesium:iron ratios displayed by these rocks.

The alkali enrichment trend displayed by the AFM plot is poorly discriminated ~~distinguished~~ on the NKC diagram (Figure 42), which is dominated by the potassium feldspar-deficient dacite porphyries, plagioclase-quartz aplites, and leucocratic varieties of the Guichon and Bethlehem granodiorites. With decreasing age and increasing LDI, prior to intrusion of the dacite porphyries, the rocks show an initial relative enrichment of sodium, followed upon emplacement of the porphyritic quartz latite unit by substantial increases in potassium with respect to sodium and calcium. The latter part of this trend very roughly approximates the normal progressive enrichment of potash relative to soda and lime that usually results from the differentiation of calc-alkaline magma. Olade (1974, 1976) showed that a similar trend for the Guichon Creek Batholith resulted from the crystallization of potassium feldspar-rich rocks of the Witches Brook Phase. A parallel to the trondhjemitic differentiation trend displayed by the batholith (see Figure 19) is not obvious in Figure 42.

The AKF illustration in Figure 43 shows an obvious rock-type effect. All of the mafic-rich granodiorites, quartz diorites, and dacites plot in the Fe-Mg-rich part of the diagram near the F apex. This is largely attributable to the abundance of ferromagnesian silicates (hornblende, actinolite, and epidote) having low Al_2O_3:CaO+Na_2O molecular ratios, combined with the generally low K_2O contents of these rocks. Mafic-rich units containing significant

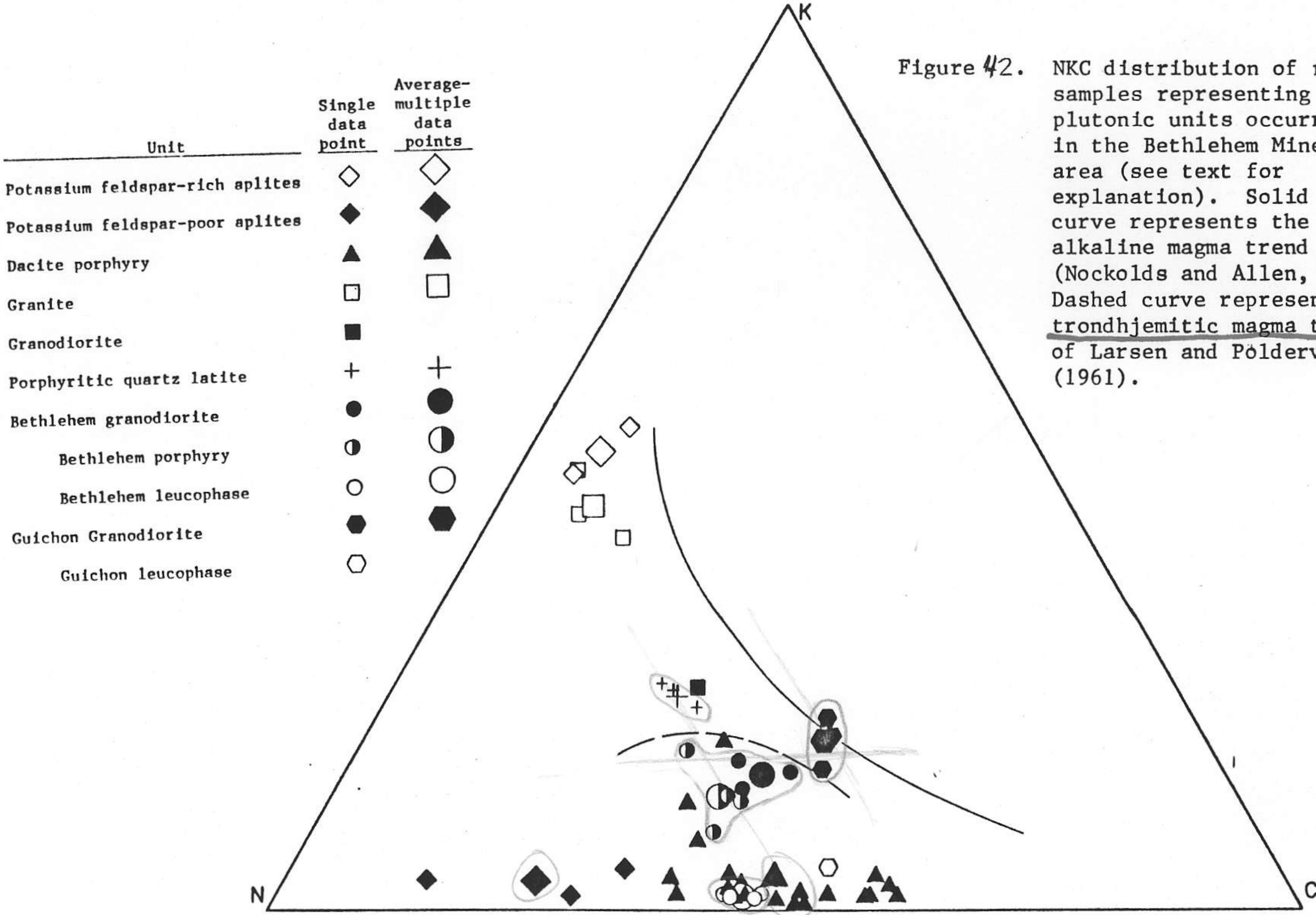

Figure 42. NKC distribution of rock samples representing the plutonic units occurring in the Bethlehem Mine area (see text for explanation). Solid curve represents the calc-alkaline magma trend (Nockolds and Allen, 1953). Dashed curve represents the trondhjemitic magma trend of Larsen and Poldervaart (1961).

Unit	Single data point	Average-multiple data points
Potassium feldspar-rich aplites	◇	◇
Potassium feldspar-poor aplites	◆	◆
Dacite porphyry	▲	▲
Granite	□	□
Granodiorite	■	
Porphyritic quartz latite	+	+
Bethlehem granodiorite	●	●
Bethlehem porphyry	◑	◑
Bethlehem leucophase	○	○
Guichon Granodiorite	⬢	⬢
Guichon leucophase	⬡	

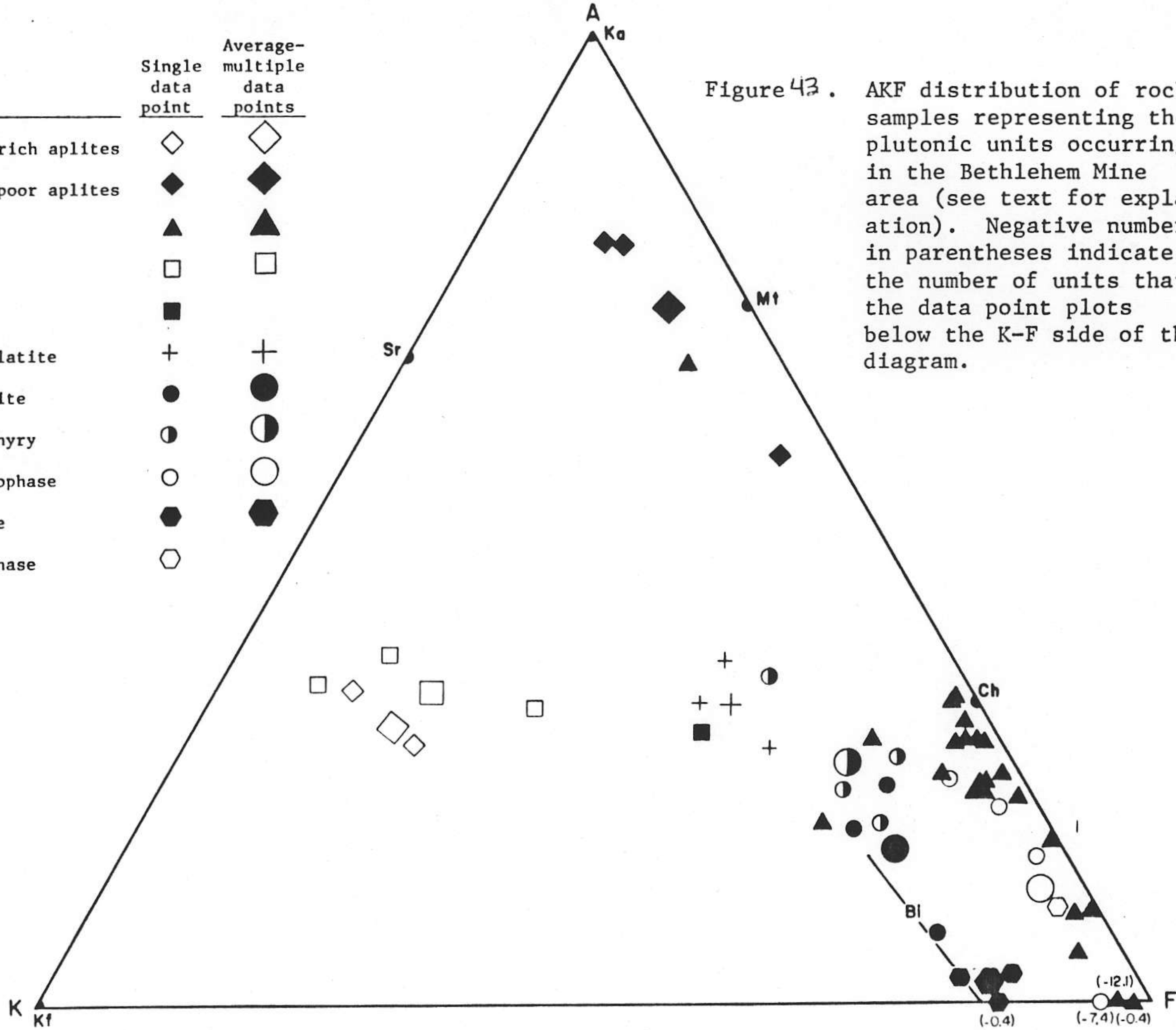

Figure 43. AKF distribution of rock samples representing the plutonic units occurring in the Bethlehem Mine area (see text for explanation). Negative numbers in parentheses indicate the number of units that the data point plots below the K-F side of the diagram.

biotite and potassium feldspar plot near the biotite compositional field, whereas those without, or with only small amounts of these minerals, and composed of substantial amounts of amphibole and (or) epidote, occur along or near the F end of the A-F join. Leucocratic, highly silicic rocks plot nearer the K or A apexes.

A weak to moderately developed temporal trend is expressed on the AKF diagram for the biotite- and potassium feldspar-bearing, predacite porphyry plutonic succession. This trend extends from early Guichon granodiorite at the lower boundary of the biotite field, progressively through Bethlehem granodiorite and porphyry at the top of the field, and porphyritic quartz latite and the granodiorite near the middle of the diagram, to granite adjacent the A-K join. The trend occurs largely in response to decreasing abundances of mafic minerals, increasing biotite:hornblende ratios, and increasing amounts of potassium feldspar. It is terminated and (or) followed by intrusion of the more mafic potassium feldspar- and biotite-deficient dacite porphyries, which plot back near the F apex.

The ACF diagram (Figure 44) shows rock groupings much like those on the AKF diagram. Ferromagnesian silicate-bearing rocks containing small to modest amounts of potassium feldspar cluster near the center of the diagram. Leucocratic, highly silicic rocks plot closer to the A apex. The predacite porphyry plutonic rocks display a progressive decrease in CaO, FeO_T, and MgO with decreasing age. This trend is ascribable to decreases in (1) the abundances of mafic minerals, and (2) the anorthite content of plagioclase (see Figure 38), with increasing differentiation. It is terminated and (or) followed by emplacement of the more mafic and more calcic dacite porphyries, which plot near the

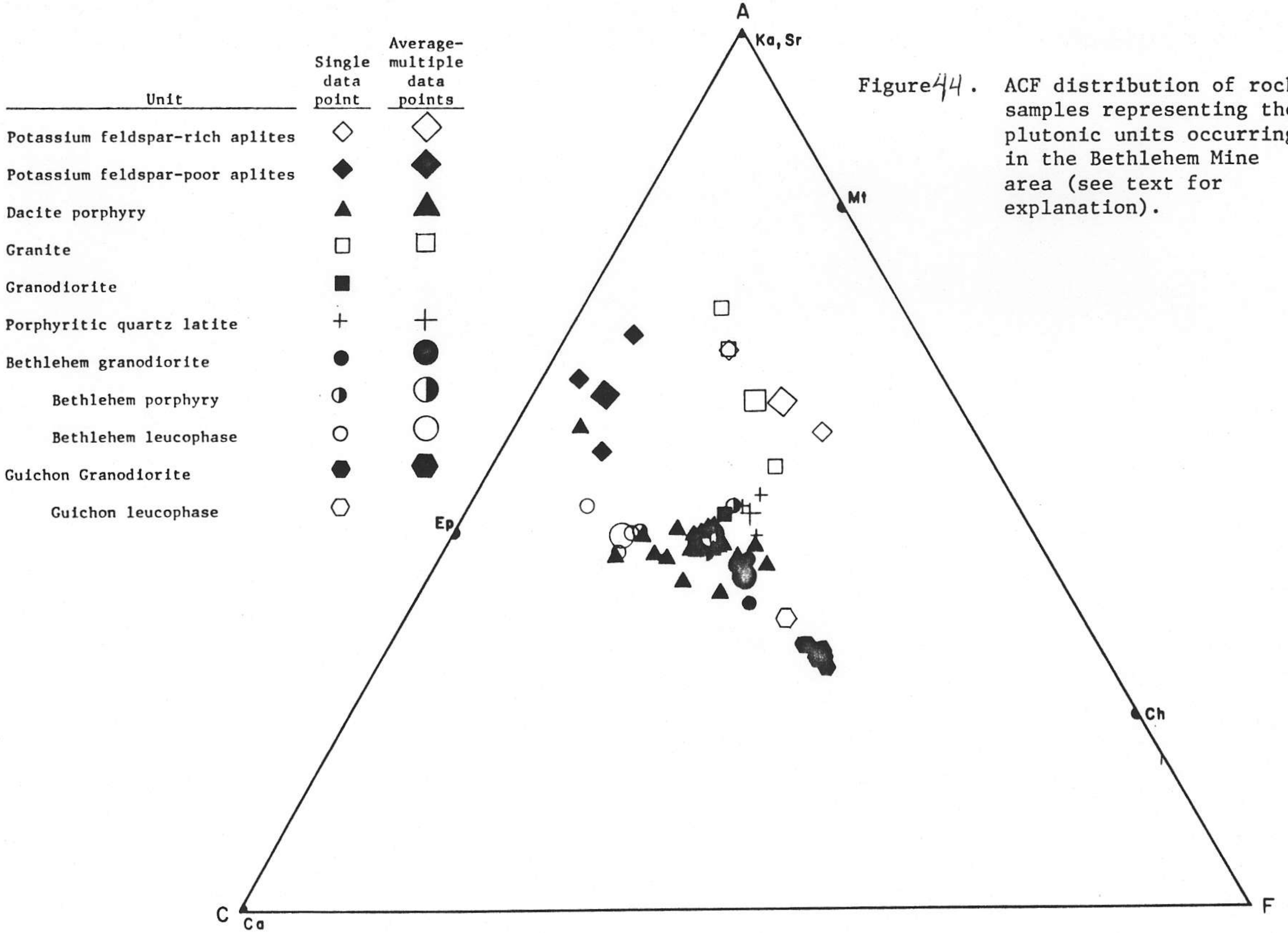

Figure 44. ACF distribution of rock samples representing the plutonic units occurring in the Bethlehem Mine area (see text for explanation).

center of the diagram with earlier rocks of the series.

Major oxide variations with decreasing age of emplacement of the Bethlehem plutonic succession ~~is~~ are illustrated in Figure 45. Except for perturbations caused by the intergradational Bethlehem leucophase, the average weight percent of major oxides in each unit undergo relatively systematic changes with time. CaO, FeO_T, MgO, and TiO_2 decrease with decreasing age, whereas SiO_2 and K_2O increase. Na_2O increases from Guichon granodiorite to Bethlehem granodiorite and leucophase, and then declines regularly to a minimum value in the granite unit, which contains about the same quantity Na_2O as the Guichon granodiorite. The quantity of Al_2O_3 remains nearly constant between Guichon granodiorite and Bethlehem granodiorite and related rocks, but decreases progressively with emplacement of the potash-rich porphyritic quartz latite, granodiorite, and granite. Each of the above major oxide trends, however, experiences pronounced reversals due to ~~formation~~ the presence of the dacite porphyries, and in this respect these trends are consistent with all temporal chemical and mineralogical variations presented for the Bethlehem plutonic sequence.

Larsen variation diagrams for the Bethlehem plutonic rocks are presented in Figures 46-53. With the exceptions of Na_2O and K_2O, all of the major oxide components show tightly grouped linear clusters of data points exhibiting strong correlations with LDI. TiO_2, Al_2O_3, FeO_T, MgO, and CaO correlate negatively with LDI, but correlations between LDI and ~~with~~ SiO_2, and possibly K_2O, are positive. Data points for K_2O are ~~quite~~ fairly scattered and the resulting correlation is weak (sr=0.429). There is no correlation between K_2O and SiO_2 (sr=0.167), and especially ~~There is no hint of a correlation~~ between Na_2O and LDI (sr=0.001). The ~~major oxide~~ variation diagrams

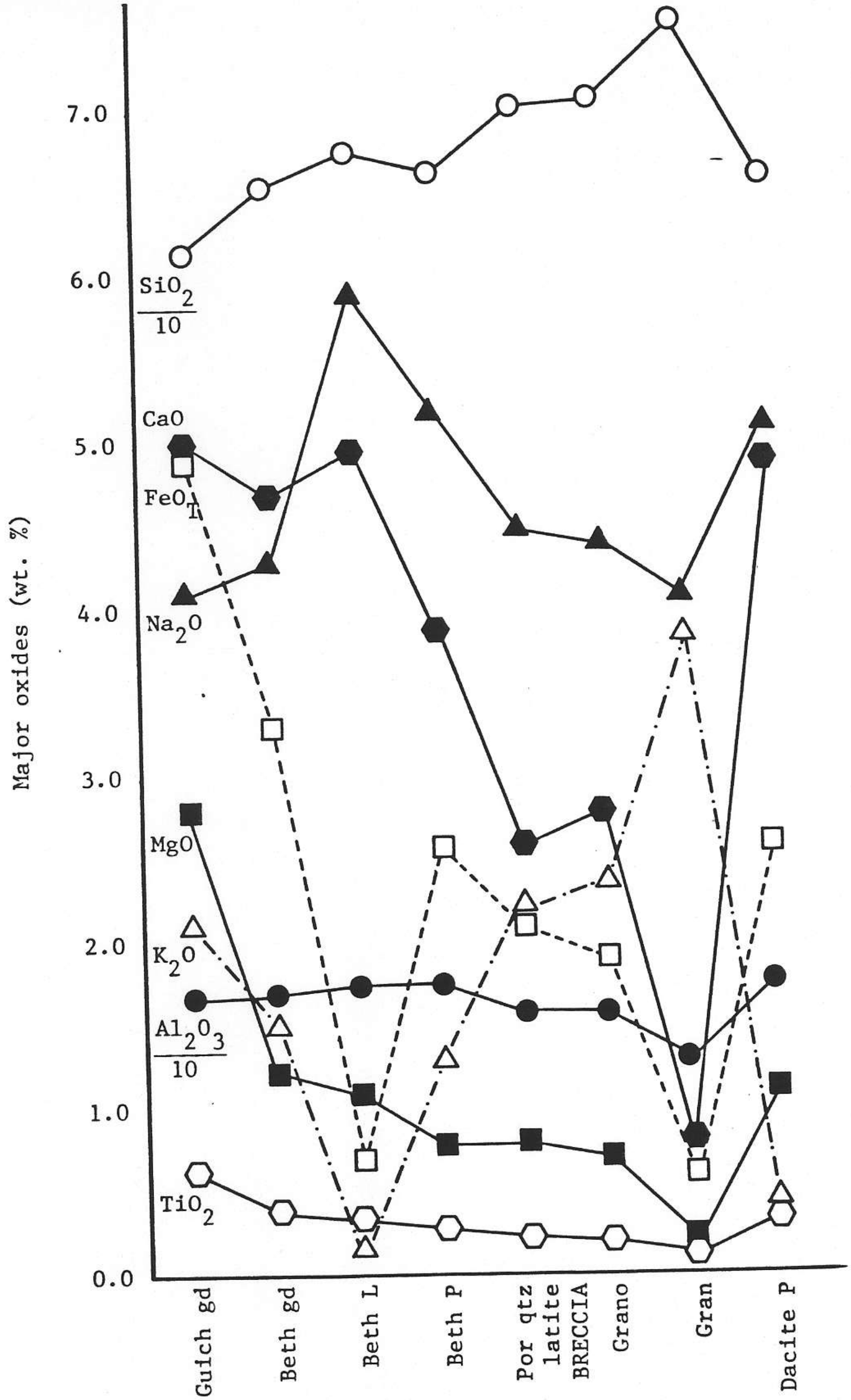

Figure 45. Plot of major oxide analyses versus order of intrusion of Bethlehem plutonic suite.

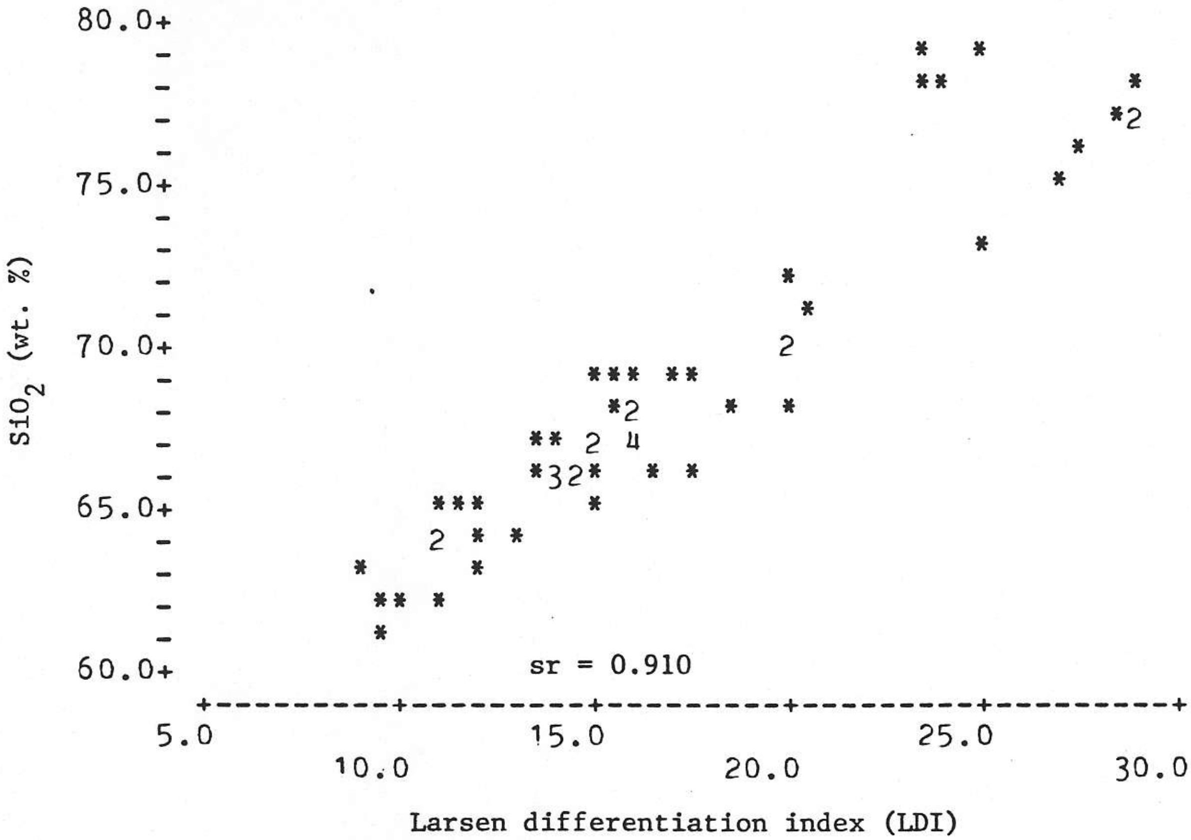

Figure 46. Larsen variation diagram for SiO_2 from plutonic rocks at the Bethlehem mine. Numerical plots indicate number of coincident data points.

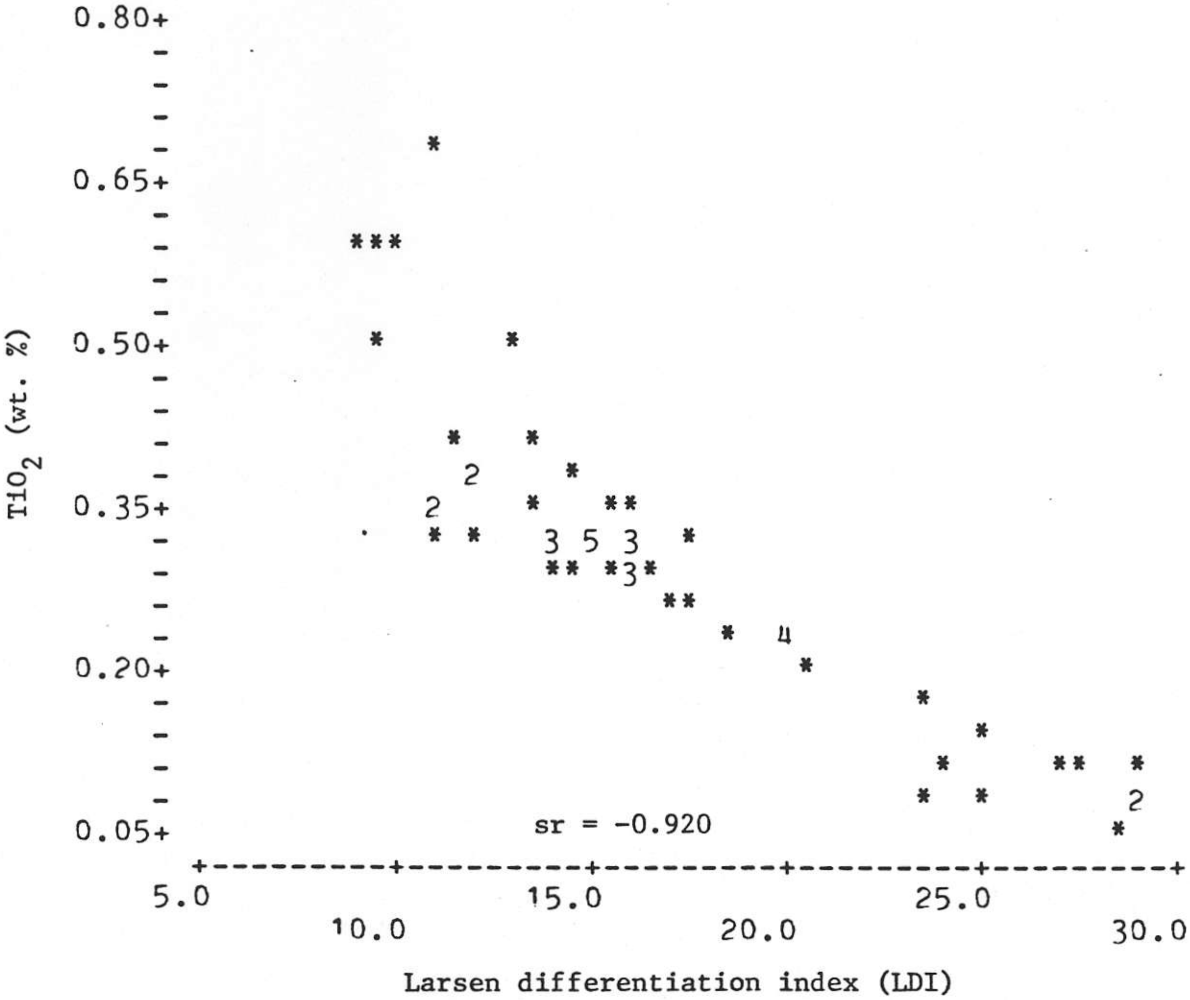

Figure 47. Larsen variation diagram for TiO_2 from plutonic rocks at the Bethlehem mine. Numerical plots indicate number of coincident data points.

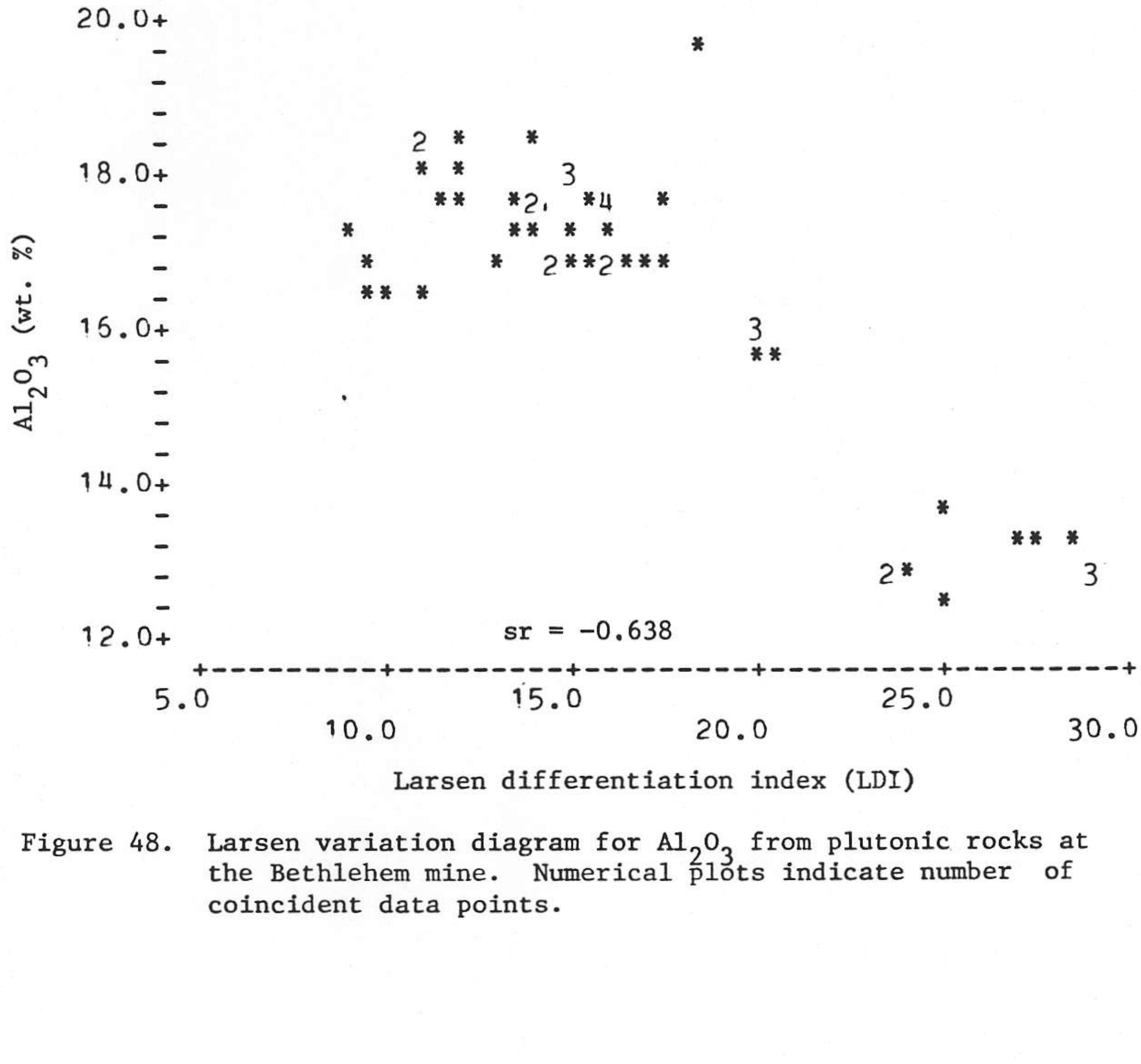

Figure 48. Larsen variation diagram for Al_2O_3 from plutonic rocks at the Bethlehem mine. Numerical plots indicate number of coincident data points.

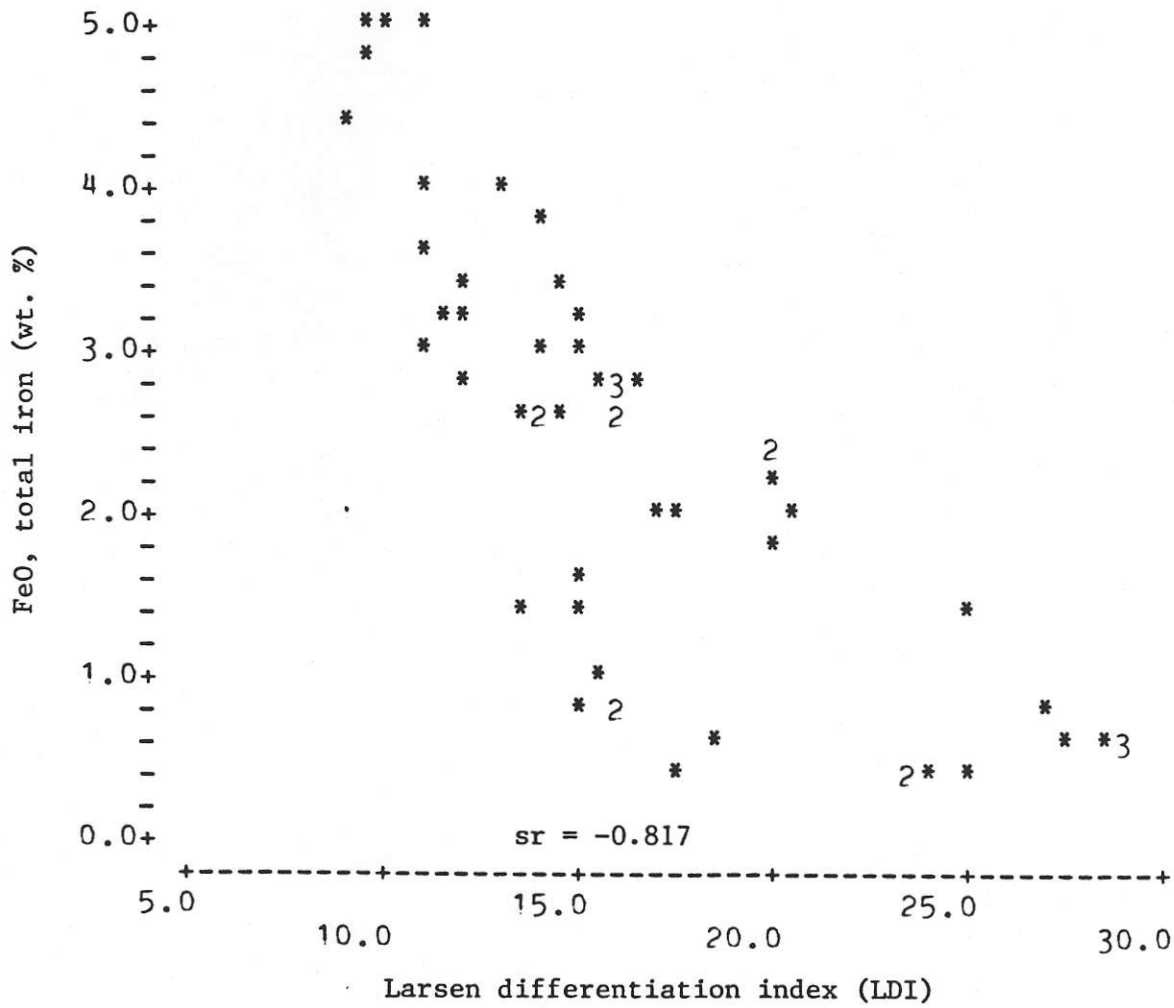

Figure 49. Larsen variation diagram for FeO (total iron) from plutonic rocks at the Bethlehem mine. Numerical plots indicate number of coincident data points.

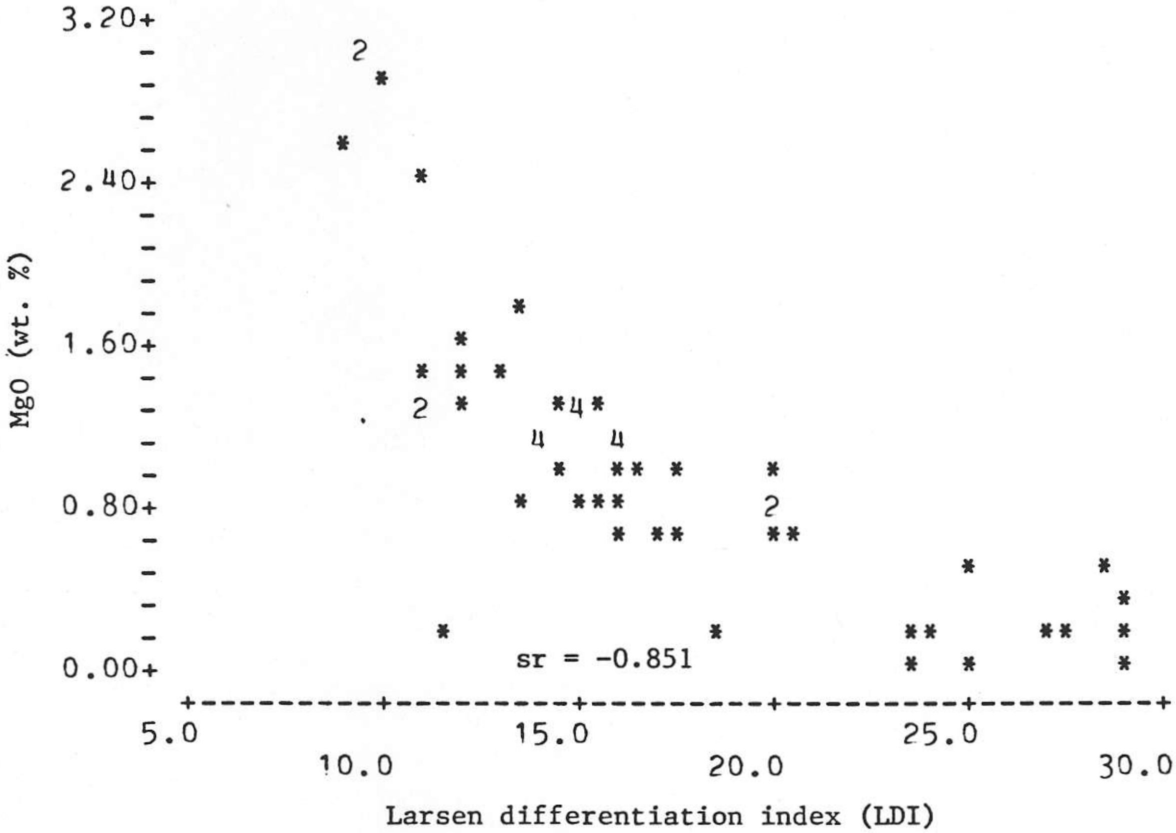

Figure 50. Larsen variation diagram for MgO from plutonic rocks at the Bethlehem mine. Numerical plots indicate number of coincident data points.

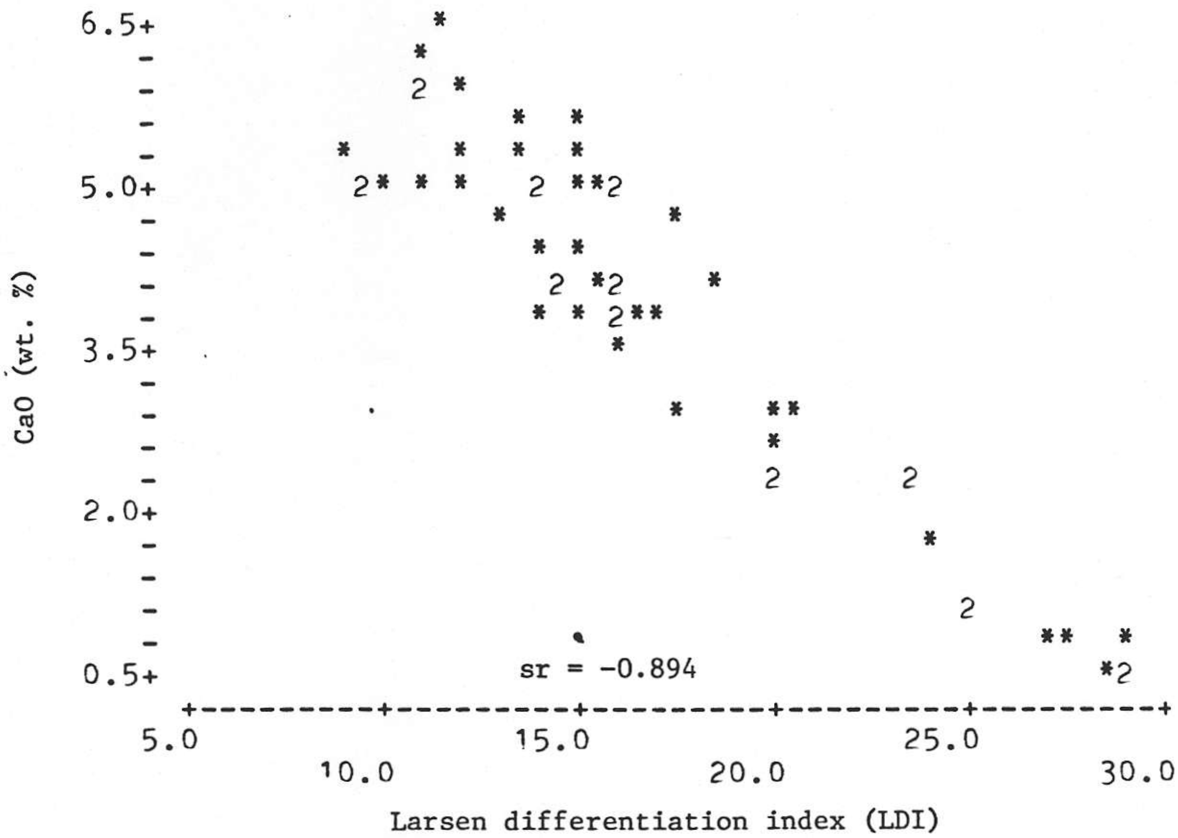

Figure 51. Larsen variation diagram for CaO from plutonic rocks at the Bethlehem mine. Numberical plots indicate number of coincident data points.

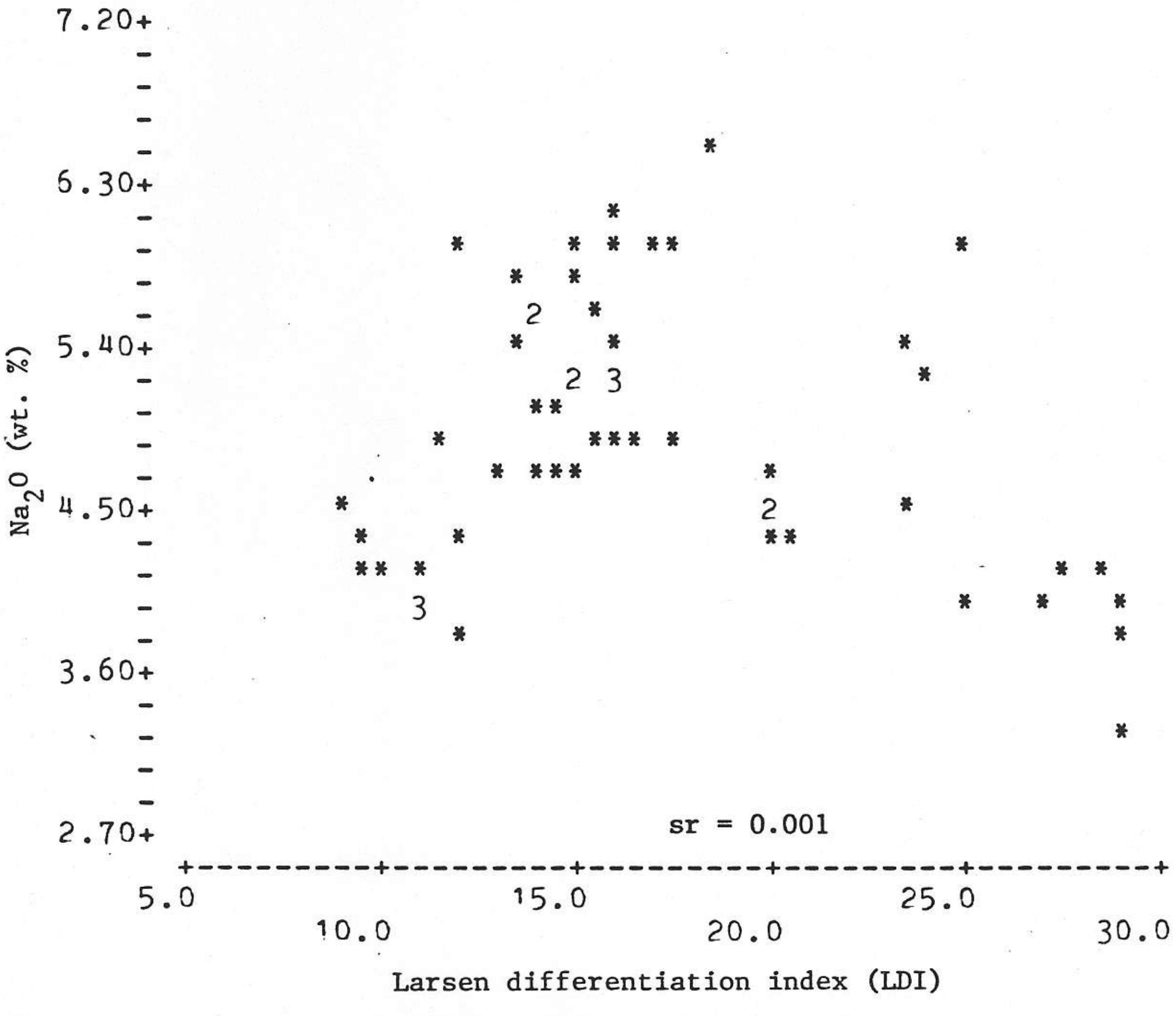

Figure 52. Larsen variation diagram for Na_2O from plutonic rocks at the Bethlehem mine. Numerical plots indicate number of coincident data points.

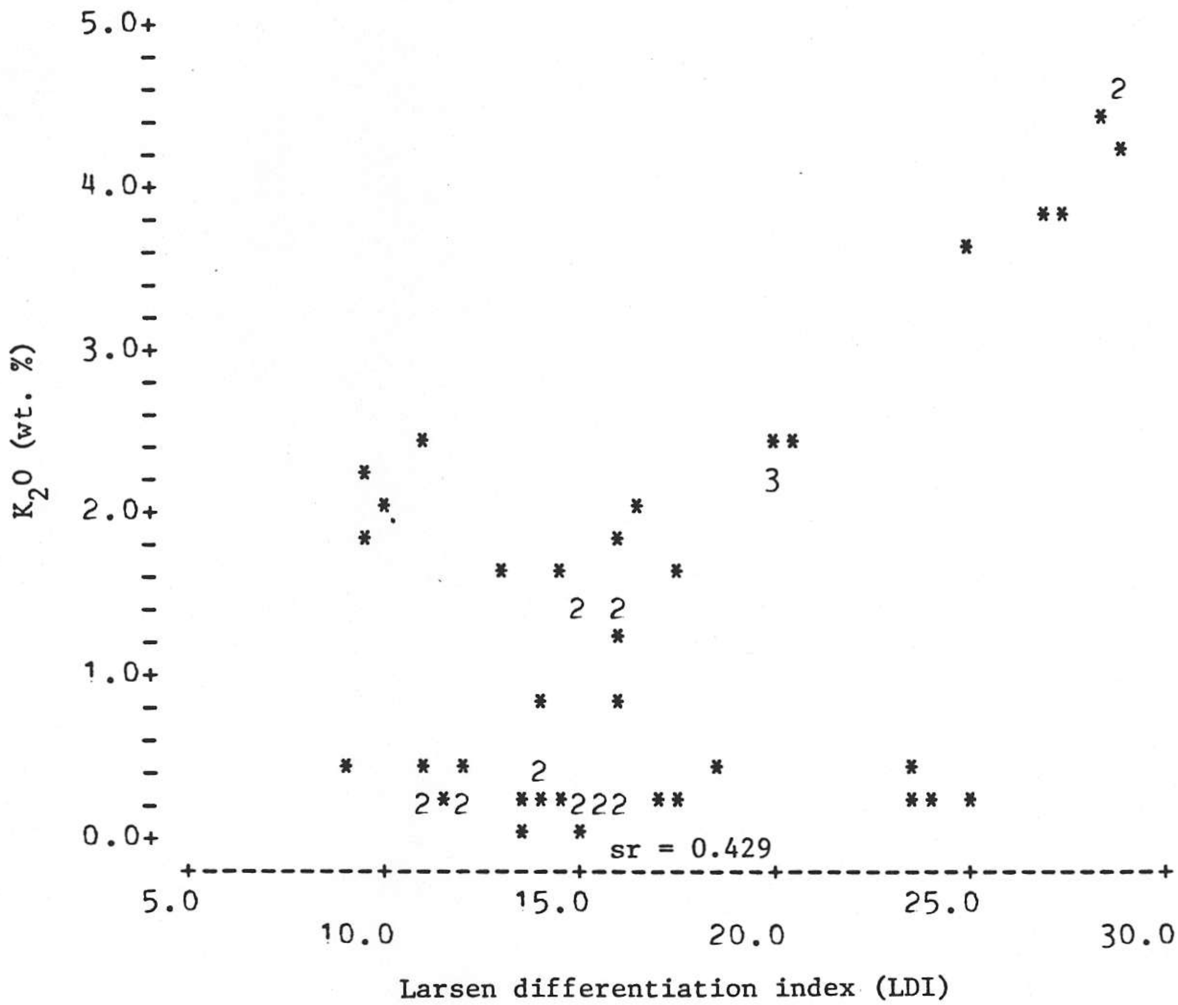

Figure 53. Larsen variation diagram for K_2O from plutonic rocks at the Bethlehem mine. Numerical plots indicate number of coincident data points.

for major oxides display chemical trends closely resembling those for the Guichon Creek Batholith, Na_2O being the only notable exception. The scattering of points at the low end of the FeO_T curve is caused by the low iron contents of highly actinolitic and (or) leucocratic rocks of the Bethlehem leucophase, plagioclase-quartz aplites, and dacite porphyry (sample no. 52).

There is no indication of progressive K_2O enrichment between successive major plutonic phases of the batholith. Consequently, any weak K_2O enrichment trends in the rocks at the Bethlehem mine, and those, if any, associated with Witches Brook Phase magmatism, more likely resulted from differentiation that occurred locally either within the batholith or at the source of the magma. The restriction of potash-rich units found on the Bethlehem property to margins and cupolas of the irregular intrusive apophysis of the Bethlehem granodiorite suggest that they are genetically related to differentiation occurring at the apophysis. Differences in sodium variation trends between the Bethlehem plutonic rocks and major phases and varieties of the batholith may be companion effects since both sodium and potassium are commonly mobilized by the same or similar geochemical mechanisms.

Plutonic rocks from the Bethlehem mine area are rather widely distributed on the SiO_2-K_2O plot of Figure 23. However, they have low K_2O abundances similar to intrusive rocks from the Guichon Creek Batholith and the island-arc regions described earlier. The dacite porphyry unit, in particular, contains unusually small amounts of potash, especially with respect to its relatively high silica content. As shown in Table 20, these rocks have K_2O concentrations that range from 0.05 to 1.98 weight percent and average 0.36 weight percent, but they contain from 63.4 to 69.2 weight percent SiO_2, with an average of

66.2 weight percent. Although these K_2O-deficient dacite porphyries have relatively large quantities of SiO_2, a characteristic in common with the batholith, they appear to be approximately equivalent to the "low K suite" of intrusive rocks recognized by Gulson and others (1972) and Mason and McDonald (1978) in some island arcs of the southwest Pacific.

Minor-Element Variations. Minor-element analyses for total contained copper, molybdenum, lead, zinc, and silver in samples of the plutonic rocks at Bethlehem are listed with major oxide analyses in tables presented previously. Figure 54 shows average (except granodiorite) metal concentrations plotted against the order of intrusion of the Bethlehem plutonic rocks. Bethelehem porphyry has been excluded because it occurs entirely within the Jersey ore zone and is strongly mineralized. With the possible exception of zinc, no temporal trends in metal values are apparent. However, many samples contain small amounts of microscopic, epigenetic copper-sulfide mineralization that would obscure any primary magmatic trends. Moreover, concentrations of lead, silver, and, in part, molybdenum are at or below their respective detection limits, and any trends that may exist cannot be identified at these levels of analytical sensitivity.

Zinc appears to decrease in abundance with decreasing age and increasing fractionation until it increases again with intrusion of the dacite porphyry. Zinc is present in unusually small amounts in Bethlehem leucophase. Marked changes in zinc concentration in Bethlehem leucophase and dacite porphyry closely parallel similar changes in the temporal chemical and mineralogical trends outlined previously, and imply that zinc occurs largely as a primary constituent of the rocks. Indeed,

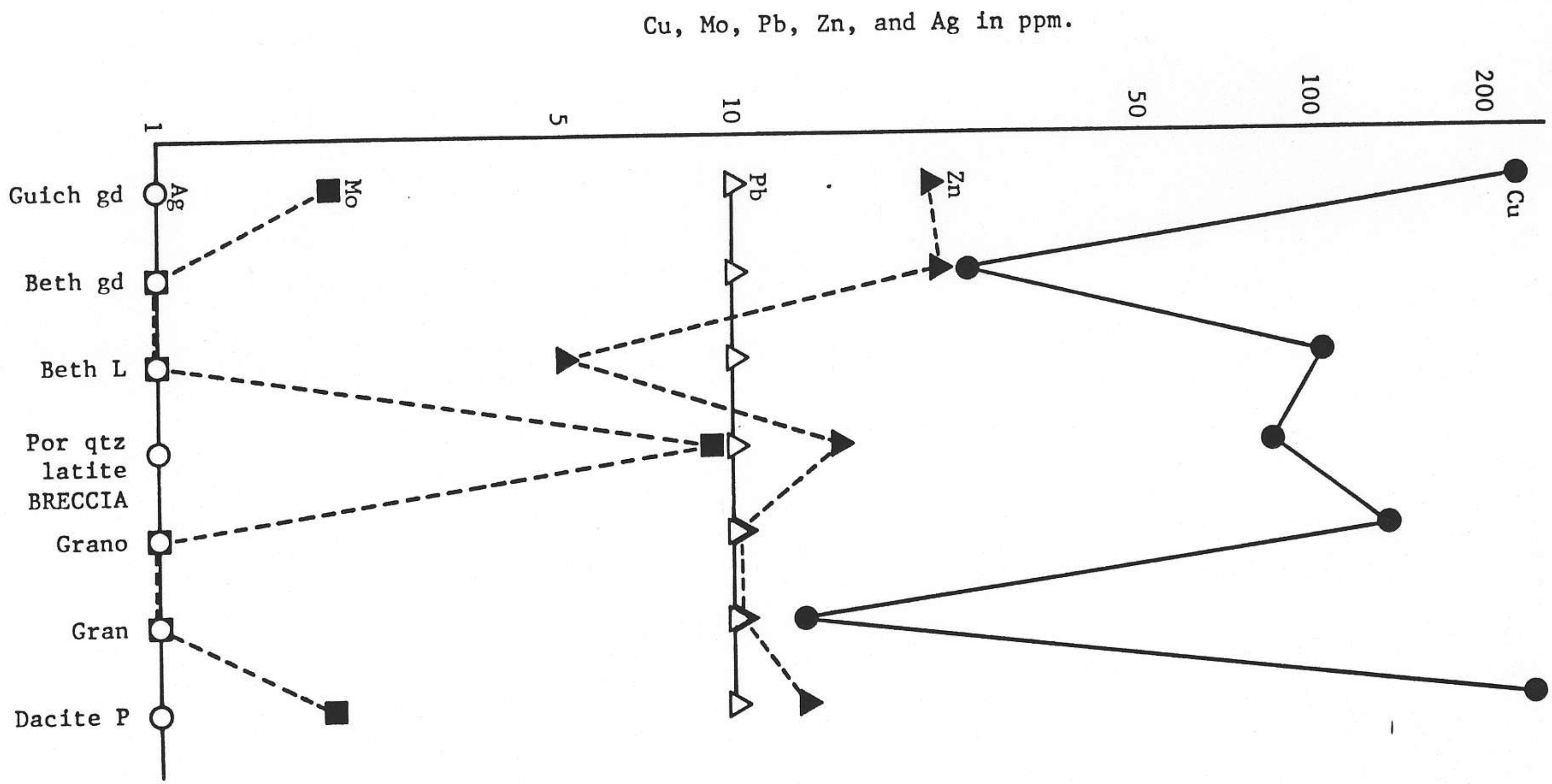

Figure 54. Plots of ~~selected minor element~~ Cu, Mo, Pb, Zn and Ag contents versus order of intrusion of Bethlehem plutonic suite.

average zinc abundances in the plutonic rocks at Bethlehem are in close agreement with those for the major phase and varieties of the Guichon Creek Batholith. The temporal variations for zinc most nearly approximate those of hornblende (cf. Figure 38), and especially those of FeO_T (cf. Figure 45) for which zinc commonly substitutes in the lattice of ferromagnesian silicates. Major decreases in zinc and FeO_T in Bethlehem leucophase probably occurred when these components were flushed out during actinolization of hornblende.

Copper and zinc both show weak negative correlations with the Larsen differentiation index (Figures 55 and 56). For copper, this tendency is attributable to progressively decreasing quantities of mafic minerals that are ordinarily partially replaced by traces of chalcopyrite. In the case of zinc, decreasing abundances of primary zinc-bearing ferromagnesian silicate minerals causes a similar effect.

3 Spaces

Concluding Remarks. Variations in the Larsen differentiation index, bulk rock densities, and the abundances of mineral phases and chemical components of ~~the~~ plutonic rocks exposed at the Bethlehem mine define relatively systematic changes with decreasing age of emplacement. However, all of these trends undergo dramatic reversals upon intrusion of the dacite porphyries. These reversals are documented only for the postbreccia dacite porphyry units, but must apply equally to those of prebreccia age. The Bethlehem leucophase causes highly erratic fluctuations in many of the chemical and mineralogical trends, but it appears to be a local, intergradational variety of normal Bethlehem granodiorite and therefore is probably not of great petrogenetic importance.

Excluding the dacite porphyries and the older Guichon granodiorite,

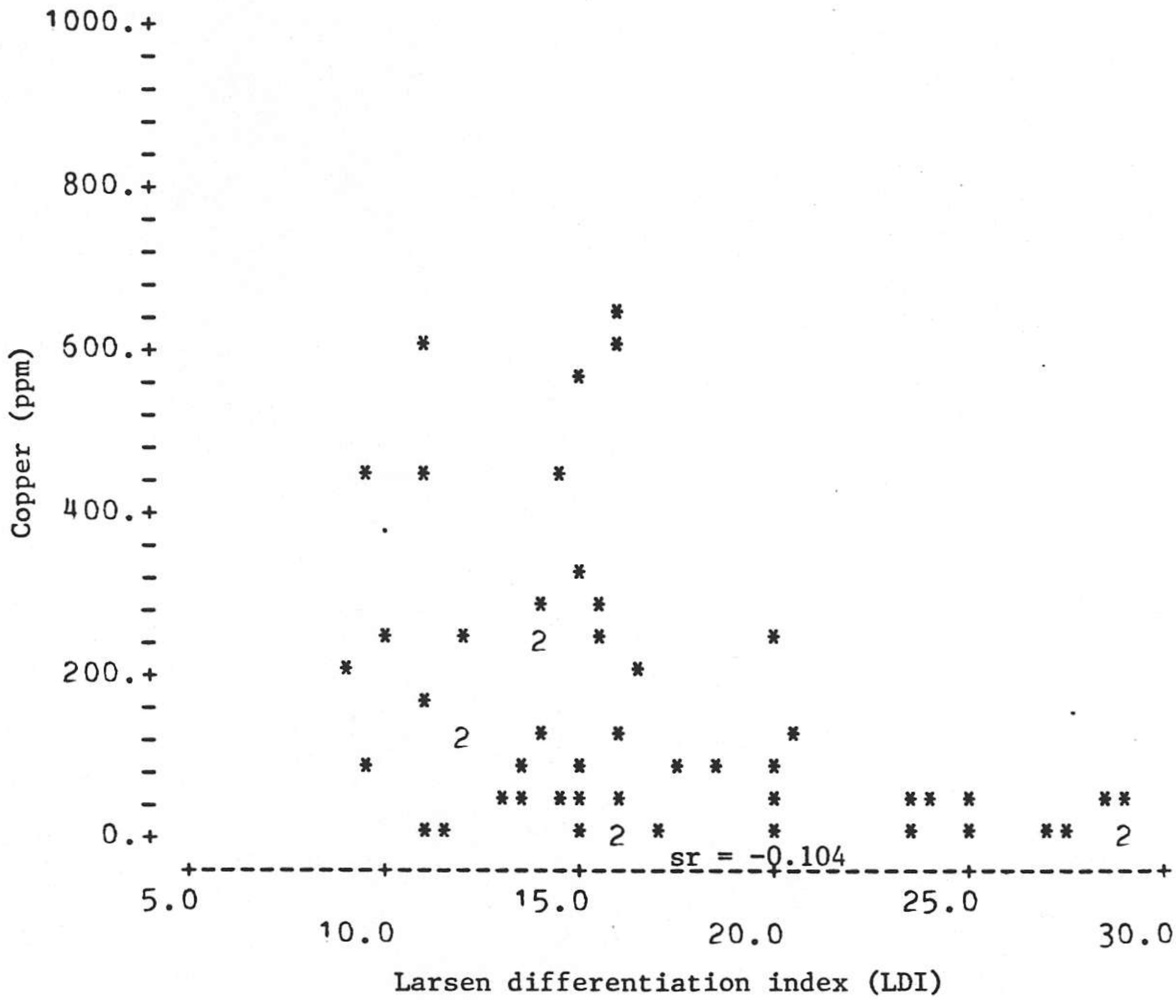

Figure 55. Larsen variation diagram for copper from plutonic rocks at the Bethlehem mine. Numerical plots indicate number of coincident data points. Two data points representing Bethlehem porphyry (nos. 32 and 36 in Table 10) have copper values exceeding 1000 ppm and are not shown on this diagram.

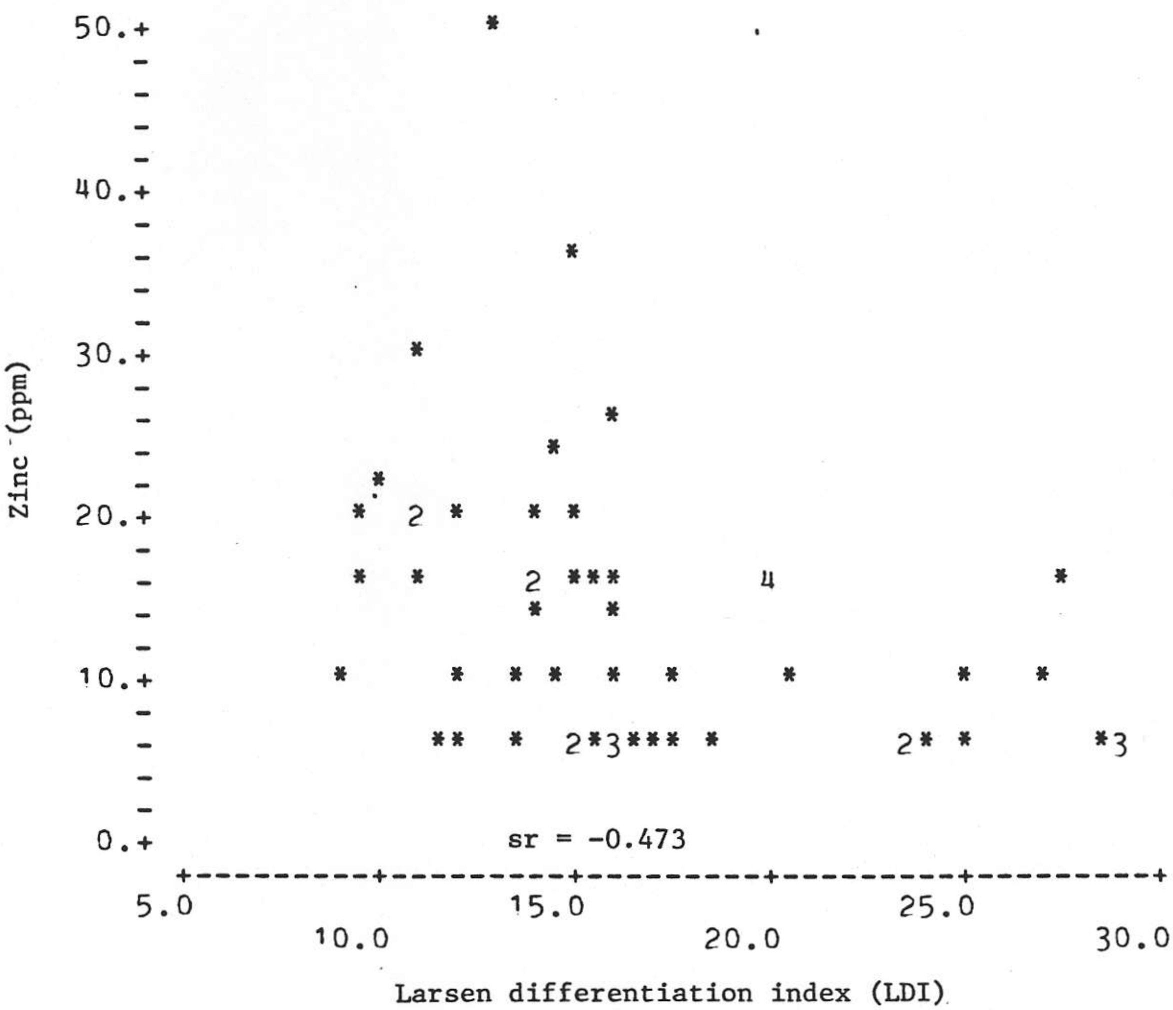

Figure 56. Larsen variation diagram for zinc from plutonic rocks at the Bethlehem mine. Numerical plots indicate number of coincident data points.

the rocks appear to form a coherent differentiation sequence resulting from the progressive fractionation of Bethlehem granodiorite magma in or near an irregular, intrusive ~~intrusive~~ apophysis of the main Bethlehem Phase of the Guichon Creek Batholith. The modest amounts of potash associated with this differentiation sequence may have been derived from Bethlehem granodiorite and (or) the now potash-deficient dacite porphyries possibly by the separate or combined effects of flowage differentiation, filter pressing, and (or) volatile transfer of alkalis. The diffuse, intergradational, irregular distribution of potassium feldspar in Bethlehem granodiorite along parts of its highly digitated, intrusive contact with Guichon granodiorite suggest that flowage differentiation and filter pressing were operative at least locally. These mechanisms may have aided in the formation of many of the leucocratic subvarieties of plutonic rocks at Bethlehem. Northcote (1969) has invoked the volatile transfer of alkalis toward the cooler, low-pressure margins and cupolas of magmas to account for some of the late-stage differentiation in the Guichon Creek Batholith. Therefore, the presence of abundant volatiles associated with porphyry copper mineralization may in part explain why both magmatic and hydrothermal potassium feldspar are locally highly concentrated in mineralized areas. Why some Highland Valley ore deposits contain copious hydrothermal potassium feldspar and others only late-stage potassium feldspar-rich rocks may be chiefly a consequence of the timing between late-magmatic concentration and crystallization of alkalis, and the accumulation or introduction of a hydrous fluid phase combined with the onset of hydrothermal circulation.

The dacite porphyries represent a substantially less differentiated, more mafic and more basic, potash-deficient magma that was intruded during and following development of the potash-rich differentiation sequence. The dacite porphyries may be Bethlehem granodiorite from which most of the alkalis were removed prior to injection into the dike swarm. This interpretation could also explain the more calcic composition of their plagioclases. The dacite porphyry magma was probably derived locally in the cupolas and apophyses of the Bethlehem granodiorite magma chamber, but may ~~could~~ have evolved deeper in the primary magma chamber below the batholith. In the latter case, the porphyritic quartz latite, granodiorite, and granite units could be considered members of the Witches Brook Phase, which might, in part, be the potash-rich equivalents (derivatives?) of the dacite porphyries. Alternatively, the relatively more primative dacite porphyry magma may have ascended directly from much greater depths, perhaps from near the zone of partial melting that originally generated the primary magma for the batholith. However, such a source makes it difficult to explain the abrupt change in compositions and textures of the dikes south of Highland Valley. Such a change is most easily understood if the dikes are viewed simply as periodic injections of the differentiating phases and varieties of the batholith.

Genesis of Breccias and Dacite Porphyries

The association of breccias and dacite porphyries with copper mineralization at Bethlehem was stressed by Carr (1960, 1966) and Wood (1968). Wood (1968) proposed that the breccias formed primarily as intrusion breccias caused by magma stoping along the leading edges of the Bethlehem granodiorite intrusion. However, several characteristics of the breccias would preclude such an origin. These features include: (1) numerous fragments of Bethlehem granodiorite and those of younger porphyritic quartz latite and dacite porphyry; (2) the occurrence of breccia elsewhere than at the contact between the Guichon and Bethlehem units; (3) the absence of Bethlehem granodiorite as matrix material; and (4) the paucity of xenoliths in Bethlehem granodiorite.

Carr (1966) postulated that impermeable "chilled" rinds formed around dacite porphyry magmas that were intruded into cold, well-fractured country rocks, so that the volatiles released during later stages of crystallization were impounded. Explosive release of these volatiles and consequent brecciation occurred when increasing internal pressures exceeded the confining pressures imposed by the host rocks. However, the scarcity of prebrecciation porphyry masses and the comparatively small number of dacite porphyry fragments in most of the breccias (except at the northeast wall of the Jersey pit) indicate that the major episode of dacite porphyry magma emplacement followed, rather than preceded, breccia formation.

The Bethlehem breccias are here interpreted to have originated by explosive release of volatiles trapped in the upper parts of the magma chambers(s) that ultimately produced the dacite porphyry dikes with which brecciation is so closely associated in time and space. A vapor (aqueous fluid) phase may have begun to separate from the dacite porphyry magma(s) as a result of pressure decreases and concommitant crystallization (e.g., Norton and Cathles, 1973; Whitney, 1975, 1977) accompanying the upward emplacement of the melt from deeper levels within the partially crystallized batholith or its underlying, differentiating magma chamber. Higher level intrusion of the prebreccia dacite porphyry dikes probably occurred at this time, and were accompanied or quickly followed by the early, prebreccia, potassic alteration and copper mineralization found in some of the breccias.

Mass transfer of magma across the vapor-saturat~~ion~~ed surface ~~of~~ in a cooling pluton by convection or reintroduction of magma within the partially molten core would, according to Whitney (1975), greatly enhance the formation of a vapor phase. Moreover, he has indicate~~s~~d that small amounts of CO_2 presumably present in the melt would also substantially augment exsolution of the aqueous fluid. More recent experimental work by Whitney (1977) suggests that vapor generation extends to greater depths (7 km) in magmas of granodioritic and quartz dioritic (dacitic) composition, as compared to those of quartz monzonitic composition ~~melts~~ (3-4 km), and that the more basic magmas would intrude closer to the surface and remain partially molten longer, thus providing a source of ~~resulting in substantial~~ vapor generation very close to the surface (volcanism) and for an extended period of time.

Norton and Cathles (1973) and Whitney (1975, 1977) postulate that a vapor saturated cap may form when coalescing, upward-migrating aqueous fluids exsolved from a magma ~~is~~ are trapped by the cooled rind of the pluton. Several features of the Bethlehem breccias suggest that subsequently, in contrast to the simple collapse mechanism of breccia formation proposed by Norton and Cathles (1973), fracturing of the cooled rind and adjacent wallrocks permitted the rapid escape of these volatiles, perhaps expressed at the surface in explosive volcanic venting, with consequent brecciation in a fluidized system as proposed by Reynolds (1954). Features which imply forceful (intrusive) breccia emplacement, rather than collapse, include: (1) the transgressive nature of breccia contacts (see Figure 28), particularly in the Jersey pit (Figure 29); (2) the occurrence, below Bethlehem granodiorite roof rocks, of breccia containing fragments predominately of Guichon granodiorite ~~fragments~~; (3) the heterogeneous distribution of fragment lithologies; (4) the presence of abundant cataclastic matrix, including interstitial rock "flour"; and (5) the rounded shapes of many fragments.

Rapid escape of contained volatiles would have abruptly enhanced crystallization of the adjacent dacite porphyry melt, thus causing the formation of a second "chill" rind, which ~~may have~~ might then trap~~ped~~ much of this melt. However, small quantities of magma probably escaped at this time to form those few areas where the breccia contains dacite porphyry matrix. After compaction and consolidation of the breccias, additional pulses of magma injection, withdrawal, and (or) crystallization accompanied by fracturing and faulting may have broken the second rind and permitted the injection of the postbreccia dacite porphyry intrusions. Repeated tapping of this magma in the tectonically mobil, ~~island~~ volcanic arc setting of the batholith would explain the multiple ages of dacite porphyry emplacement. A significant portion of the more finely crystalline fragments of dacite porphyry, including some of those pinkish aphanitic clasts closely resembling the finely crystalline margins of many of the postbreccia dikes, were probably derived from the initial "chill" rind.

The various breccia masses may be the byproducts of several vapor-saturated caps, or of a single cap that vented along more than one channelway. The lithologic diversity between bodies of breccia and the absence of physical continuity between some, suggest multiple sources, consistent with the expected irregular topography of a magma cupola. Pressures necessary to cause an "explosive" release of trapped volatiles may have resulted simply from the~~ir~~ accumulation of these volatiles in a restricted water-rich magma or from subsequent injection of magma originating at depth in or below the crystallizing batholith.

Regardless of mechanisms, dacite porphyry intrusions and brecciation were accompanied and (or) closely followed by widespread and intense fracturing and associated hypogene mineralization and alteration, which presumably was accomplished by fluids and mineralizers derived from late-stage concentration in the dacite porphyry magma chamber(s).

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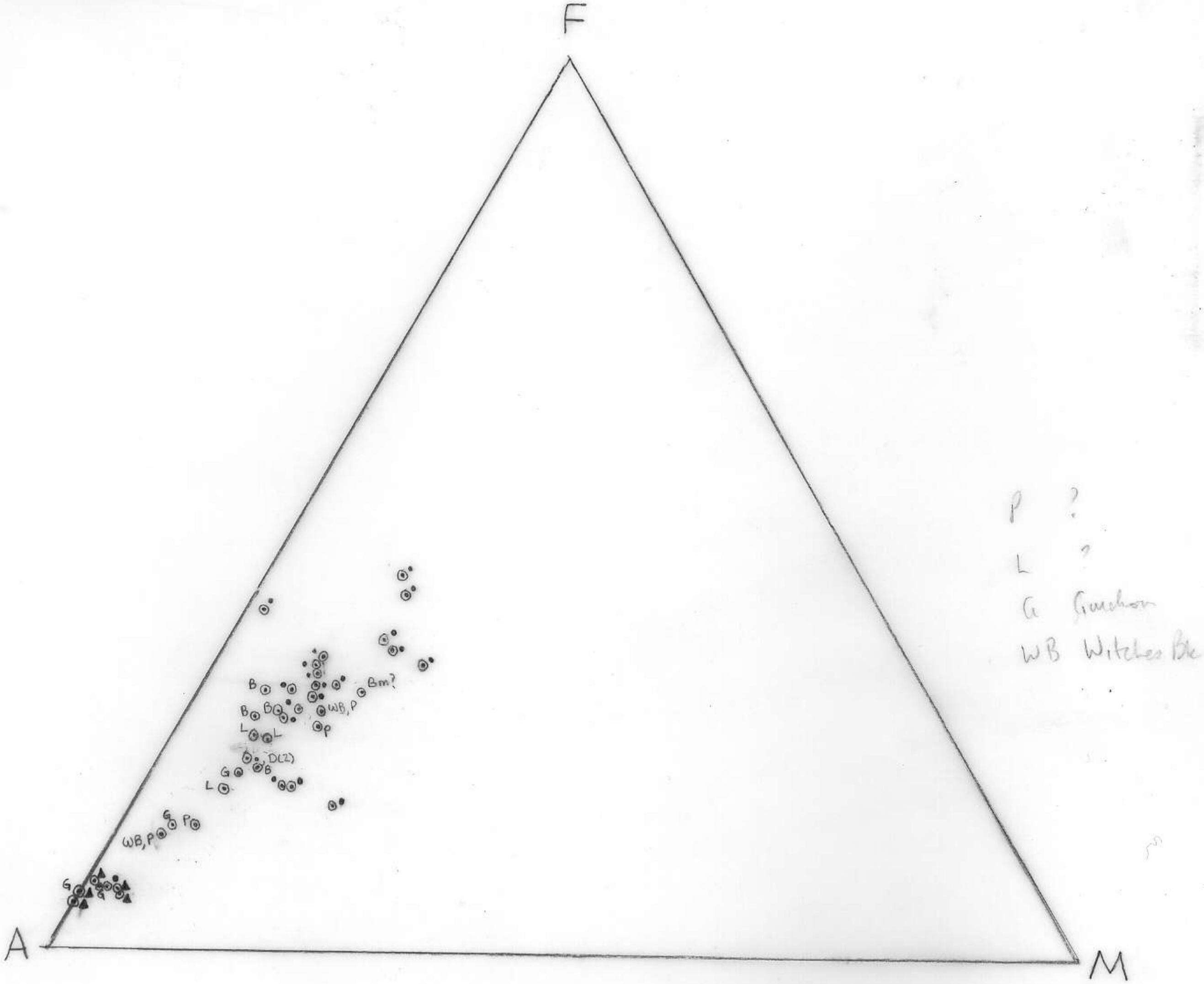

Dykes from the Guichon Creek Batholith

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