Early Paleozoic Alkalic and Calc-Alkalic Plutonism and Associated Contact Metamorphism, Central Virginia Piedmont

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By LOUIS PAVLIDES, J.G. ARTH, J.F. SUTTER, T.W. STERN, *and* HENRY CORTESINI, JR.

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A description of the plutonic and contact-metamorphic history of part of the central Virginia Piedmont.

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[Plates in pocket]

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EARLY PALEOZOIC ALKALIC AND CALC-ALKALIC PLUTONISM AND ASSOCIATED CONTACT METAMORPHISM, CENTRAL VIRGINIA PIEDMONT

By LOUIS PAVLIDES, J.G. ARTH, J.F. SUTTER, T.W. STERN, and HENRY CORTESINI, JR.

ABSTRACT

Early Paleozoic plutonism in the central Virginia Piedmont emplaced the igneous Lahore Complex and the younger Ellisville pluton into deformed metavolcanic rocks of the Chopawamsic Formation as well as into greenschist-facies metasedimentary rocks of the Mine Run Complex. The Lahore Complex consists of a small, altered pluton of serpentine and (or) actinolite-diopside metapyroxenite at its north end that has been intruded by the shoshonitic, potassic-alkalic Lahore pluton. This pluton is composed of a narrow band of pyroxene monzonite on its east margin that grades into the more abundant amphibole monzonite on its west side. The pyroxene monzonite, composed chiefly of andesitic plagioclase and lesser amounts of perthitic microcline, has augite and greenish-brown biotite as less abundant constituents. Accessory epidote occurs as large euhedral magmatic grains as well as granular saussuritic alteration of plagioclase. The Lahore pluton is cut by dikes, some of which may have been derived from the Ellisville pluton.

Calc-alkaline, peraluminous granodiorite characterizes the younger Ellisville pluton. Andesitic plagioclase is the characterizing major mineral, and quartz is generally more abundant than microcline and the less common orthoclase that constitute the remaining major felsic minerals. Brown-to-green biotite is the ubiquitous dimensionally aligned accessory that defines foliation. Myrmekite, amphibole, titanite, and apatite are accessory. Subhedral magmatic epidote that locally encloses allanite is an important and characterizing accessory. Opaques are rare and are probably mostly ilmenite.

The granitoids of both the Lahore and Ellisville plutons have a flow foliation. Emplacement of the Ellisville warped the regional tectonic foliation of the country rocks around its margin. Gravity data suggest that the Ellisville may have an appreciable subsurface extension to the northeast from its surface exposure.

The emplacement of the Lahore and Ellisville plutons into deformed, greenschist-facies country rocks has elevated their metamorphic grade. Muscovite porphyroblasts enclosing fibrolite developed in country rock near the pluton contacts may have formed through late-stage metasomatic alteration by fluids emanating from the plutons. Kyanite, staurolite, and chloritoid, in places closely associated with each other within the contact-metamorphosed rocks of the Chopawamsic Formation and Mine Run Complex, are of prograde metamorphic origin. This thermal metamorphism locally may have contributed to upgrading the original volcanogenic sulfide deposits within the Chopawamsic Formation into the ore deposits that comprise the Mineral district of Virginia. Based on geobarometric (Al-in-hornblende) estimates and order-of-magnitude geothermometric calculations (amphibole-plagioclase geothermometer), a general depth of emplacement of about 18–13 km (6–4.5 kb) is estimated for the Lahore and Ellisville plutons at a temperature of emplacement of about 760°C.

A combination of U/Pb (zircon), Rb/Sr (whole-rock isochron), and $^{40}Ar/^{39}Ar$ (age spectra and isochrons of amphiboles) geochronologic data supports an age of about 450 Ma for the Lahore pluton and a younger age of about 440 Ma for the Ellisville. $^{40}Ar/^{39}Ar$ plateau and Ar/Ar isochron ages for amphibole also indicate that heat from the Ellisville pluton reset some of the amphiboles within the adjacent part of the Lahore pluton and some of the amphiboles within mafic olistoliths in the Mine Run Complex; these amphiboles have $^{40}Ar/^{39}Ar$ plateau and Ar/Ar isochron ages analytically indistinguishable from the age of the Ellisville pluton.

The earliest Silurian $^{40}Ar/^{39}Ar$ plateau ages of the magmatic amphiboles within the Ellisville pluton contrast with the Alleghanian (Carboniferous) metamorphic ages of amphiboles to the east of the Long Branch thrust fault. Juxtaposition of these two terranes by faulting post-date Alleghanian amphibolite-grade metamorphism. Thrusting did not appreciably thermally affect the greenschist-facies rocks west of the Long Branch thrust.

The Lahore pluton is a monzonitic, K-alkalic pluton as characterized on AFM and SiO_2-alkalic diagrams and by its strongly fractionated REE patterns. Its high content of Sr (1027–1540 parts per million [ppm]) and Ba (1644–2060 ppm) and overall enrichment in LILE and other critical chemical features strongly support its shoshonitic character. The Ellisville pluton, however, is primarily of granodioritic composition with characteristics like those generally found in orogenic granodiorites formed along continental margins. Both the shoshonitic monzonites of the Lahore pluton and the granodiorites of the Ellisville pluton could have formed along the ancestral North American (Laurentia) continental margin after accretion of deformed and metamorphosed back-arc and island-arc terranes along the Mountain Run fault zone. The Lahore has an initial $^{87}Sr/^{86}Sr$ of 0.7046 and could have been derived from a mantle source whereas the Ellisville with an initial $^{87}Sr/^{86}Sr$ of 0.7062 could have formed within deep crustal levels. An alternative scenario for the origin of the Lahore is that it formed as a distal, continentward facies from a shoshonitic magma after accretion. The high K-magma could have been supplied from a mantle wedge above a still active subduction zone that had formed the island arc to the east of the Lahore pluton.

INTRODUCTION

Metamorphosed and complexly deformed sedimentary, volcanic, and plutonic rocks of Proterozoic to late

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Paleozoic age comprise the geology of the northern and central Piedmont of Virginia (Pavlides, 1980, 1981, 1989; Pavlides and others, 1980 and 1982b; Drake, 1985; Drake and Lyttle, 1981; Drake and Morgan, 1981; Bobyarchick and others, 1981; Seiders and Mixon, 1981; Wier, 1977; and Wier and Pavlides, 1985). The Piedmont is characterized by low relief with deep weathering that has resulted in extensive saprolitization and concomitant sparse bedrock exposure. Fossils are sparse, and those documented to date are limited to the coeval Quantico and Arvonia Formations of probable Late Ordovician age as summarized by Pavlides and others (1980) and Kolata and Pavlides (1986).

This report considers the geology of the Lahore Complex (formally introduced herein) and the Ellisville pluton and their country rocks, the Chopawamsic Formation and Mine Run Complex. Pavlides (1989) considered the igneous rocks of the Lahore "block" to have been an olistostromal mass rather than of in situ intrusive origin because, in contrast to the Ellisville pluton, they appeared to lack an aureole of contact-metamorphosed rocks. Additional petrographic studies by Pavlides have now identified the presence of the contact-metamorphic assemblage of muscovite with fibrolite at two localities at the northeast end of the Lahore "block." The Lahore Complex is now considered to be a composite intrusive composed of the Lahore pluton and a mafic pluton at its north end, which the Lahore pluton is interpreted to intrude.

During 1980, a trench dug for a gas pipeline across part of the Ellisville pluton and some of its enclosing rocks exposed unweathered rocks at numerous places within the pluton and provided excellent samples for petrographic, chemical, and isotopic study. The age of the Ellisville pluton, formerly the Ellisville Granodiorite of Hopkins (1960), has been determined by both the U/Pb method on zircon, the Rb/Sr method on whole rocks, and by the $^{40}Ar/^{39}Ar$ method on amphibole, as being about 440 Ma. Similarly the age of the Lahore pluton has been determined as about 450 Ma. These ages are an important temporal benchmark in understanding the regional geology of the area.

The name Ellisville pluton rather than Ellisville Granodiorite for the Ellisville rocks has been adopted for several reasons. Since the partial mapping of the Ellisville by Hopkins, monzonitic rocks of the Lahore Complex were included as part of the Ellisville Granodiorite of Hopkins (1960) on the geologic map of Virginia (Milici and others, 1963), thus inadvertently extending the significance of the lithologic term "Granodiorite." In our own mapping of the Ellisville, we found granodiorite as the almost invariable local bedrock exposure. Such granodiorite typically is megacrystic to porphyritic and where weathered to saprolite it may leave a grus or lag concentrate of megacrystic feldspar. Indeed, because of widespread saprolitization such grus is the feature that permits areas to be mapped as granodiorite. However, many areas within the Ellisville mass are free of grus and apparently are made up of a non-porphyritic fine-grained granitoid that has not been found as fresh bedrock. Because there is a possibility that such areas of non-porphyritic saprolite may be underlain by a granitoid other than granodiorite, the non-lithologic term Ellisville pluton is used.

Normative, modal, and chemical analyses and petrographic descriptions of the granitoids of the Lahore Complex and Ellisville pluton are contained in tables within the body of the text as are isotopic data for U/Pb, Rb/Sr, and $^{40}Ar/^{39}Ar$ geochronology. Petrographic descriptions of rocks and electron microprobe data and calculation methods for their minerals are listed in the various appendixes along with descriptions of the analytical techniques used for U/Pb, Rb/Sr, and Ar/Ar methods. For convenience, the tables in the appendices will be referred to by combining the capitalized letter assigned to the appendix with the hyphenated table number in that appendix, for example appendix A table A2 as table A-2.

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REGIONAL SETTING

The rocks described in the Central Virginia Piedmont (fig. 1) by Pavlides (1989) belong to four lithotectonic belts (pl. 1). These belts contain rocks of Proterozoic through Carboniferous age that formed along and offshore of ancestral North America. The westernmost, continental margin belt (pl. 1) consists of the Precambrian Blue Ridge massif (ancestral North America), of which only the Late Proterozoic Catoctin Formation (Ƶc

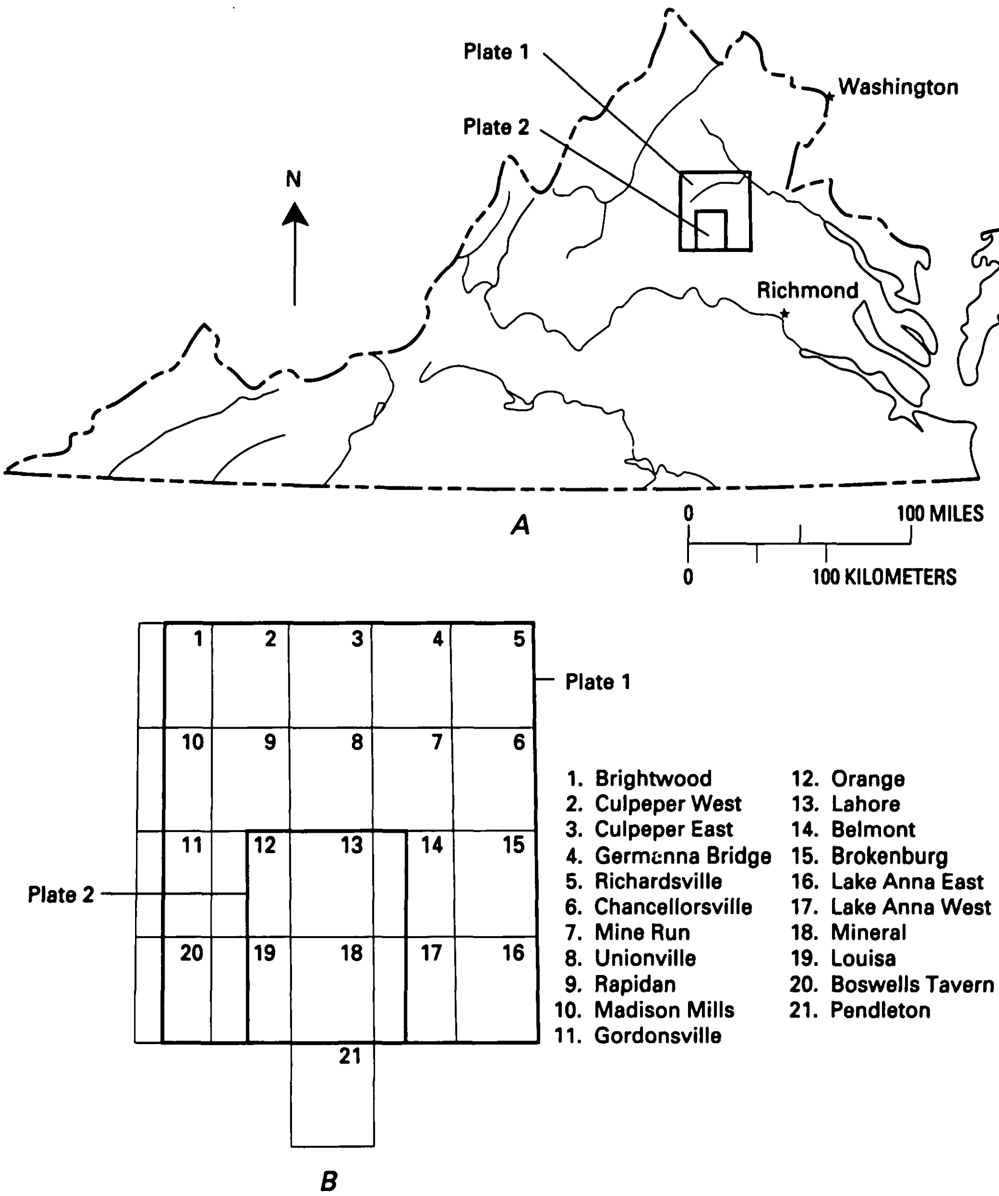


FIGURE 1.—Maps of Virginia showing location of plates 1 and 2 and topographic index maps included in plates 1 and 2 or cited in report.

of pl. 1) is shown. The Catoctin is overlain by an unnamed lenticular quartzite and granule conglomerate (Ꞓq of pl. 1) that forms a basal deposit. Locally the Tomahawk Creek Formation of Pavlides (1990) (Ꞓt of pl. 1), a phyllite- and graywacke-bearing unit intervenes between the Catoctin (Ƶc) and the basal clastic lenses (Ꞓq). The True Blue Formation of Pavlides (1990) (OꞒt of pl. 1) composed chiefly of slate siltstone, lesser argillite, lenses of quartzite and Everona limestone, and minor amounts of chert and ironstone, directly overlies either the Catoctin or the basal clastic lenses. These continental margin deposits are separated from rocks to their east by the Mountain Run fault zone (pl. 1), a major fault along which offshore terrane to the east accreted by thrusting onto the continental margin prior to about 450 Ma. The Mountain Run fault zone subsequently underwent additional movements including strike-slip faulting in the pre-Jurassic as well as late Cenozoic steep normal faulting that produced local scarps (Pavlides, 1987a, 1987b). Successively eastward from the Mountain Run fault (pl. 1) are the back-arc melange terrane of the Mine Run Complex (OꞒmI-IV), an island-arc terrane (Ꞓc and Ꞓt) that comprises the Central Virginia volcanic-plutonic belt and an easternmost, possibly exotic terrane (PzƵp), represented by the Po River Metamorphic Suite (Pavlides, 1989), which will not be discussed in this report.

The continental margin deposits are, in part, coeval to the Mine Run Complex, which is interpreted to be an olistostromal-tectonic block-in-phyllite and (or) schist melange, contained in four imbricated thrust slices, each with its own characterizing exotic block assemblage (Pavlides, 1989 and pls. 1 and 2). The Mine Run Complex melanges are interpreted as having formed in a back-arc marginal sea informally named the Mava basin, which lay between the ancestral continent of North America and an offshore island arc, now represented in Virginia by the Chopawamsic Formation and coeval Ta River Metamorphic Suite (Pavlides, 1989). The island-arc terrane and melange deposits were telescoped progressively westward by thrusting from about the Middle to Late Cambrian (Penobscot orogeny) up through Late Ordovician time. These rocks were episodically folded and faulted during this interval of time (Pavlides, 1989). During as well as following the deformation and metamorphism of the island-arc and back-arc terranes, plutonism occurred and granitoids such as monzogranite of the Goldvein pluton (O€g) were emplaced in the back-arc terrane whereas plagiogranite tonalites (O€pg) were emplaced in the island-arc terrane (pl. 1). An interval of uplift and erosion followed, and this composite terrane then foundered and underwent local sedimentation. To the east (present geographic coordinates) sand and pelitic sediments were unconformably deposited on the volcanic and plutonic rocks of the foundered and eroded island-arc rocks. These sediments now constitute the metasedimentary Quantico Formation (Oq of pl. 1). The unconformity at its base had been recognized and ascribed as Penobscotian by Pavlides (1973) and later was more thoroughly documented (Pavlides and others, 1980) in areas farther to the northeast of plate 1. Farther to the west from the region of Quantico outcrop, unnamed clastic sediments (Ou of pl. 1; see also Pavlides, 1990) were accumulating in what probably were successor basins (or a basin) that had formed over the former site of the back-arc basin. The Lahore and Ellisville plutons were emplaced as post-kinematic intrusions after about 450 Ma. The Mountain Run fault zone that had juxtaposed the melange and continental margin deposits (Pavlides, 1989) underwent additional modification and movement during the Alleghanian orogeny when thrusting and strike-slip faulting caused additional westward telescoping and deformation of the terranes of the Piedmont and the Blue Ridge. The folding, high-grade regional metamorphism and local westward thrusting of the Quantico reflect Alleghanian events and are decribed later. These events also include the emplacement of the Carboniferous granitoids of the Falmouth Intrusive Suite at 300–325 Ma (Pavlides and others, 1982b). The sediments (Ou of pl. 1) west of the Quantico did not undergo high-grade metamorphism but probably were folded during the Alleghanian orogeny.

In the Mesozoic, grabens such as the Culpeper basin and half-grabens containing mostly Triassic terrestrial and some lake-bed sediments and Jurassic mafic flows and sills formed during a regime of tensional tectonics. This tectonism may represent an early episode of continental rifting, related to the eventual opening of the Proto-Atlantic farther to the east.

GEOPHYSICAL FEATURES

Structural and stratigraphic relationships, some not discernable by geologic mapping, are brought out when aeromagnetic and gravity maps are compared with the geologic map. Only a few of these will be discussed below. Both magnetic and gravity highs are associated with melange zone III (O€mIII of pl. 1*A* and 1*B*) of the Mine Run Complex. The mafic and ultramafic blocks it contains are, in part, responsible for its characteristic aeromagnetic and gravity features. Magnetite formed through regional metamorphism (Pavlides, 1989, text and fig. 7*A*) is abundant in the phyllite and schist matrix and in the enclosed mafic and ultramafic exotic blocks and forms regional linear anomalies. This magnetic grain of melange zone III is modified by the Ellisville pluton, which has intruded melange zone III and nearby rocks as a post-kinematic pluton (pl. 1*A*). The irregular oval-shaped magnetic high east of the Lahore pluton and northeast of the Ellisville pluton (fig. 1*A*) may have been caused by magnetite formed through contact metamorphism by these plutons of country rocks as well as possibly by an intrusion just below the present erosion surface on the southeast side of this magnetic anomaly. This intrusion is interpreted as a northeasterly extension of the Ellisville pluton (described below). Other contact metamorphic minerals in country rocks within the area of this magnetic anomaly also support the presence of a subjacent unexposed intrusion. High gravity values along the north part of the Ellisville pluton (pl. 1*B*) rule out significant volumes of the Ellisville pluton here. It may form a relatively thin mass over dense rocks of melange zone III or of the Lahore Complex. A similar thin overhang of Ellisville over country rock may occur along part of the east side of the Ellisville where a magnetic high of the country rock extends into the Ellisville margin (pl. 1*A*).

The geometry of the north and east margin of the Ellisville possibly suggests a general sheetlike shape that may thin here either as an original feature of the pluton or due to subsequent removal by erosion. The sinuous, convex bend of the generally northeast magnetic trend of melange zone III (pl. 1*A*) is related to the shouldering aside of the regionally metamorphosed country rocks by the Ellisville pluton when it was emplaced. Emplaced as a semitabular mass it may have been derived locally from a major feeder fracture. This fracture in part may now be represented by the curved, dikelike, southwest-trending "tail" of the pluton proper, which together form a tadpole-shaped intrusion (see Pavlides, 1989, figs. 1*A* and 1*B*). The westward deflection of the linear regional aeromagnetic anomalies on the west side of the pluton reflects forceful magma emplacement on the west side.

The Ellisville pluton, in its central and southern parts, is characterized by low gravity values (pl. 1*B*) that reflect the contrast of the lower density granodiorite to the higher density country rocks. A less well-defined gravity low extends northeastward from the center of the Ellisville pluton to about the south end of melange zone I (O₵mI of pl. 1*B*) and is interpreted to reflect a deep-seated extension of the Ellisville in that area.

Other gravity anomalies also reflect additional lithologic and structural relationships within the Piedmont in this area. For example, melange zone III with its content of mafic exotic blocks generally is characterized by a gravity high along its trend. Melange zone III appears to dip eastward beneath melange zone II judging from the location of the steepest part of the gravity gradient, which is within melange zone II (O₵mII of pl. 1*B*). Similarly, the Green Springs pluton, which intrudes melange zone IV (O₵mIV of pl. 1*B*), in part, has an associated gravity high that extends several kilometers east of its eastern contact. This pattern suggests subsurface extension of the Green Springs pluton beneath melange zone IV (pl. 1*B*).

The metamafic, high-density rocks of the Catoctin Formation (Ƶc) in the northwest part of plate 1*B* clearly underlie and extend northeastward beneath the Mesozoic basin rocks as indicated by the northeast-trending broad positive gravity anomaly with a closure of 28 milligals (pl. 1*B*). However, the gravity high immediately to the northeast of this broad positive anomaly probably reflects the presence of mafic sills within the Mesozoic basin here as mapped by Lee and Froelich (1989).

The Mountain Run fault zone is strongly delineated by the gravity data. The positive gravity high of the Catoctin has a northeast-trending gravity gradient steeply dipping to the southeast at its contact with and within the Mountain Run fault zone (pl. 1*B*). The gravity low northwest of the Green Springs mass also has a steep southeast-dipping gradient on its north side, a gradient that is a continuation of that described above for the Catoctin. The linearity and steepness of these complementary and continuous gradients suggest that the Mountain Run fault zone is a steep fault in this area. Dextral strike slip of pre-Jurassic(?) basalt-dike age (Pavlides, 1987a, p. 93–94; 1987b, p. 94) is believed to be among the latest major movements along what originally was a thrust fault (Pavlides, 1989). This later faulting probably also imparted the striking linearity to the Mountain Run fault zone. A steep aeromagnetic gradient (pl. 1*A*) also extends from the Catoctin southeastward into the Mountain Run fault zone and further supports a steep attitude here for this fault; it also is consistent with and reflects the linear trend of the fault.

LOCAL STRATIGRAPHIC SETTING

The regional stratigraphic setting was described earlier. A more detailed stratigraphic description is given below for the rocks of immediate interest in the vicinity of the Lahore Complex and the Ellisville pluton (pl. 2).

CHOPAWAMSIC FORMATION

The rocks of the Cambrian Chopawamsic Formation have been interpreted as a volcanic chain that was on the continentward side of a Cambrian island arc. The lithology, petrography, and geochemistry of the Chopawamsic Formation and its associated stratabound sulfide deposits that constitute the Mineral district of Virginia have been discussed elsewhere (Pavlides, 1981, 1989; Pavlides and others, 1982c; Craig, 1980; and Craig and others, 1978). In addition, a number of topical studies of the sulfide deposits of the Mineral district give considerable information about individual deposits (Cox, 1979; Hickman, 1947; Grosh, 1949a and 1949b; Katz, 1961; Miller, 1978; and Sandhaus, 1981). Therefore, the sulfide deposits of the Chopawamsic Formation will not be discussed in this report except as they may pertain to contact metamorphism.

LITHOLOGY AND PETROGRAPHY

The Chopawamsic Formation is a sequence of apparently lensoid, interbedded metavolcanic and metasedimentary rocks that individually have no great lateral extent. In the vicinity of the Ellisville pluton, metasedimentary rocks are in greater abundance than metavolcanic rocks and the Chopawamsic Formation is thicker than it is in areas along strike to the northeast and southwest.

METAVOLCANIC ROCKS

The protoliths of the metavolcanic rocks of the Chopawamsic Formation included mafic to felsic island-arc tholeiites and calc-alkaline varieties as suggested by their geochemical features (Pavlides, 1989; Pavlides and others, 1982c; and Pavlides, 1981). The Chopawamsic has undergone both regional greenschist-facies metamorphism and, in the vicinity of the Ellisville pluton, local amphibolite grade contact metamorphism. However, many of the original lithologies and their features can still be recognized.

The metavolcanic rocks include silicic, intermediate, and mafic varieties, some of which probably were flows, as suggested by their highly vesicular character. Fragmental rocks are mainly breccias and tuffs. Many fine-grained feldspathic schists and phyllites without identifiable fragments are similar mineralogically and chemically to the more distinctive volcanic rocks and may be metatuffs.

Metavolcanic Rocks of Felsic to Intermediate Composition

The silicic metavolcanic rocks (SiO_2 more than 65 percent) of the Chopawamsic Formation are typically light gray, and some have small phenocrysts of quartz or feldspar or both. Some felsites contain albitic plagioclase and quartz in a finer grained quartzofeldspathic groundmass (Pavlides and others, 1982c, fig. 4*A*) and have a high-sodium and low-potassium content (Pavlides and others, 1982c, fig. 5, analyses 2 and 7) and are keratophyres. In some rocks, plagioclase phenocrysts, originally more calcic than albite, are now slightly altered to epidote. The intermediate metavolcanic rocks have 53 to 65 percent SiO_2, are dark to light green, and commonly have a nematoblastic groundmass texture formed by prismatic amphibole intergrown with fine-grained quartz and feldspar.

Metafelsite and intermediate composition wall rock near massive sulfide deposits of the Mineral district are equigranular schists and phyllites and porphyritic and fragmental rocks. Quartz, sodic plagioclase, muscovite, and chlorite are the most common major mineral constituents; contact-metamorphic minerals include biotite, hornblende, garnet, staurolite, kyanite, and chloritoid (discussed later). Disseminated pyrite and magnetite are fairly common within a few hundred meters of massive sulfide bodies. Some of the porphyritic felsite near Mineral (pl. 2*B*) contains quartz-eye and feldspar phenocrysts or both; some of the quartz phenocrysts are as much as 1 cm in diameter and have resorbed margins.

Fragmental Metavolcanic Rocks

Near Mineral (pl. 2), fragmental rocks of the Chopawamsic Formation are fairly abundant. Elsewhere clasts of volcanic rock chips and of well-formed feldspar crystals are found in rocks that probably originated as mixed lithic tuffs and as crystal tuffs. Epiclastic volcanic conglomerate, however, is scarce in the Chopawamsic. Where found, it consists of metavolcanic clasts and rounded quartz grains set in a fine-grained quartz groundmass. Fragmental structures in the felsic and intermediate metavolcanic rocks near Mineral may be irregular and coarse, showing light-colored, fine-grained quartzose or quartz-feldspar rock mosaics, 5 to 10 cm in size, surrounded by various mixtures of mica, chlorite, hornblende, garnet, and pyrite.

Mafic Metavolcanic Rocks

The mafic rocks of the Chopawamsic Formation are defined as having an SiO_2 content of less than about 53 weight percent. Such rocks include greenschist, greenstone, and various dark schists. Greenschist and massive to somewhat schistose greenstone constitute about one-third of the rock sequence drilled along mineralized zones in the Mineral district. Principal minerals of these greenschist are blue-green amphibole, albitic plagioclase, quartz, and also rocks in the greenstone. Epidote, magnetite, and chlorite are minor accessories in greenschist. Dark schist is rich in biotite and chlorite and may have originated as fine-grained volcanic layers of basaltic to intermediate composition or a mixture of clastic sediments with mafic volcanic debris.

METASEDIMENTARY ROCKS

Schists and Phyllites

Schists and phyllites constitute a substantial part of the Chopawamsic Formation in the Ellisville pluton area. Some schists could originally have been tuffaceous rather than pelitic and could have formed by the regional metamorphism of argillized and silicified felsite. Typically, schists and phyllites are light-colored to gray-green, fine- to medium-grained rocks and consist mostly of mixtures of quartz, muscovite-sericite, feldspar, chlorite, garnet, staurolite, and calc-silicate minerals. In thin section, some rocks have fine-grained groundmass mosaics that resemble recrystallized cherty quartz but actually are composed of substantial amounts of untwinned sodic plagioclase intergrown with quartz; such rocks may be volcanic rather than metasedimentary in origin. Similar rocks in which the mosaics are nearly all quartz could be metasedimentary rocks or silicified metavolcanic rocks. Among the minerals formed by contact metamorphism, red-brown poikiloblastic biotite overprints the rock foliation. Garnet porphyroblasts are common, both in metasedimentary as well as metavolcanic rocks of the Mineral district.

Some of the staurolite-bearing rocks apparently are pelitic, but others contain feldspar and quartz-eye phenocrysts, and some of the rocks with staurolite contain feldspar-rich laminae alternating with quartzose (cherty) and micaceous laminae. Such rocks are considered to be volcanic or mixed volcanic and sedimentary. Staurolite from the Arminius deposit (pl. 2*C*) also has been reported in "pelitic quartzites of the wall rock ... and as part of the gangue with pyrite and (or) magnetite and pyrrhotite disseminated rock within the sulfide lens" (Cox, 1979, p. 57). Staurolite in this deposit is also reported to be highly zincian, containing as much as 7.0±2 percent Zn (Cox, 1979, p. 57). The aluminous and iron-rich composition required for staurolite and chloritoid generally signifies a sedimentary origin for rocks containing these minerals. The evidence cited for the volcanic origin of these rocks suggests that the primary iron and aluminum content of the volcanic rock protolith was residually enriched by hydrothermal alteration prior to the metamorphism that formed the staurolite and chloritoid.

CARBONATE

Although not exposed at the surface, marble boulders were reported by Katz (1961, p. 55) on the main dump and surrounding areas of the Sulfur mine (pl. 2*B*). Speculatively, this may represent metalimestone, perhaps part of a reefal unit of an ancient volcanic edifice. Alternately, it may be carbonate chemically precipitated during accumlation of the volcanic rocks as suggested by Gair (1988) for the Ducktown, Tenn., massive sulfide deposit.

TA RIVER METAMORPHIC SUITE

Metapyroxenite, hornblendite, amphibolite, and garnetiferous schist of the Ta River Matamorphic Suite occur in two small thrust slices that are emplaced upon the Chopawamsic Formation and that lie below the Long Branch thrust. The northern of the two thrust slices is exposed along an arm of Lake Anna and the southernmost one is near Mineral (pls. 1 and 2). The lithologic composition and amphibolite grade of the rocks in these thrust slices is similar to that of the Ta River Metamorphic Suite that lies east of the Quantico Formation (pl. 1).

MINE RUN COMPLEX

LITHOLOGY AND PETROGRAPHY

PHYLLITE AND SCHIST

The matrix rocks of the different melange zones of the Cambrian and (or) Ordovician Mine Run Complex, except where contact metamorphosed, are commonly phyllite and metasandstone within the greenschist facies of regional metamorphism. These rocks have been described elsewhere (Pavlides, 1989). Characteristically, they contain chlorite, muscovite, biotite, and, in places, garnet. The exotic blocks enclosed by the matrix phyllite

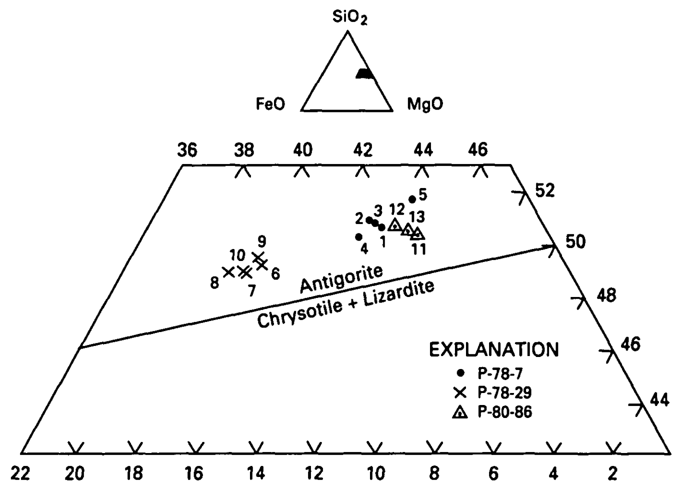


FIGURE 2.—Plot of serpentine compositions with respect to weight percent normalized SiO_2-MgO-FeO. Composition fields are modified from Wicks and Plant (1979, fig. 1). Data compiled from table A-1.

and metasandstone also show mineral assemblages and compositions indicative of greenschist facies except where thermally prograded by the Ellisville pluton.

EXOTIC BLOCKS

SERPENTINITE, TALC SCHIST, AND CHLORITE-ROCK

Antigorite is the characteristic mineral of serpentinite blocks in melange zone III of the Mine Run Complex. Chromian magnetite, chromian penninite, and magnestite are locally abundant. Some serpentinites are highly amphibolitic and a few contain thin, microscopic-to-macroscopic gash-veinlets filled with fine-grained fibrous talc. Chemical analyses of serpentinite blocks within melange zone III (pl. 2*A*) and their chondrite-normalized rare earth element patterns have been published elsewhere (Pavlides, 1989, table 3 and fig. 8c). Their protoliths generally are considered to have been pyroxene-bearing peridotites.

Electron microprobe analyses of serpentine from three different serpentinite blocks within melange zone III are given in table A-1: their location and petrographic descriptions are given in Appendix E-1. The normalized ratios of SiO_2-MgO-FeO from these probe analyses are plotted on a modified diagram for serpentine minerals published by Wicks (1979, fig. 1.29) and Wicks and Plant (1979, fig. 1), and all fall within the antigorite field (fig. 2). Antigorite has also been identified in X-ray analyses of whole-rock serpentinite samples of these rocks (Personal commun., Debby Kay, 1986). The association of antigoritic serpentinite, chromian magnetite and the apparent absence of brucite are mineralogic features observed for regional greenschist-facies-grade serpentinite rocks elsewhere (Coleman, 1971, p. 907; Aumento, 1970).

Blocks of talc schist within melange zone III have a chemical composition that clearly indicates their ultramafic origin (Pavlides, 1989, table 3). A monomineralic block of chlorite within melange zone III may represent black-wall (Pavlides, 1989, table 3) commonly found along the margin of serpentinites (Chidester, 1962).

Greenstones and Greenschists

In addition to serpentinite, a wide variety of other exotic blocks is present in the various melange zones of the Mine Run Complex. Many of these are metamorphosed mafic rocks; chemical analyses, as well as the chondrite-normalized rare earth element (REE) patterns of some of them, have been listed and illustrated elsewhere (Pavlides, 1989). Greenschists (foliated) and greenstones (massive) generally contain pleochroic green and blue-green amphibole, pleochroic green chlorite, plagioclase, epidote-clinozoisite, muscovite, and quartz. Electron microprobe analyses for some of these minerals from various greenstone and greenschist blocks are listed in tables A-2 through A-6. Greenschists have plagioclase (table A-2) that ranges from albite (An_3) to sodic oligoclase (An_{12-17}) as plotted on figure 9. Amphiboles of greenschists in the nomenclatural usage of Leake (1978), and as modified by Rock and Leake (1984) and used in this report, compositionally are calcic amphiboles (table A-3). The majority span the fields of magnesiohornblende and actinolitic hornblende (figs. 3 I*A* and II*A*). Amphibole classification as determined from electron microprobe analyses and computer calculations is discussed in appendix F-1 and in the section dealing with amphiboles from the amphibole monzonites of the Lahore pluton. Epidote has the compositional range of Fe-epidote (Holdaway, 1972), namely Ps_{20-30} (table A-5); it occurs as pseudomorphous replacement of plagioclase, in large granular clots, and as a groundmass constituent. Clinozoisite (table A-5) is present in some greenschist and has a Ps range of 4 to 18 (Fe-clinozoisite to Al-epidote of Holdaway [1972, p. 333]). Locally, it is very abundant in essentially bimineralic amphibole-epidote greenstone. Chlorite generally is a pale-green, pleochroic groundmass constituent in greenschists, greenstones, and serpentinites. The chlorites (table A-4) have been recalculated to include an estimate of H_2O content, and the resulting major element content may not be truly representative of the chlorite. With this caveat in mind the chlorites discussed in this report are plotted on a modified classification diagram (fig. 4) of Foster (1962).

LAHORE COMPLEX

The name Lahore Complex was used informally by Pavlides (1989). It is herein proposed as a formal name. The Lahore Complex consists of the Lahore pluton (Ola and Olp) and the mafic pluton (Olm) at its north end, which the Lahore pluton partially encloses (pl. 2*A*).

The name Lahore is from the community of that name located in the north central part of the Lahore pluton (pl. 2) where saprolite of amphibole monzonite (Ola) is exposed in nearby road cuts. Fresh bedrock of amphibole monzonite is mostly found along streams or their nearby enclosing slopes. Pyroxene monzonite (Olp) bedrock is exposed in fields along the west side of Route 522 near the north end of the pluton. The rocks within the mafic pluton of the Lahore Complex are poorly exposed in a few places at its north end (pl. 2*B*). The relative and isotopic ages of the Lahore pluton are discussed later in the section on Geochronology.

GRANITOID NOMENCLATURE

The nomenclature for plutonic rocks used in this report is that recommended by the International Union of Geological Sciences or IUGS (Streckeisen, 1976). The rock classification is determined by the modal composition of plutonic rocks as related to their ternary components of quartz, alkali feldspar, and plagioclase (fig. 5). The granitoid rocks of the Lahore pluton of the Lahore Complex are monzonites (tables 1 and 2) and their characterizing accessory minerals are used to subdivide them into pyroxene monzonites and amphibole monzonites. However, the chemical composition of these rocks (tables 3 and 4) is not comparable with the average chemical composition of monzonite cited in the literature. For example, the Lahore monzonites have MgO and CaO contents higher than that for average monzonites (compare tables 3 and 6 with Hyndman, 1985, tables 3–7). Indeed the CaO and MgO contents of the Lahore monzonites approximate those of diorite and gabbro as a comparison of the above-cited tables indicates. On the chemical classification scheme of De La Roche and others (1980), the Lahore plutonic rocks fall mostly in the monzogabbro field of the R1-R2-diagram (fig. 5*B*). Therefore, although the IUGS classification scheme is used herein for international nomenclatural conformity, it should be recognized that the granitoids of the Lahore pluton are not chemically compatible with such a purely mineralogic classification. The mineralogic and chemical aspects of the Lahore pluton rocks are interpreted as representing a shoshonitic suite, which is discussed more fully later under Geochemistry.

LAHORE PLUTON

The Lahore pluton consists of pyroxene monzonite and amphibole monzonite. The dark-gray to black, fine- to medium-grained, massive to faintly foliated pyroxene-bearing monzonite on the east side of the pluton grades westward into mesocratic, fine- to medium-grained, generally strongly foliated, amphibole-rich monzonitic rocks that comprise the bulk of the granitoid mass (pl. 2*A*). Foliation in the amphibole-bearing monzonites is commonly defined by the pronounced alignment of long, tabular crystals of feldspar and less so by the alignment of the ubiquitous amphibole.

MINERALOGY AND PETROGRAPHY

PYROXENE MONZONITES

In general, the pyroxene monzonites have a color index of 36 to 44. Their modal composition and related petrographic description are given in table 1.

Pyroxene: Large, unaltered, microscopically colorless, locally twinned, nonpoikilitic and poikilitic pyroxene (fig. 6) is an abundant constituent. The presence of magnetite in these rocks suggests that the pyroxenes contain both FeO and Fe_2O_3. Electron microprobe analyses (table B-5) calculated on the basis that both FeO and Fe_2O_3 are present indicate that the pyroxene is in the compositional range of augite (fig. 7). Pyroxene poikilitically encloses apatite, opaque oxides, and small crystal of biotite and plagioclase (fig. 6).

Plagioclase: A modally abundant constituent that occurs as zoned and unzoned crystals. Some plagioclase crystals have saussuritized cores and clean, albitic rims (fig. 8). Zoned plagioclase from pyroxene monzonite (table B-6A) has core compositions ranging between labradorite-bytownite (analyses 2, 6, 10, and 12) and rim compositions (analyses 4, 8, 11, 14, and 20) in the range of sodic andesine. The average composition of zoned plagioclase is andesine (table B-6A, nos. 5, 9, and 15). Unzoned or poorly zoned plagioclase grains (table B-6A, analyses 23–26) are generally andesine. The average compositions of zoned and unzoned plagioclase (table B-6A, nos. 1, 5, 9, 15, 19, and 26) are plotted on the Or-Ab-An diagram of figure 9.

Potassic feldspar: Fine-grained microcline is an important groundmass mineral, constituting up to 28 percent of some of these rocks (table 1). Its range in chemical composition is given in table B-7A. The BaO content in the potassic feldspar varies broadly in different grains, from as low as 0.58 percent in analysis 16 in table B-7A, to as much as 1.21 percent in analysis 28 of table B-7A. Potassic feldspar clearly has formed later than plagioclase, which it locally replaces (fig. 8*B*) in some pyroxene monzonite.

Biotite: Greenish-brown biotite is an abundant medium-grained, groundmass accessory and occurs also as small chadacrysts in poikilitic pyroxene. The chemical composition of groundmass biotite is listed in table B-8A and is mineralogically characterized in figure 10. Spectrophotometric and wet chemical analyses by H. Smith and W. d'Angelo (1984) on a biotite concentrate from specimen P-81–10 indicate that it has a total FeO content of 17.1 percent, of which 3.4 percent is Fe_2O_3 and 14.0 percent is FeO. H_2O^+ is 2.2 percent and H_2O^- is 0.1 percent. The total FeO of this analysis contrasts with the total FeO (for a 3 point average) for a biotite from this rock, determined by electron microprobe analysis, and which is 18.17 percent (table B-8A, no. 4).

Magnetite: The opaque oxide is crystalline magnetite and is an important accessory that imparts a moderate magnetic susceptibility to these rocks. It commonly occurs as discrete euhedral crystals.

Apatite: Euhedral small crystals of apatite are accessory and occur in the groundmass and as inclusion in pyroxene.

Amphibole: Single grains of amphibole are rare in pyroxene monzonite. Locally, however, pyroxene occurs enclosed, with irregular contacts, in the cores of amphibole grains (fig. 11). Such amphibole is interpreted to have formed by alteration from pyroxene during a later stage of crystallization of pyroxene monzonite when the magma became richer in H_2O. Most such amphibole is present in the gradational zone between pyroxene and amphibole monzonites.

Quartz: Sparse, fine grains of quartz occur as a groundmass constituent in several rocks. However, it is not present as a normative mineral in these rocks (see analyses 1–3, table 1).

Epidote: A fine-grained, subhedral to anhedral minor constituent. Electron probe analyses (table B-9, analyses 1 and 2) indicate that compositionally it is Ps_{25} or an Fe-epidote (Holdaway, 1972, p. 333).

AMPHIBOLE MONZONITES

The bulk of the Lahore granitoid mass consists of rocks that grade from amphibole monzonite to amphibole quartz monzonite in modal composition (fig. 5). The amphibole monzonites of the Lahore block are typically mesocratic, medium-grained and well-foliated rocks and have a perceptible magnetic susceptibility (outcrop and hand specimens attract hand-held magnets such as stud finders). The marked foliation of these rocks is mostly imparted by the alignment of long tabular crystals of feldspar rather than of the associated biotite or hornblende. However, in detail, the feldspar alignment is not rigorous; indeed, many crystals lie at some small angle to the overall foliation of the rock. Modal analyses of these rocks are given in table 1 and their ternary compositions

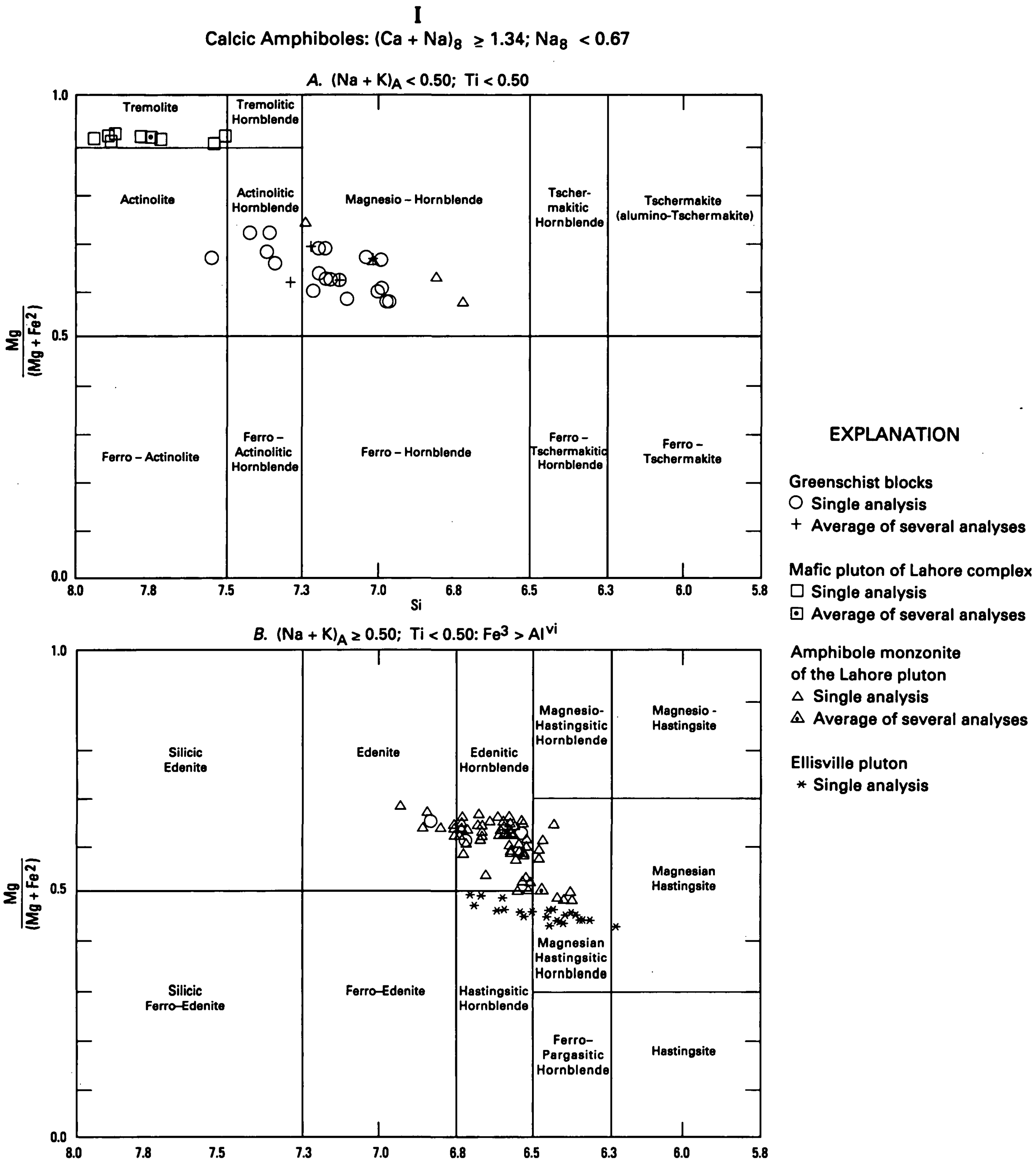


FIGURE 3.—Diagrams showing amphiboles from the Lahore and Ellisville plutons and some of the enclosing country rocks. Diagrams are from Rock and Leake (1984, fig. 1).

I. Amphiboles from (1) greenschist blocks within melange zone III of the Mine Run Complex listed in table A-3; (2) mafic pluton of the Lahore Complex listed in table B-3; (3) amphibole monzonite of the Lahore pluton listed in table B-10; (4) Ellisville pluton listed in table C-6.

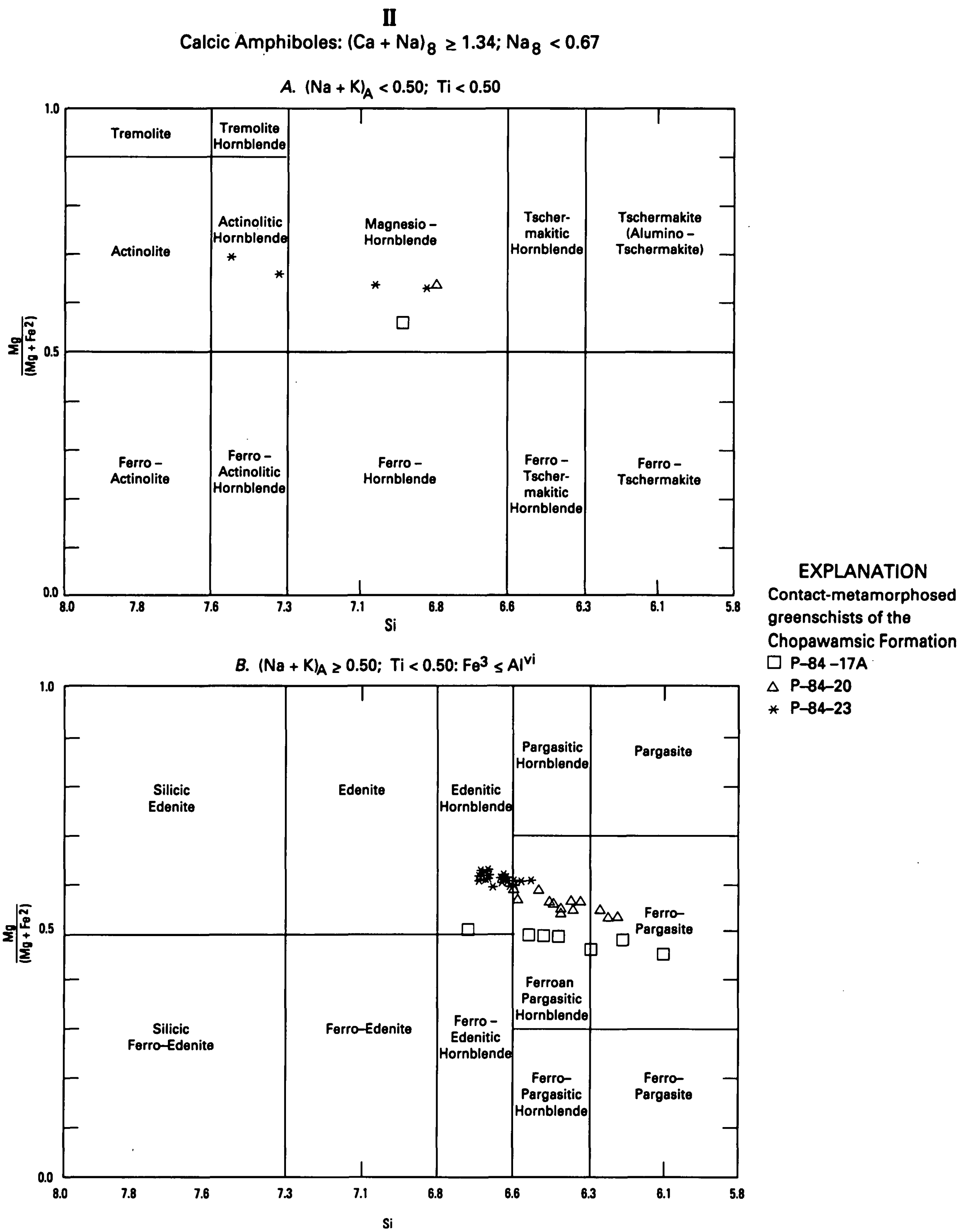


FIGURE 3.— II. Amphiboles from contact-metamorphosed greenschists of the Chopawamsic Formation listed in table D-9.

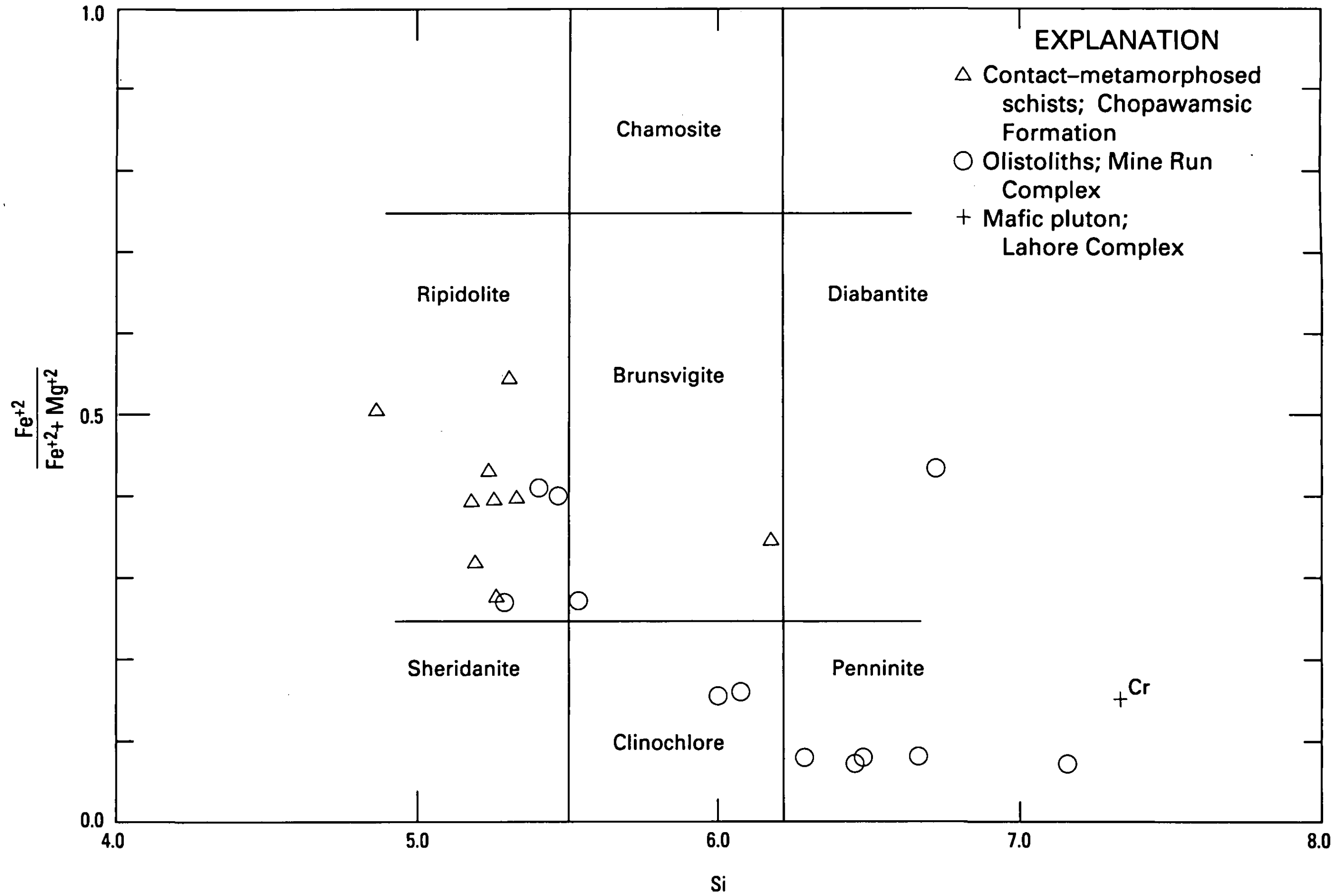


FIGURE 4.—Chlorites from contact-metamorphosed schists of the Chopawamsic Formation, olistoliths of the Mine Run Complex and from the mafic pluton of the Lahore Commplex plotted on the chlorite classification diagram modified from Foster (1962, fig. 9). Analyses are listed respectively in tables A-4, B-4, and D-7.

are plotted in figure 5*A*. The most abundant feldspar is potassic, most commonly microcline, and less commonly orthoclase. Plagioclase and quartz occur in varying but lesser amounts. The dominant dark mineral is amphibole, with biotite generally being present in lesser amounts. Pyroxene is generally less abundant than biotite.

Plagioclase: Fine- to medium-grained subhedral and anhedral plagioclase occurs as a groundmass constituent. It is commonly altered to a mass of small epidote-zoisite grains. The amount of saussuritic alteration varies in different rocks and locally plagioclase crystals may be completely pseudomorphed. Plagioclase saussuritization also is common in the pyroxene monzonites described above. In places, fine-grained white mica also occurs as an alteration that clouds plagioclase. Plagioclase occurs as both untwinned and twinned crystals and in some amphibole monzonites, it is zoned. Electron microprobe analyses of optically zoned plagioclase from amphibole monzonite are listed in table B-6B. Some plagioclase has cores that are more calcic than rims (analyses 25–27 and 29–31). Other plagioclase grains have cores less calcic than rims but with dissimilar compositions at two different places in the rim (analyses 34, 35, 37 and 42, 44, 46). These asymmetrical reverse zoned grains are enigmatic. They may be artifacts of the nonrigorous visual estimate made of edges and centers of grains poorly defined under the electron microprobe optics. Commonly, plagioclase has clear, sodic rims, generally where in contact with potassic feldspar. Small grains of plagioclase are common inclusions within poikilitic microcline megacrysts.

Potassic feldspar: Microcline, white in color in outcrop, is characterized in this section by gridiron twinning. In some rocks, orthoclase is also present. Microcline occurs conspicuously as long, perthitic and nonperthitic tabular megacrysts. Where perthitic, it has the structure of thread (most common), ribbon, and patch perthite. Megacrystic microcline is inclusion-free as well as sparsely poikilitic, commonly containing small inclusions of quartz or plagioclase as well as enclosing

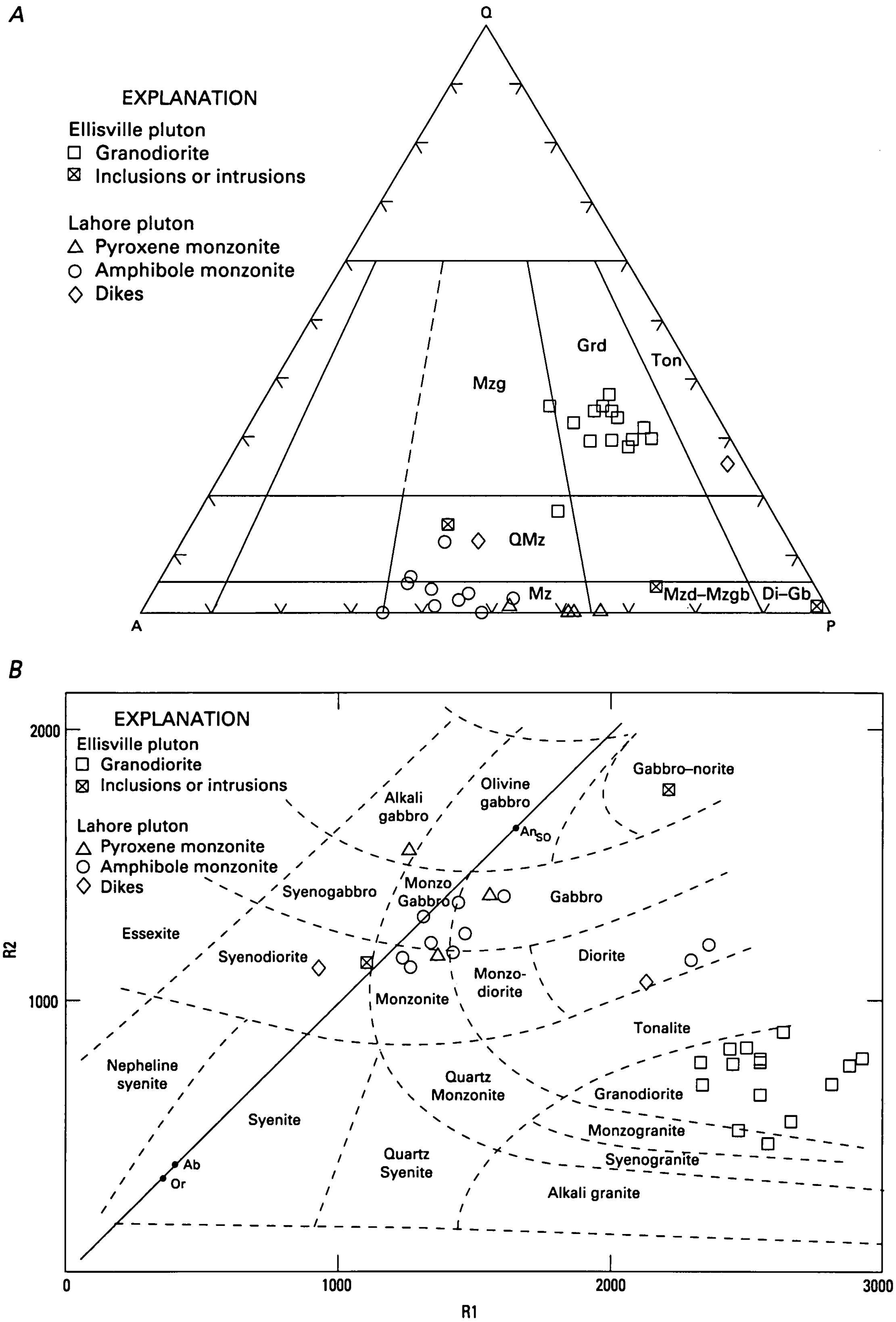


FIGURE 5.—Diagram showing composition fields of the granitoids of the Lahore and Ellisville plutons on (*A*) modal A-Q-P diagram of Streckeisen (1976). Fields are: Di-Gb, diorite-gabbro; Grd, granodiorite; Mz, monzonite; Mzd-Mzgb, monzodiorite-monzogabbro; Mzg, monzogranite; QMz, quartz monzonite and Ton, tonalite (*B*) chemical R1-R2 diagram of De La Roche and others (1980). R_1=4Si-11(Na+K)-2(Fe+Ti); R_2=6Ca+2Mg+Al

TABLE 1.—*Normative and modal compositions of monzonites (A and B) and dikes (C) of the Lahore pluton*

	A. Pyroxene monzonite				B. Amphibole monzonite										C. Dikes	
TABLE NO.	1	2	3	4	5	6	7[1]	8	9	10	11[1]	12	13	14[1]	15	16
FIELD NO.	P-78-53	P-81-10A	P-81-10	P-80-84	P-80-66	P-80-68	P-81-12	P-81-14	P-81-13	P-80-70	P-81-11	P-78-52	P-80-72	P-81-15	P-80-74A	P-80-75
MAJOR OXIDE COMPOSITION (WATER-FREE): calculated from table 3 (complete chemical analyses and analytical methods are given in table 3)																
SiO_2	51.6	52.6	52.9	56.4	54.9	55.0	56.0	56.8	56.6	56.3	57.0	57.8	57.8	57.8	57.9	63.8
Al_2O_3	14.7	15.6	15.6	15.0	16.2	15.0	16.5	16.4	17.2	14.1	16.4	14.2	16.7	15.4	18.1	16.2
Fe_2O_3	3.3	3.4	3.6	2.7	3.5	3.4	3.2	2.8	3.5	3.4	3.0	2.8	2.6	2.6	2.5	2.4
FeO	5.8	5.2	5.2	3.9	4.3	4.1	4.2	4.2	3.1	3.7	4.2	4.0	3.0	3.3	2.7	2.1
MgO	6.9	5.8	5.8	5.7	4.5	6.0	4.0	4.3	3.6	6.5	3.7	5.3	4.2	4.9	3.0	2.7
CaO	9.0	8.4	8.3	7.6	7.4	7.5	6.6	6.4	6.2	7.5	6.0	6.9	6.0	6.4	5.9	5.8
Na_2O	2.5	2.5	2.5	3.0	2.8	2.8	2.8	2.8	2.8	2.6	3.0	2.9	3.4	3.0	4.7	4.2
K_2O	4.3	4.5	4.2	4.4	4.7	4.7	5.1	4.7	5.6	4.5	5.3	4.8	5.1	5.3	4.4	1.9
TiO_2	1.0	1.0	1.0	.5	.8	.7	.8	.9	.7	.7	.8	.7	.6	.6	.4	.6
P_2O_5	.8	.8	.8	.5	.7	.6	.7	.6	.6	.6	.6	.6	.5	.5	.3	.2
MnO	.2	.1	.2	.1	.2	.2	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
CO_2	.02	.02	.01	.06	.07	.02	.02	.02	.02	.01	.01	.02	.04	.01	.02	.02
Total	100.12	99.92	100.11	99.86	100.07	100.02	100.02	100.02	100.02	100.01	100.11	100.12	100.04	99.91	100.02	100.02
NORMATIVE MINERAL COMPOSITION (WEIGHT PERCENT)																
Q	-	-	-	1.0	1.7	.1	2.6	4.2	3.1	2.5	3.1	3.8	1.9	2.4	-	17.2
or	25.5	26.7	24.9	26.1	27.7	27.8	30.2	28.0	33.4	26.4	31.3	28.4	30.0	31.1	25.8	11.3
ab	20.3	20.8	20.9	25.5	23.3	23.3	23.4	23.5	23.4	22.4	25.0	24.3	29.2	25.7	39.5	35.9
an	16.3	18.2	19.1	14.3	18.0	14.7	17.4	18.2	17.9	13.5	15.9	11.8	15.0	12.8	15.5	19.4
wo	9.6	7.7	7.2	8.2	5.7	7.5	4.7	3.9	3.6	8.4	4.1	7.6	4.8	6.5	4.8	3.2
en	6.4	9.2	13.1	14.3	11.2	15.0	9.9	10.8	8.9	16.2	9.1	13.3	10.4	12.1	5.5	6.8
fs	2.4	3.4	4.8	4.3	4.0	3.9	4.0	4.3	1.9	3.1	4.2	4.2	2.7	3.1	1.7	1.1
fo	7.5	3.8	.9	-	-	-	-	-	-	-	-	-	-	-	1.5	-
fa	3.1	1.5	.4	-	-	-	-	-	-	-	-	-	-	-	.5	-
mt	4.8	4.9	5.2	3.9	5.0	4.9	4.6	4.0	5.1	4.9	4.3	4.0	3.8	3.8	3.7	3.5
il	1.9	1.9	1.9	1.0	1.5	1.3	1.6	1.6	1.3	1.3	1.5	1.2	1.1	1.2	.81	.1
ap	2.0	1.8	1.8	1.3	1.8	1.5	1.6	1.4	1.4	1.3	1.4	1.4	1.1	1.2	.8	.5
cc	.05	.05	.02	.14	.16	.05	.05	.05	.05	.02	.02	.05	.09	.02	.05	.05
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
di	18.5	14.7	13.8	15.8	10.9	14.2	9.0	7.6	6.9	16.0	8.0	14.6	9.1	12.4	9.2	6.0
di-wo	9.6	7.7	7.2	8.2	5.7	7.5	4.7	3.9	3.6	8.4	4.1	7.6	4.8	6.5	4.8	3.2
di-en	6.4	5.2	4.8	5.8	3.9	5.4	3.1	2.6	2.7	6.4	2.7	5.3	3.4	4.7	3.4	2.4
di-fs	2.4	1.9	1.8	1.7	1.4	1.4	1.2	1.0	.6	1.2	1.2	1.7	.9	1.2	1.0	.4
hy	-	5.6	11.3	11.0	9.9	12.1	9.6	11.4	7.6	11.7	9.5	10.5	8.7	9.3	2.8	5.0
hy-en	-	4.0	8.2	8.5	7.3	9.6	6.9	8.2	6.2	9.8	6.5	8.0	6.9	7.4	2.1	4.3
hy-fs	-	1.5	3.0	2.6	2.6	2.5	2.7	3.2	1.3	1.9	3.0	2.5	1.8	1.9	.7	.7
ol	10.6	5.3	1.2	-	-	-	-	-	-	-	-	-	-	-	2.0	-
ol-fs	7.5	3.8	.9	-	-	-	-	-	-	-	-	-	-	-	1.5	-
ol-fa	3.1	1.5	.4	-	-	-	-	-	-	-	-	-	-	-	.5	-
DI	46.0	47.5	45.7	52.6	52.7	51.2	56.3	55.7	59.9	51.3	59.5	56.5	61.2	59.3	65.3	64.4

TABLE 1.—*Normative and modal compositions of monzonites (A and B) and dikes (C) of the Lahore pluton*—Continued

	A. Pyroxene monzonite				B. Amphibole monzonite										C. Dikes	
TABLE NO.	1	2	3	4	5	6	7[1]	8	9	10	11[1]	12	13	14[1]	15	16
FIELD NO.	P-78-53	P-81-10A	P-81-10	P-80-84	P-80-66	P-80-68	P-81-12	P-81-14	P-81-13	P-80-70	P-81-11	P-78-52	P-80-72	P-81-15	P-80-74A	P-80-75
MODAL COMPOSITION: THIN SECTION ANALYSES																
PLAGIOCLASE	31.2	29.2	20.9	30.5	21.6	11.2	17.4	9.6	9.9	16.9	8.2	20.9	32.0	18.5	24.6	43.6
MICROCLINE	16.8	20.0	24.9	27.9	34.1	39.6	31.3	24.9	-	34.5	39.2	34.4	33.0	41.1	25.3	-
ORTHOCLASE	-	-	-	-	-	-	-	-	27.7	-	-	-	-	-	-	1.0
QUARTZ	.1	.6	1.0	1.4	.3	1.6	5.6	4.8	2.8	.4	6.7	3.5	6.2	4.5	6.7	15.4
MYRMEKITE	.8	.5	-	1.7	.8	1.1	.4	3.3	-	-	1.0	1.9	.9	.2	-	-
AMPHIBOLE	-	2.8	6.9	6.1	27.4	38.1	32.5	9.8	35.4	36.6	27.8	25.4	16.2	32.2	24.9	15.5
PYROXENE	22.1	18.0	17.0	20.4	1.3	1.3	.2	14.7	1.8	3.1	1.2	4.1	-	1.4	.2	-
BIOTITE	22.7	25.0	21.3	10.0	8.9	.6	5.8	17.7	.2	.9	7.8	7.2	3.7	.7	1.3	7.4
EPIDOTE	-	-	5.9	.1	.2	.6	-	-	-	3.6	.2	.1	2.7	-	6.1	10.8
SAUSSURITIC EPIDOTE	.5	.9	-	-	-	2.1	5.6	13.5	13.9	1.3	7.7	.1	1.8	.8	8.0	1.3
TITANITE	-	-	-	-	2.3	.4	-	-	-	.2	.2	.2	.2	-	-	.2
APATITE	-	.1	.1	-	-	.2	.2	.2	.1	-	-	.2	-	.1	-	.1
WHITE MICA[2]	1.3	-	-	-	1.3	2.5	-	-	-	-	-	.6	-	-	1.6	4.4
MAGNETITE	3.1	2.6	2.0	.9	1.6	.2	.2	1.2	2.6	.2	-	.7	-	.4	-	-
RUTILE	-	-	-	-	-	-	.2	-	-	-	-	-	-	-	-	-
CHLORITE	.5	-	-	.9	-	-	-	-	5.6	1.0	-	-	3.0	-	-	-
ZIRCON	-	-	-	-	-	-	-	.2	-	-	-	-	-	-	-	-
ALLANITE	-	-	-	-	-	-	-	-	-	-	-	-	.1	-	-	-
FLUORITE	-	-	-	-	-	-	-	-	-	.3	-	.6	-	-	-	-
OTHER	.9	.3	-	-	.3	.6	.4	.2	.1	1.0	-	.2	.2	.2	1.2	.2
Total	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100
MODAL COMPOSITION: SLAB COUNTS (VOLUME PERCENT)																
PLAGIOCLASE	38.0	35.3	36.1	33.2	28.2	25.8	25.3	33.4	23.7	23.4	23.6	26.3	31.0	24.0	-[3]	-[3]
POTASSIC FELDSPAR	18.3	20.6	23.4	28.9	29.2	30.2	34.2	28.2	43.8	31.3	38.3	29.2	43.8	38.6	-	-
QUARTZ	-	.1	-	.7	-	1.0	.6	.8	.2	7.4	3.4	1.7	3.1	3.7	-	-
OTHER	43.7	44.0	40.6	37.2	42.6	42.9	40.0	37.6	32.3	37.9	34.7	42.8	22.1	33.7	-	-
RECAST MODAL ANALYSES[4]																
PLAGIOCLASE	36.2	34.4	36.1	33.2	26.9	21.2	19.7	19.9	9.8	22.1	15.9	25.6	29.2	23.2	-	-
MICROCLINE	18.3	20.6	23.4	28.9	29.2	30.2	34.2	28.2	-	31.3	38.3	29.2	43.8	38.6	-	-
ORTHOCLASE	-	-	-	-	-	-	-	-	43.8	-	-	-	-	-	-	-
QUARTZ	.1	.1	.7	.7	.3	1.0	.6	.8	.2	7.4	3.4	1.7	3.1	3.7	-	-
MYRMEKITE	.7	.4	-	1.6	.8	1.1	.4	2.8	-	-	.9	2.0	.7	.2	-	-
AMPHIBOLE	-	2.5	5.2	5.7	27.4	38.1	32.5	8.2	24.7	29.8	25.7	26.8	13.4	30.9	-	-
PYROXENE	19.3	16.1	12.7	18.9	1.3	1.3	.2	12.3	1.3	2.5	1.1	4.3	-	1.3	-	-
BIOTITE	19.9	22.4	15.9	9.3	8.9	.6	5.8	14.9	.1	.7	7.2	7.6	3.1	.7	-	-
EPIDOTE	-	-	4.4	.1	.2	.6	-	-	-	2.9	.2	.1	2.2	-	-	-
SAUSSURITIC EPIDOTE	.4	.8	-	-	-	2.1	5.6	11.3	13.9	1.1	7.1	.1	1.5	.8	-	-
TITANITE	-	-	-	-	2.3	.4	-	-	-	.2	.2	.2	.2	-	-	-

TABLE 1.—*Normative and modal compositions of monzonites (A and B) and dikes (C) of the Lahore pluton*—Continued

	<-------A. Pyroxene monzonite------->				<------------------------------------B. Amphibole monzonite------------------------------------>										<---C. Dikes--->	
TABLE NO.	1	2	3	4	5	6	7[1]	8	9	10	11[1]	12	13	14[1]	15	16
FIELD NO.	P-78-53	P-81-10A	P-81-10	P-80-84	P-80-66	P-80-68	P-81-12	P-81-14	P-81-13	P-80-70	P-81-11	P-78-52	P-80-72	P-81-15	P-80-74A	P-80-75
								RECAST MODAL ANALYSES (CONT.)								
APATITE	-	.1	.1	-	-	.2	.2	.2	.1	-	-	.2	-	.1	-	-
WHITE MICA[2]	1.1	-	-	-	1.3	2.5	-	-	-	-	-	.6	-	-	-	-
MAGNETITE	2.7	2.3	1.5	.8	1.6	.2	.2	1.0	1.8	.2	-	.7	-	.4	-	-
RUTILE	-	-	-	-	-	-	.2	-	-	-	-	-	-	-	-	-
CHLORITE	.4	-	-	.8	-	-	-	-	3.9	.8	-	-	2.5	-	-	-
ZIRCON	-	-	-	-	-	-	-	.2	-	-	-	-	-	-	-	-
ALLANITE	-	-	-	-	-	-	-	-	-	-	-	-	.1	-	-	-
FLUORITE	-	-	-	-	-	-	-	-	-	.2	-	.6	-	-	-	-
OTHER	.8	.3	-	-	.3	.6	.4	.2	.1	.8	-	.2	.1	.2	-	-
Total	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.		
COLOR INDEX[5]	42.	44.	40.	36.	42.	43.	44.	48.	42.	37.	42.	40.	20.	41.	34.	35.
POINT COUNT	1110.	1207.	1129.	1056.	1133.	1230.	1206.	1063.	1142.	1207.	1202.	1158.	1105.	1202.	1057.	1223.
								TERNARY PROPORTIONS[6]								
PLAGIOCLASE	67.	63.	61.	53.	49.	45.	42.	53.	35.	38.	36.	46.	40.	36.	43.	73.
POTASSIC FELDSPAR	33.	37.	39.	46.	51.	53.	57.	45.	65.	50.	59.	51.	56.	58.	45.	2.
QUARTZ	-	-	-	1.	-	2.	1.	2.	-	12.	5.	3.	4.	6.	12.	25.
Total	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.

PETROGRAPHIC DESCRIPTIONS AND LOCATIONS[7]

A. Pyroxene monzonite

1. P-80-53 -- Pyroxene-biotite monzodiorite: massive, fine-grained mesocratic rock with hypidiomorphic-granular texture. Plagioclase is generally clouded in different amounts by fine-grained white-mica alteration and locally has clear albite margins. Microcline twinned generally is in smaller sized grains than plagioclase. Pyroxene commonly is twinned and rarely is slightly altered by chlorite. Greenish-brown biotite is an abundant accessory as is magnetite. Apatite is minor. Lahore Quadrangle at lat. 38°11'40.5"N. and long. 77°56'58"W.

2. P-81-10A -- Pyroxene-biotite monzonite: massive, medium-grained, mesocratic rock with hypidiomorphic-granular texture. Pyroxene is poikilitic and twinned. Zoned plagioclase has alteration in core and clear rim. Biotite is greenish brown and the opaque is magnetite. Lahore Quadrangle at lat. 38°11'07"N. and long. 77°56'31"W.

3. P-81-10 -- Pyroxene-biotite monzonite: massive, medium-grained, mesocratic rock. Pyroxene occurs as large poikilitic grains that enclose small grains of apatite, magnetite, and biotite. Plagioclase is zoned and some has cores clouded with granular epidote alteration; the rims of such plagioclase are clear (albite?). Biotite is common and green amphibole locally replaces pyroxene. Opaque is magnetite. Lahore Quadrangle at lat. 38°11'08"N. and long. 77°56'31.5"W.

4. P-80-84 -- Biotite-pyroxene monzonite: strongly foliated (dimensional orientation of elongate grains), medium-grained mesocratic rock. Groundmass plagioclase grains are well aligned; small plagioclase grains occur as chadacrysts within microcline and in such cases are generally myrmekitic. Augitic pyroxene is locally altered to chlorite. Magnetite is abundant in the groundmass as well as intergrown with pyroxene. Lahore Quadrangle at lat. 38°13'04"N. and long. 76°56'45"W.

TABLE 1.—*Normative and modal compositions of monzonites (A and B) and dikes (C) of the Lahore pluton*—Continued

B. Amphibole monzonite

5. P-80-66 -- Biotite-amphibole monzonite: strongly foliated (dimensional alignment of felsic and mafic minerals), medium-grained, mesocratic rock. Microcline is locally perthitic. Green, symplectic (myrmekitic), locally poikilitic amphibole is abundant and in one large grain contains a relict core of pyroxene. Brown biotite is a common accessory. Euhedral to subhedral magnetite, a common accessory is locally mantled by titanite. Titanite also occurs as small granules. Lahore Quadrangle at lat. 38°10'15"N. and long. 77°59'00"W.

6. P-80-68 -- Amphibole monzonite: strongly foliated (dimensional alignment of hornblende and tabular feldspar), medium-grained, mesocratic rock. Microcline occurs as a groundmass constituent and in aligned metacrysts and, in places, is perthitic. Plagioclase is locally clouded by fine-grained granular zoisitic alteration. Where plagioclase is in contact with or is enclosed by microcline it forms myrmekite or has albitic rims. Abundant green poikilitic amphibole contains fine-grained biotite, microcline, quartz and apatite as inclusions and in places it encloses relict pyroxene. Brown biotite is a minor groundmass accessory as are epidote, apatite, magnetite and titanite. Lahore Quadrangle at lat. 38°11'47"N. and long. 77°57'24"W.

7. P-81-12 -- Biotite-amphibole monzonite: strongly foliated, medium-grained mesocratic rock. Microcline is the most strongly aligned mineral. Highly poikilitic, green amphibole is crowded with inclusions of fine-grained green amphibole, quartz, and apatite. Plagioclase is clouded with finely granular epidote-zoisite and white-mica alteration. Zoned plagioclase commonly has clear rims. Accessory greenish-brown biotite commonly encloses fine-grained titanite, rutile, and apatite. Titanite and apatite also occur as groundmass constituents and magnetite is a common opaque accessory. Lahore Quadrangle at lat. 38°09'29"N. and long. 77°58'46"W.

8. P-81-14 -- Amphibole-pyroxene monzonite: foliated, medium-grained, mesocratic rock. Microcline poikilitically encloses quartz and unaltered plagioclase. Groundmass plagioclase is almost completely altered to an aggregate of clinozoisite and white mica except in a few places where the plagioclase retains a clear rim. Unaltered pyroxene is common but in many places along its margin it is altered to green amphibole. Locally amphibole is pseudomorphous after pyroxene. Brown biotite is accessory and locally encloses apatite, but apatite is also a groundmass constituent. Bulbous protrusions of myrmekite into microcline are common. Accessory magnetite is locally rimmed by titanite. Lahore Quadrangle at lat. 38°12'15"N. and 77°58'58"W.

9. P-81-13 -- Epidote-amphibole monzonite: foliated medium-grained, mesocratic rock. Orthoclase, the characterizing feldspar, is perthitic and forms long tabular crystals. Green amphibole formed through replacement of pyroxene that is still present as relict in cores of amphibole. Brown biotite is very sparse and has been pseudomorphously replaced by green chlorite. Plagioclase is common. Quartz with undulose extinction is a very sparse constituent. Other accessory minerals are apatite and epidote, with epidote also occurring in thin veinlets; granular titanite with leucoxene alteration also is a minor accessory. Magnetite is an abundant accessory commonly rimmed by granular epidote. Lahore Quadrangle at lat. 38°09'42"N. and long. 77°58'40"W.

10. P-80-70 -- Biotite-amphibole quartz monzonite: strongly foliated (dimensional orientation of elongate grains), medium-grained mesocratic rock. Large tabular microcline commonly with ribbon perthite is the characterizing feldspar. Large green amphibole encloses relict pyroxene that is surrounded in places by a bleach zone. Plagioclase is generally altered to fine-grained white-mica and granular-epidote aggregates. Green biotite is commonly enclosed in amphibole. Accessory magnetite is commonly rimmed by titanite, and titanite occurs in the goundmass as individual grains and subhedral crystals. Groundmass epidote is a common accessory and fluorite(?) is locally present. Green chlorite may, in part, have formed from amphibole. Lahore Quadrangle at lat. 38°11'22"N. and long. 77°57'41"W.

11. P-81-11 -- Biotite-amphibole monzonite: strongly foliated, coarse-grained, mesocratic rock. Microcline is locally perthitic. Megacrysts of green poikilitic amphibole enclose fine-grained quartz and microcline. Plagioclase is untwinned and clouded by fine-grained, granular epidote alteration. Myrmekite occurs with microcline grains. Accessory brownish-green biotite poikilitically encloses fine-grained titanite and apatite. Biotite generally occurs in clumps and in a few places is closely associated with well-formed epidote. Lahore Quadrangle at lat. 38°10'09"N. and long. 77°57'36"W.

12. P-78-52 -- Biotite-amphibole monzonite: strongly foliated (dimensional alignment of elongate grains), medium-grained, mesocratic rock. Feldspar laths of plagioclase and microcline are particularly well aligned. Subhedral green amphibole that is locally poikilitic also encloses relict pyroxene. Greenish-brown biotite in places encloses apatite. Magnetite and titanite are minor accessories. Lahore Quadrangle at lat. 38°12'19"N. and long. 77°56'45"W.

13. P-80-72 -- Biotite-amphibole monzonite: strongly foliated (dimensional alignment of elongate minerals), medium-grained, mesocratic rock. Strongly aligned tabular microcline locally contains ribbon and patch perthite. Twinned plagioclase is clouded by white-mica and granular-epidote alteration. Untwinned plagioclase is myrmekitic where enclosed by or in contact with microcline and commonly also has a clear albitic(?) rim. Green amphibole and green chlorite formed from amphibole are commonly poikilitic. Green biotite is accessory and epidote also occurs as a well-formed groundmass constituent. Allanite is closely associated with epidote and locally with titanite. Magnetite is the accessory opaque. Lahore Quadrangle at lat. 38°10'54"N. and long. 77°57'53"W.

14. P-81-15 -- Amphibolitic quartz monzonite: strongly foliated (dimensional alignment of elongate minerals), medium-grained mesocratic rock. Microcline occurs in aligned, elongate, tabular, poikilitic, and nonpoikilitic crystals. Common inclusions in poikilitic microcline are small grains of quartz and albite(?) rimmed plagioclase. Groundmass quartz ranges in grain size from medium to fine. Locally untwinned plagioclase is clouded by alteration. Green poikilitic to nonpoikilitic amphibole is less aligned than the feldspars. Poikilitic amphibole encloses small grains of quartz, plagioclase, microcline, epidote, and biotite as well as unaltered pyroxene: euhedral magnetite and apatite are additional inclusions. Biotite also occurs as a groundmass constituent. Lahore Quadrangle at lat. 38°11'37"N. and long. 77°57'37"W.

TABLE 1.—*Normative and modal compositions of monzonites (A and B) and dikes (C) of the Lahore pluton*—Continued

C. Dikes

15. P-80-74A -- Dike of biotite-amphibole quartz monzonite within the Lahore pluton. Massive, fine-grained, melanocratic rock. Microcline forms small phenocrysts as well as being a groundmass constituent. It is commonly perthitic. Deep-green amphibole is a sparse microphenocrystic consitituent but is abundant in the groundmasses granular epidote. Lahore Quadrangle at lat. 38°09'50"N. and long. 77°58'19"W.

16. P-80-75 -- Dike of biotite-amphibole tonalite within the Lahore pluton. Foliated, fine-grained, mesocratic rock. Aligned fine-grained brown biotite imparts the mineral foliation to this rock. Green, locally poikilitic amphibole forms small phenocrysts. Amphibole also is a groundmass constituent as is abundant subhedral epidote. Accessory minerals include granular to crystalline titanite, apatite, and white mica. This dike may be a late-magmatic phase of the granodiorite of the Ellisville pluton intruded into the Lahore Complex. Lahore Quadrangle at lat. 38°10'06"N. and long. 77°57'33"W.

1/ Samples used in geochronologic studies.
2/ Mostly fine-grained alteration on feldspar.
3/ Slab not usable for point counts.
4/ Recast modal analysis used plagioclase, potassic feldspar, and quartz percentages determined by slab counts. Plagioclase percentage, however, was reduced by the amount of saussuritic epidote and white-mica alteration, where present in thin section. The practice of accepting slab counts for the feldspars and quartz, which commonly differ from thin section counts of these minerals, necessitates normalizing the other modal constituents to values other than those counted in thin section.
5/ Color index is from Shand (1943, p. 196) and is modified as: 0-30, leucocratic; 30-60, mesocratic; 60-90, melanocratic; 90-100, hypermelanic. Dark minerals summed to determine numerical values of color index in this report include: biotite, amphibole, pyroxene, epidote, titanite, and opaque.
6/ Ternary proportions calculated from values obtained by slab counts, except for P-80-74A and P-80-75, which use the thin section analyses.
7/ Grain size in the petrographic descriptions is defined as: fine, less than 1 mm; medium, 1-5 mm; coarse, 5 mm-3 cm; and very coarse, greater than 3 cm (Williams, Turner and Gilbert, 1982, p. 54.)

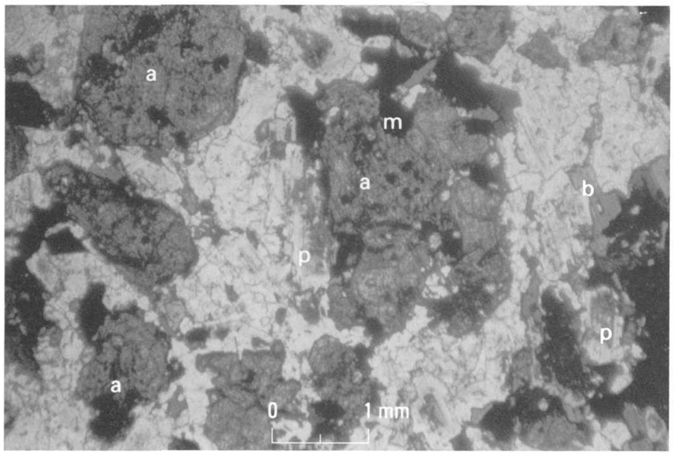


FIGURE 6.—Photomicrograph of pyroxene monzonite (P-81–10) of the Lahore pluton with euhedral and subhedral, nonpoikilitic and poikilitic augite (a). Groundmass consists mostly of zoned plagioclase (p) and brown biotite (b). Inclusions in poikilitic pyroxene are apatite, plagioclase and magnetite (m). Plane light. Lahore Quadrangle at lat 38°11′07″N. and long 77°56′31″W.

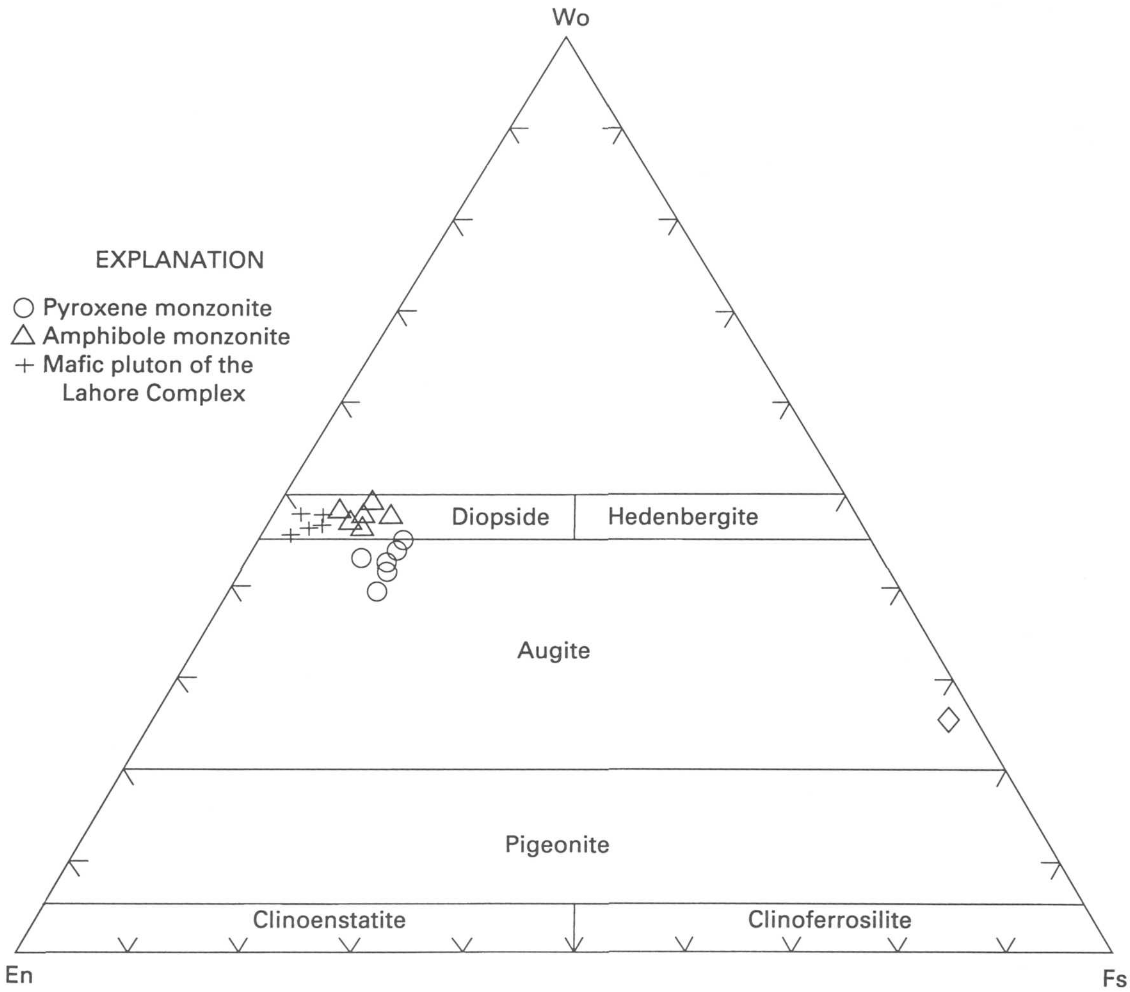


FIGURE 7.—Diagram showing compositional range of pyroxenes from monzonites of the Lahore pluton and the mafic pluton of the Lahore Complex. Pyroxene diagram is from Morimoto (1988). Pyroxenes calculated on the basis that Fe is present as both FeO and Fe_2O_3 by the computer program of Freeborn and others (1985). Analyses are from table B-1B (metapyroxenites, nos. 9–16), table B-5B (pyroxene monzonites: nos. 66, 70, 74, 75, 99, and 110, and amphibole monzonites, nos. 59, 60, 61, 76, 80, 84, and 88).

TABLE 2.—*Normative and modal compositions of granodiorites and inclusions/intrusions of the Ellisville pluton*

	Granidiorites															Inclusions/Intrusions		
TABLE NO.	1[1]	2	3	4[1]	5	6	7[1]	8	9	10	11[1]	12[1]	13[1]	14	15[1]	16	17	18
FIELD NO.	P-80-38	P-80-20	P-80-24	P-80-33	P-80-32	P-80-26	P-80-37	P-25	P-80-9	P-80-41	P-80-36	P-80-39	P-80-42	P-80-8	P-80-40	P-80-44	P-80-45	P-80-43
hy-en	.6	1.4	2.4	3.1	3.5	1.9	4.0	1.7	1.6	4.0	3.5	3.8	4.0	1.9	3.3	9.5	12.8	7.0
hy-fs	--	3.7	1.4	.5	.3	--	1.4	.7	.2	1.9	1.0	1.6	1.7	.6	.9	2.1	4.3	4.5
DI	87.3	81.4	79.3	76.5	75.8	74.3	73.1	79.0	75.6	72.7	74.3	73.8	71.4	73.8	74.2	24.0	33.0	57.4
MODAL COMPOSITION: THIN SECTION ANALYSES																		
PLAGIOCLASE	35.4	39.0	42.2	31.1	38.4	39.8	49.1	54.3	40.3	47.0	40.5	45.8	47.5	41.5	41.4	7.3	18.6	57.0
MICROCLINE	29.2	13.5	14.2	16.2	11.2	18.3	7.2	--	29.3	6.3	11.8	4.9	5.4	--	15.8	9.6	10.3	.3
ORTHOCLASE	--	1.1	.6	--	--	--	6.5	6.7	--	--	--	--	--	20.4	--	--	--	--
QUARTZ	23.6	30.7	27.0	28.6	25.8	27.2	14.8	27.8	21.0	23.5	30.8	32.8	25.8	26.3	23.6	2.9	2.4	.7
MYRMEKITE	0.9	1.5	1.3	2.6	2.3	3.4	2.9	.1	.2	.8	1.5	.5	.8	.4	.6	--	--	--
BIOTITE	2.2	9.7	11.2	11.4	12.2	9.2	14.2	9.1	5.3	15.7	11.6	9.4	15.0	8.7	12.7	.2	--	32.5
AMPHIBOLE	--	--	.9	.1	--	.1	--	--	--	.9	.3	1.0	1.6	--	--	41.3	51.4	3.4
EPIDOTE	2.4	2.2	1.3	4.8	4.9	.7	3.7	1.7	2.6	4.7	2.3	3.1	2.0	2.0	2.9	.2	5.7	3.5
SAUSSURITIC EPIDOTE	--	--	--	--	--	--	.3	--	.2	.8	.3	1.0	--	--	1.3	4.7	--	--
ALLANITE	--	--	--	.1	.1	--	.1	--	--	--	.1	.5	.3	--	.1	--	--	--
TITANITE	.1	.2	.7	.3	.4	--	.6	.1	--	.2	.4	.1	.5	.1	.8	3.7	4.0	1.8
APATITE	--	.6	--	.1	.1	--	--	--	--	--	--	.5	.2	--	.1	.1	--	.2
MUSCOVITE	4.8	1.6	--	4.1	3.5	.9	--	--	.9	--	--	--	.4	--	.4	--	--	--
PYROXENE	--	--	--	--	.3	--	--	--	--	--	.1	--	--	--	--	29.3	5.2	--
OTHER	1.4	--	.6	.6	.8	.4	.5	.2	.2	.4	.2	.4	.4	.5	.4	.5	.7	.2
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
MODAL COMPOSITION: SLAB COUNTS (VOLUME PERCENT)																		
PLAGIOCLASE	40.7	50.2	48.3	44.1	44.2	--[2]	43.9	44.4	51.2	40.6	47.6	44.4	47.7	44.9	42.2	--[2]	33.9	--[2]
POTASSIC FELDSPAR	21.8	13.3	13.0	17.4	12.0	--	13.8	13.0	9.3	10.9	11.9	12.0	8.6	26.9	14.7	--	10.9	--
QUARTZ	34.0	24.7	23.7	25.5	27.5	--	23.4	31.1	25.4	30.0	23.8	28.5	25.6	14.6	28.9	--	2.0	--
OTHER	3.5	11.8	15.0	13.0	16.3	--	18.9	11.5	14.1	18.5	16.7	15.1	18.1	13.6	14.2	--	53.2	--
RECAST MODAL ANALYSES[3]																		
PLAGIOCLASE	40.7	50.2	48.3	44.1	44.2	39.8	43.9	44.4	51.2	40.6	47.6	44.4	47.7	44.9	42.2	7.3	33.9	57.0
MICROCLINE	21.8	12.3	12.5	17.4	12.0	18.3	7.3	--	9.3	10.9	11.9	12.0	8.6	--	14.7	9.6	10.9	.3
ORTHOCLASE	--	1.0	.5	--	--	--	6.5	13.0	--	--	--	--	--	26.9	--	--	--	--
QUARTZ	34.0	24.7	24.2	25.5	27.5	27.2	23.4	31.1	25.4	30.0	23.8	28.5	25.6	14.6	28.9	2.9	2.0	.7
MYRMEKITE	.31	.11	.21	.41	.53	.42	.40	.10	.30	.61	.50	.50	.70	.50	.4	--	--	--

TABLE 2.—*Normative and modal compositions of granodiorites and inclusions/intrusions of the Ellisville pluton*—Continued

	<----	----	----	----	----	----	----	Granodiorites	----	----	----	----	----	----	---->	Inclusions/Intrusions		
TABLE NO.	1[1]	2	3	4[1]	5	6	7[1]	8	9	10	11[1]	12[1]	13[1]	14	15[1]	16	17	18
FIELD NO.	P-80-38	P-80-20	P-80-24	P-80-33	P-80-32	P-80-26	P-80-37	P-25	P-80-9	P-80-41	P-80-36	P-80-39	P-80-42	P-80-8	P-80-40	P-80-44	P-80-45	P-80-43
MAJOR OXIDE COMPOSITION (WATER-FREE): calculated from table 4 (complete chemical analyses and analytical methods are given in table 4)																		
SiO_2	73.0	72.1	70.1	71.0	70.0	70.4	68.5	69.3	69.3	68.5	68.9	68.4	68.0	68.3	68.0	53.8	54.4	55.4
Al_2O_3	15.4	15.3	16.8	14.9	15.4	15.9	15.3	15.6	15.7	15.3	15.6	15.8	16.0	16.2	16.3	9.7	12.1	20.0
Fe_2O_3	1.0	.3	.8	1.7	1.7	1.8	1.8	1.6	1.5	1.5	1.7	1.4	1.4	1.6	1.6	2.4	2.4	2.1
FeO	.3	2.3	1.4	1.3	1.2	1.0	2.0	1.4	1.1	2.1	1.7	1.9	1.9	1.4	1.5	5.1	5.0	4.3
MgO	.2	.6	1.0	1.2	1.4	.8	1.6	.7	.9	1.6	1.4	1.5	1.6	.9	1.3	10.6	8.7	2.8
CaO	1.9	2.2	2.6	3.3	3.5	4.0	3.7	3.3	4.2	3.8	3.6	3.6	4.2	4.4	3.8	14.4	10.4	5.8
Na_2O	3.8	3.6	3.8	3.1	3.5	2.8	3.2	3.8	3.2	3.3	3.2	3.3	3.5	3.5	3.6	1.6	2.0	4.6
K_2O	4.0	3.1	3.0	2.9	2.8	2.9	3.1	3.6	3.7	3.0	3.2	3.2	2.7	3.2	3.3	1.3	2.0	3.0
TiO_2	.1	.3	.3	.4	.3	.3	.5	.4	.3	.5	.5	.5	.4	.4	.4	1.0	1.3	1.1
P_2O_5	.04	.11	.2	.13	.11	.11	.21	.15	.11	.19	.15	.20	.14	.19	.13	.2	.4	.7
MnO	.02	.04	.03	.05	.02	.03	.04	.03	.02	.06	.03	.04	.04	.01	.03	.03	1.2	.1
CO_2	.01	.02	.01	.02	.01	.02	.01	.13	.02	.02	.01	.01	.02	.01	.02	.01	.01	.02
Total	99.77	99.97	100.04	100.	99.94	100.06	99.96	100.01	100.05	99.87	99.99	99.85	99.90	100.11	99.98	100.14	99.91	99.92
NORMATIVE MINERAL COMPOSITION (WEIGHT PERCENT)																		
Q	30.9	32.0	29.6	33.6	29.6	33.9	27.7	26.3	27.3	26.7	28.2	26.4	25.3	25.9	24.5	2.8	4.2	.2
C	1.4	2.2	3.0	1.2	.6	1.3	.5	.2	--	.1	.7	.7	.05	--	.3	--	--	.4
or	23.9	18.5	17.7	16.9	16.8	17.0	18.3	21.0	21.6	17.9	18.6	19.1	16.1	18.6	19.4	7.7	11.8	17.9
ab	32.5	30.8	32.1	25.9	29.3	23.5	27.1	31.7	26.6	28.1	27.5	28.2	30.0	29.3	30.3	13.5	17.0	39.3
an	9.2	10.2	11.6	15.2	16.4	19.0	16.9	14.8	18.0	17.6	16.6	16.7	19.5	19.3	17.8	15.4	18.2	23.8
wo	--	--	--	--	--	--	--	--	.7	--	--	--	--	.5	--	22.7	12.9	--
en	.6	1.4	2.4	3.1	3.5	1.9	4.0	1.7	2.2	4.0	3.5	3.8	4.0	2.2	3.3	26.3	21.7	7.0
fs	--	3.7	1.4	.5	.3	--	1.4	.7	.3	1.9	1.0	1.6	1.7	.7	.9	5.8	7.3	4.5
mt	.8	.4	1.2	2.5	2.5	2.6	2.6	2.4	2.2	2.2	2.5	2.1	2.1	2.4	2.4	3.5	3.5	3.1
hm	.5	--	--	--	--	.03	--	--	--	--	--	--	--	--	--	--	--	--
il	.2	.5	.6	.7	.6	.5	1.0	.8	.6	1.0	.9	.9	.8	.7	.7	1.9	2.5	2.1
ap	.1	.3	.4	.3	.3	.3	.5	.4	.3	.5	.4	.5	.3	.5	.3	.5	.9	1.7
cc	.02	.05	.02	.05	.02	.05	.02	.3	.05	.05	.02	.02	.05	.02	.05	.02	.02	.05
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
di	--	--	--	--	--	--	--	--	1.4	--	--	--	--	.9	--	43.1	24.8	--
di-wo	--	--	--	--	--	--	--	--	.7	--	--	--	--	.5	--	22.7	12.9	--
di-en	--	--	--	--	--	--	--	--	.6	--	--	--	--	.3	--	16.8	8.9	--
di-fs	--	--	--	--	--	--	--	--	.1	--	--	--	--	.1	--	3.7	3.0	--
hy	.6	5.0	3.8	3.6	3.9	1.9	5.4	2.3	1.9	5.9	4.6	5.4	5.7	2.5	4.2	11.6	17.1	11.6

TABLE 2.—*Normative and modal compositions of granodiorites and inclusions/intrusions of the Ellisville pluton*—Continued

	<-----Granodiorites														----->Inclusions/Intrusions			
TABLE NO.	1[1/]	2	3	4[1/]	5	6	7[1/]	8	9	10	11[1/]	12[1/]	13[1/]	14	15[1/]	16	17	18
FIELD NO.	P-80-38	P-80-20	P-80-24	P-80-33	P-80-32	P-80-26	P-80-37	P-25	P-80-9	P-80-41	P-80-36	P-80-39	P-80-42	P-80-8	P-80-40	P-80-44	P-80-45	P-80-43
BIOTITE	0.7	7.2	10.1	6.1	8.1	9.2	12.3	9.3	8.1	12.9	11.7	9.2	12.8	10.1	10.2	.2	--	32.5
AMPHIBOLE	--	--	.8	.05	--	.1	--	--	--	.7	.3	1.0	1.4	--	--	41.3	37.4	3.4
EPIDOTEO	.71	.61	.22	.63	.20	.73	.31	.74	.03	.92	.33	.01	.72	.32	.3	.2	5.4	3.5
SAUSSURITIC EPIDOTE	--	--	--	--	--	--	--	--	.3	.6	.3	1.0	--	--	1.1	4.7	--	--
ALLANITE	--	--	--	.05	.1	--	.1	--	--	--	.1	--	.3	--	.1	--	--	--
TITANITE	.03	.2	.6	.2	.3	--	.5	.1	--	.2	.4	.5	.4	.1	.7	3.7	3.8	1.8
APATITE	--	.5	--	.05	.1	--	--	--	--	--	--	.1	.2	--	.1	.1	--	.2
MUSCOVITE	1.4	1.2	--	2.2	2.3	.9	--	--	1.3	--	--	.5	.3	--	.3	--	--	--
AUGITE	--	--	--	--	.2	--	--	--	--	--	--	--	--	--	--	--	--	--
OPAQUE	--	--	--	--	.1	--	--	--	--	--	--	--	--	--	.1	--	--	--
PYROXENE	--	--	--	--	--	--	.3	--	--	--	.1	--	--	--	--	29.3	4.9	--
OTHER	.4	--	.5	.3	.5	.4	.4	.2	.3	.3	.2	.3	.3	.6	.2	.5	.8	.2
COLOR INDEX[4/]	1.	9.	13.	9.	12.	10.	16.	11.	12.	18.	15.	14.	16.	13.	13.	80.	52.	41
POINT COUNT	734.	1165.	1191.	1162.	1213.	1163.	1192.	1238.	1106.	1136.	1235.	1239.	1194.	1201.	1104.	1246.	1135.	1241.
TERNARY PROPORTIONS[5/]																		
PLAGIOCLASE	42.	57.	57.	51.	53.	47.	54.	50.	60.	50.	57.	52.	58.	52.	49.	37.	73.	98.
POTASSIC FELDSPAR	23.	15.	15.	20.	14.	21.	17.	15.	11.	13.	14.	14.	11.	31.	17.	48.	23.	1.
QUARTZ	35.	28.	28.	29.	33.	32.	29.	35.	29.	37.	29.	34.	31.	17.	34.	15.	4.	1.

PETROGRAPHIC DESCRIPTIONS AND LOCATIONS[6/]

Granodiorites

1\. P-80-38 -- Monzogranite; massive, highly leucocratic and fine grained with allotriomorphic-granular texture: Mineral Quadrangle at lat. 38°05'59"N. and long. 77°58'12"W.

2\. P-80-20 -- Biotite granodiorite; massive, leucocratic fine-grained and equigranular, with hypidiomorphic granular texture. Quartz occurs as large grains or as granoblastic intersertal grains; plagioclase is present in twinned or untwinned grains that locally are altered to granular epidote. Microcline is the dominant potassic feldspar and is locally perthitic. Greenish-brown biotite is the characterizing mica, and accessory apatite occur as small euhedral grains: Mineral Quadrangle at lat. 38°04'29"N. and long. 77°58'09"W.

3\. P-80-24 -- Biotite granodiorite; rudely foliated, medium-grained porphyritic leucocratic rock with phenocrysts of microcline up to 2 cm long. Microcline phenocrysts are porphyritic with inclusions of quartz, plagioclase and biotite. Myrmekite occurs at contacts with plagioclase and microcline. Quartz occurs in discrete large grains. Brown biotite is major accessary and titanite, epidote, and green amphibole are less abundant accessories: Mineral Quadrangle at lat. 38°06'41.5"N. and long. 77°58'18"W.

4\. P-80-33 -- Biotite granodiorite; rudely foliated to massive, medium-grained hypidiomorphic-granular leucocratic rock. Quartz occurs as single, medium-sized grains and in fine-grained granoblastic clots. Both plagioclase and microcline are locally poikilitic and some plagioclase is altered by fine-grained white mica. Green biotite is the characterizing accessory. Epidote is locally associated with allanite and also forms, in places, symplectic intergrowths with quartz. Titanite and apatite occur mostly in subhedral crystals: Louisa Quadrangle at lat. 38°02'12"N. and long. 78°00'30"W.

5\. P-80-32 -- Biotite granodiorite; foliated, medium-grained leucocratic rock with foliation imparted by crystallographic and dimensional alignment of biotite and ruder dimensional alignment of felsic grains. Quartz occurs as large single grain and as granoblastic aggregates. Some of the plagioclase is zoned. Epidote occurs in large grains, many of which enclose zoned allanite, and such epidote has developed radiating fractures that emanate from the border of the allanite grain. Augite is a minor accessory. Louisa Quadrangle at lat. 38°02'07.5"N. and long. 78°00'32.5"W.

6\. P-80-26 -- Biotite granodiorite: massive, leucocratic, medium-grained and with an allotriomorphic-granular texture. Plagioclase groundmass grains are unzoned whereas megacrysts are zoned. Microcline generally forms smaller sized grains than plagioclase. Green biotite is the characterizing accessory and medium-grained epidote is a common groundmass constituent. In places, epidote encloses subhedral, zoned crystals of allanite and such epidote in places has radial fractures that emanate around the enclosed allanite. Louisa Quadrangle at lat. 38°00'30"N. and long. 78°02'02"W.

TABLE 2.—*Normative and modal compositions of granodiorites and inclusions/intrusions of the Ellisville pluton*—Continued

7.	P-80-37	--	Biotite granodiorite: rudely foliated (dimensional oriention of felsic grain), porphyritic, leucocratic rock. Potassic feldspar phenocrysts are up to 1.5 cm long. Plagioclase altered in places by either white mica, granular epidote, or both. Locally it contains inclusions of well-formed epidote with crystals of metamict allanite. Microcline is generally also poikilitic with inclusions of quartz, plagioclase, biotite, myrmekite, and pyroxene(?). Quartz occurs in large groundmass grains, some of which are strained and locally in granoblastic aggregates. Greenish-brown biotite is the characterizing accessory with random dimensional orientation. Subhedral groundmass epidote is also a common accessory that in places is in contact with metamict crystals of allanite; it also is abundant in clot-like aggregates of biotite. Some epidote is symplectic with quartz. Minor accessory titanite occurs in subhedral crystals with angular rhombic sections. Mineral Quadrangle at lat. 38°03'42"N. and long. 77°59'35"W.
8.	P-25	--	Biotite granodiorite: massive, leucocratic, fine-grained rock. Groundmass quartz occurs in granoblastic habit indicating considerable post-magmatic recrystallization. Greenish-brown biotite is the characterizing accessory and subhedral epidote is common whereas subhedral titanite with angular rhombic sections is a rare accessory. From quarry in Mineral Quadrangle at lat. 38°04'21"N. and long. 77°55'37"W.
9.	P-80-9	--	Biotite granodiorite: rudely foliated coarse-grained leucocratic rock. Plagioclase and microcline form megacrysts as well as groundmass constituents. Plagioclase has white-mica alteration; microcline megacrysts are poikilitic and enclose plagioclase, quartz, epidote, and biotite. Groundmass quartz occurs as granoblastic textured aggregates. Biotite is the characterizing accessory and epidote is a minor groundmass constituent. Mineral Quadrangle at lat. 38°06'28"N. and long. 77°54'44"W.
10.	P-80-41	--	Biotite granodiorite: strongly foliated (dimensional alignment of mineral grains), medium-grained, leucocratic rock. Plagioclase is zoned and in a few places it contains smaller, randomly oriented plagioclase crystals that suggest a late poikilitic crystallization phase. Microcline commonly forms poikilitic megacrysts that enclose small grains of myrmekite that locally have an albitic rim. Quartz occurs as large, single grains in the groundmass. Brownish-green biotite is the characterizing accessory whereas subhedral epidote, some in contact with allanite is a lesser accessory. Subhedral titanite is a minor accessory and green amphibole is a rare constituent. Lahore Quadrangle at lat. 38°08'57.5"N. and long. 77°56'32"W.
11.	P-80-36	--	Biotite granodiorite: well-foliated (dimensional alignment of mineral grains), medium-grained, porphyritic rock. Microcline phenocrysts up to 2 cm are poikilitic and enclose small grains of plagioclase and biotite. Groundmass plagioclase is locally zoned. Biotite is the characterizing accessory, and small amounts of green amphibole and colorless pyroxene are also present. Subhedral epidote, which commonly encloses allanite, occurs in association with biotite. Subhedral titanite and apatite are minor accessories. Mineral Quadrangle at lat. 38°03'07"N. and long. 77°59'39"W.
12.	P-80-39	--	Biotite granodiorite: foliated, coarse-grained porphyritic leucocratic rock. Both plagioclase and microcline form phenocrysts. Microcline is generally poikilitic and encloses small plagioclase and biotite grains. Myrmekite within groundmass plagioclase is formed at contacts with microcline. Quartz is granoblastic textured. Brownish-green biotite is the characterizing accessory, and subhedral epidote that commonly encloses allanite and subhedral titanite is an important accessory. Green amphibole is a minor constituent. Lahore Quadrangle at lat. 38°08'12"N. and long. 77°56'59"W.
13.	P-80-42	--	Biotite granodiorite: foliated (dimensional alignment of grains), medium-grained leucratic rock. Brown biotite with dimensional orientation wraps around dimensionally aligned large felsic grains. Microcline is nonpoikilitic, and quartz lacks granoblastic texture. Subhedral epidote commonly encloses rare allanite. Lahore Quadrangle at lat. 38°09'10"N. and long. 77°56'25"W.
14.	P-80-8	--	Biotite quartz monzonite: rudely foliated, coarsely porphyritic, leucocratic medium-grained rock. Orthoclase phenocrysts up to 5 cm long are poikilitic and enclose biotite, quartz, and epidote and small subhedral plagioclase grains that commonly have albitic rims. Zoned plagioclase in a common groundmass constituent. Quartz occurs both as single grains that are strained and in granoblastic aggregates. Greenish biotite is the characterizing accessory; epidote is minor and apatite is rare. Mineral Quadrangle at lat. 38°06'59"N. and long. 77°54'49"W.
15.	P-80-40	--	Biotite granodiorite: rudely foliated to massive, coarse-grained, leucocratic hypidiomorphic-granular rock. Megacrysts of microcline are poikilitic and enclose small crystals and grains of plagioclase, biotite and epidote. Groundmass quartz occurs in discrete non-granoblastic textured grains. Coarse-grained, brownish-green biotite is the characterizing accessory, and in places, poikilitic encloses titanite and apatite. Epidote forms large grains and commonly encloses allanite that has developed radiating fractures in the enclosing epidote. Allanite also is enclosed in quartz that has developed radiating fractures around the enclosed allanite. Green amphibote is a minor accessory. Lahore Quadrangle at lat. 38°08'15"N and long. 77°56'57"W.
			Inclusions/Intrusions
16.	P-80-44	--	Melanocratic, granofelsic textured amphibole-pyroxene tonalite: Some pyroxene closely associated with amphibole. Titanite locally concentrated in large amphibole patches. Lahore Quadrangle at lat. 38°09'28"N. and long. 77°56'14"W.
17.	P-80-45	--	Melanocratic, strongly foliated amphibole monzodiorite. Highly flattened rock with mortar structure locally present around some mineral grains. Microcline with string perthite common; plagioclase is commonly altered to epidote-zoisite. Locally epidote forms symplectite with amphibole. Titanite in subhedral to anhedral grains is commonly scattered within amphibole. Lahore Quadrangle at lat. 38°10'25"N. and long. 77°56'16"W.
18.	P-80-43	--	Mesocratic, porphyritic, strongly foliated biotite diorite. Large zoned phenocrysts of andesine and some glomeroporphyritic plagioclase are aligned along foliation. Zoned plagioclase cores altered to white-mica granular-epidote aggregates. Large epidote with allanite cores is present as is large subhedral to euhedral locally poikilitic titanite. The characterizing green biotite is dimensionally aligned and imparts the strong foliation to the rock. Lahore Quadrangle at lat. 38°09'26"N. and long. 77°56'16"W.

[1] Samples used in geochronologic studies.
[2] Slab not available.
[3] Recast modal analyses used plagioclase, potassic feldspar, and quartz percentages determined by slab counts, except for P-80-26, which used the thin section analyses.
[4] Color index is from Shand (1943, p. 196) and is modified as: 0-30, leucocratic; 30-60, mesocratic; 60-90, melanocratic; 90-100, hypermelanic. Dark minerals summed to determine numerical values of color index in this report include: biotite, amphibole, pyroxene, epidote, titanite, and opaque.
[5] Ternary proportions calculated from values obtained by slab counts, except for P-80-26 which used the thin section analyses.
[6] Grain size in the petrographic descriptions is defined as: fine, less than 1 mm; medium, 1-5 mm; coarse 5 mm-3 cm; and very coarse, greater than 3 cm (Williams, Turner, and Gilbert, 1982, p. 54).

TABLE 3.—*Chemical compositions of monzonites*[1] *and dikes of the Lahore pluton*

	<-------Pyroxene monzonite------>				<-------------------Amphibole monzonite------------------->										<-----Dikes----->	
TABLE NO.	1	2	3	4	5	6	7[2]	8	9	10	11[2]	12	13	14[2]	15	16
FIELD NO.	P-78-53	P-81-10A	P-81-10	P-80-84	P-80-66	P-80-68	P-81-12	P-81-14	P-81-13	P-80-70	P-81-11	P-78-52	P-80-72	P-81-15	P-80-74A	P-80-75
								MAJOR OXIDE COMPOSITION (WEIGHT PERCENT)[3]								
SiO_2	50.3	51.2	51.5	56.1	53.8	53.9	54.7	55.1	55.2	55.4	55.9	56.4	56.9	57.1	57.0	63.1
Al_2O_3	14.3	15.2	15.2	14.9	15.9	14.7	16.1	15.9	16.8	13.9	16.1	13.9	16.4	15.2	17.8	16.0
Fe_2O_3	3.2	3.3	3.5	2.7	3.4	3.3	3.1	2.7	3.4	3.3	2.9	2.7	2.6	2.6	2.5	2.4
FeO	5.6	5.1	5.1	3.9	4.2	4.0	4.1	4.1	3.0	3.6	4.1	3.9	3.0	3.3	2.7	2.1
MgO	6.7	5.7	5.6	5.7	4.4	5.9	3.9	4.2	3.5	6.4	3.6	5.2	4.1	4.8	3.0	2.7
CaO	8.8	8.2	8.1	7.6	7.3	7.3	6.5	6.2	6.0	7.4	5.9	6.7	5.9	6.3	5.8	5.7
Na_2O	2.4	2.4	2.4	3.0	2.7	2.7	2.7	2.7	2.7	2.6	2.9	2.8	3.4	3.0	4.6	4.2
K_2O	4.2	4.4	4.1	4.4	4.6	4.6	5.0	4.6	5.5	4.4	5.2	4.7	5.0	5.2	4.3	1.9
H_2O+	.87	.91	.90	.34	.32	.53	.90	1.4	.81	.53	.71	.73	.96	.78	.69	.86
H_2O-	.21	.25	.26	.20	.26	.42	.20	.29	.30	.39	.53	.18	.13	.21	.09	.11
TiO_2	.98	.99	.98	.53	.80	.69	.80	.84	.65	.67	.76	.64	.55	.62	.40	.55
P_2O_6	.81	.76	.74	.53	.73	.64	.64	.58	.56	.54	.60	.59	.47	.49	.32	.22
MnO	.15	.14	.15	.12	.16	.16	.13	.12	.12	.14	.13	.12	.10	.11	.05	.05
CO_2	.02	.02	.01	.06	.07	.02	.02	.02	.02	.01	.01	.02	.04	.01	.02	.02
BaO[4]	.23	.21	.21	.21	.23	:20	.21	.18	.23	.24	.19	.21	.25	.19	.29	.08
SrO[3]	.16	.14	.14	.18	.17	.15	.15	.12	.17	.20	.13	.17	.18	.15	.24	.07
Rb_2O[3]	.01	.01	.02	.01	.01	.02	.02	.02	.02	.01	.02	.01	.02	.02	.02	.01
Total	98.94	98.93	98.91	100.48	99.05	99.23	99.17	99.07	98.98	99.73	99.68	98.97	100.	100.08	99.82	100.07
								MINOR ELEMENT COMPOSITION (PARTS PER MILLION) LARGE CATIONS[4]								
Rb[5]	125	1352	141	127	133	139	175	169	151	125	200	133.5	157	165	140	72
Ba[6]	2060	1882	1881	1840	2040	1750	1881	1644	2090	2170	1756	1865	2210	1725	2610	717
K[7]	34865	36500	34000	36526	38186	38186	41500	38200	45700	36526	43200	39016	41506	43200	35695	15772
Sr[4]	1330	1208	1194	1540	1430	1300	1252	1027	1430	1670	1126	1450	1520	1260	2020	582
K/Rb	279	270	241	288	287	275	237	226	303	292	216	292	264	262	255	219
Ba/Rb	16	14	13	14	15	13	11	10	14	17	9	14	14	10	19	10
K/Ba	17	19	18	20	19	22	22	23	22	17	25	21	19	25	14	22
								HIGH VALENCE CATIONS[4,8]								
U	4.5	1.5	1.9	3.7	1.5	3.6	4.4	4.0	.9	3.4	4.6	4.4	7.4	4.1	7.1	2.1
Th	5.3	7.1	7.3	12.1	6.2	9.4	26.4	19.7	4.3	21.2	53.8	22.4	25.1	19.3	23.2	10.4
Zr[8]	174.	203.	210.	278.	163.	212.	190.	218.	135.	168.	145.	362.	142.	281.	252.	82
Hf	5.5	5.3	5.8	8.4	4.3	6.8	3.6	5.9	3.6	5.3	4.3	10.3	5.9	8.6	6.8	2.9
Nb[9]	10.0	11.	11.	7.9	5.5	18.0	14.	14.	3.7	13.0	18.	14.0	12.0	15.	6.8	8.2
Ta	.50	1.10	.64	.58	.36	1.1	1.09	.99	.33	.85	1.09	.95	.99	1.04	.54	.58
Zr/Hf	31.6	38.	36.	33.1	37.9	31.2	53.	37.	38.	31.7	34.	35.1	24.1	33.	37.1	28.3
Nb/Ta	20.	10.	17.	13.6	15.3	16.4	13.	14.	11.	15.3	17.	14.7	12.1	14.	12.6	14.1
Th/U	1.2	4.7	3.8	3.3	4.1	2.6	6.0	4.9	10.2	6.2	11.7	5.1	3.4	4.7	3.3	5.0

TABLE 3.—*Chemical compositions of monzonites*[1] *and dikes of the Lahore pluton—Continued*

TABLE NO.	1	2	3	4	5	6	7[2]	8	9	10	11[2]	12	13	14[2]	15	16
	<-------Pyroxene monzonite			------->	<----------				Amphibole monzonite					---------->	<-----Dikes	----->
FIELD NO.	P-78-53	P-81-10A	P-81-10	P-80-84	P-80-66	P-80-68	P-81-12	P-81-14	P-81-13	P-80-70	P-81-11	P-78-52	P-80-72	P-81-15	P-80-74A	P-80-75
FERROMAGNESIAN ELEMENTS[4,8]																
Co	33.1	30.2	30.0	24.6	24.7	29.7	23.4	22.2	20.5	27.7	20.7	25.0	21.2	21.8	16.1	12.7
Zn	93.	116.	113.	77.	84.	82.	106.	90.	67.	71.	81.	85.	76.	84.	56.	60.
Cr	165.	146.	148.	175.	71.	200.	67.	100.	56.	218.	165.	140.	106.	54.	48.	42.
Sc	32.0	28.2	27.9	24.7	23.9	25.9	21.6	21.5	19.0	23.1	18.6	23.3	19.3	19.5	13.0	11.8
RARE EARTH ELEMENTS[8,10]																
La	65.2	55.	61.	64.7	62.0	75.0	79.	75.	56.	78.7	77.	64.8	55.9	59.	50.1	26.2
Ce	128.	122.	119.	119.	118.	138.	144.	131.	100.	142.	150.	124.5	106.	123.	85.2	43.5
Nd	73.	65.	66.	63.	62.	71.	70.	66.	48.	73.	68.	61.5	51.	62.	43.	19.0
Sm	14.5	10.8	11.2	11.8	12.7	13.4	10.9	10.1	8.3	13.3	10.6	11.9	10.1	9.2	8.5	3.2
Eu	3.3	3.02	2.88	2.7	3.0	2.8	3.01	2.75	2.76	2.9	2.68	2.7	2.4	2.38	2.1	.76
Gd	10.0	9.4	9.55	8.0	9.4	10.0	12.0	9.9	7.2	11.2	12.7	9.6	7.4	8.6	7.7	---
Tb	1.3	1.11	1.22	1.0	1.1	1.2	1.29	1.30	1.03	1.1	1.11	1.1	.88	.92	.69	.25
Tm	.47	.39	.345	.35	.34	.17	.28	.41	.29	.24	.39	.40	.38	.29	.25	.21
Yb	2.4	2.1	2.2	1.9	2.0	1.9	2.2	2.2	1.5	1.9	2.4	2.2	1.6	1.8	1.6	.66
Lu	.34	.30	.26	.27	.29	.29	.34	.31	.24	.27	.32	.27	.24	.25	.24	.09
Y[5]	28.	20.	21.	17.	18.	24.	20.	22.	11.	17.	23.	21.	14.	15.	8.	8.
La/Yb	27.	26.	28.	34.	31.	40.	36.	34.	37.	41.	32.	30.	35.	33.	31.	40.
Nb/Y	.4	.6	.5	.5	.3	.8	.7	.6	.4	.8	.8	.7	.9	1.0	.8	1.0
OTHER ELEMENTS[4,8]																
Cs	1.2	1.6	1.5	1.6	1.3	.89	3.7	3.7	1.1	.87	3.4	1.6	1.7	1.5	2.7	1.5
Sb	<.6	<2.0	.6	.27	<.5	<.6	.6	.6	<.8	<.5	<.8	.29	<.5	<.9	.2	<.3

[1] Rocks described in table 1.

[2] Samples used in geochronologic studies.

[3] Rapid rock analyses:
a) P81-10A, P-81-10, P-81-11, through P-81-15; Z. Hamlin, analyst.
b) P-78-53, P-80-66, P-80-68, P-80-70, P-80-84, P-78-52, P-80-72, P-80-74A, P-80-75; P. Aruscavage, D. Kobilis, analysts.
c) H. Smith, R. Somers, analysts.

[4] Samples P-80-66, P-80-70, P-78-52, and P-80-74A are averages of two analyses.

[5] Isotope dilution mass spectroscopy analysis: J. Arth and J. Carlson, analysts. P-81-10A, P-81-10 through P-81-15. Instrumental Neutron Activation Analysis: G. Wandless, analyst. P-78-53, P-80-66, P-80-68, P-80-70, P-80-84, P-80-72, P-80-74A, P-80-75. X-ray spectroscopic analyses: H.J. Rose, J. Lindsay, B. McCall, G. Sellers, R. Johnson, analysts.

[6] X-ray spectroscopic analyses: R. Johnson, H. J. Rose, B. McCall, G. Sellers and J. Lindsay, analysts. Instrumental Neutron Activation Analysis: G. Wandless, analyst. P-78-53, P-80-66, P-80-68, P-80-70, P-80-84, P-80-74A, P-80-75. L. J. Schwarz, analyst.

[7] Calculated from K_2O whole-rock rapid analysis.

[8] Instrumental Neutron Activation Analysis: G. Wandless, analyst, except L.J. Schwarz, analyst.

[9] Spectrophotometric analyses:
a) P-78-53, P-80-66, P-80-68, P-80-70, P-80-84, P-78-52, P-80-72, P-80-74A, P-80-75; P. Aruscavage, D. Kay, analysts.
b) P-81-10A, P-81-10, P-81-11 through P-81-15; Z. Hamlin, analyst.
c) P. Aruscavage, analyst.

[10] All REE values of La through Lu are averages of two analyses, except samples P-78-53, P-80-68, P-80-84, and P-80-75.

TABLE 4.—*Chemical compositions of granodiorites*[1] *and inclusions/intrusions*[1] *of the Ellisville pluton*

	<-----	-----	-----	-----	-----	-----	-----	Granodiorites	-----	-----	-----	-----	-----	-----	----->	Inclusions/Intrusions		
SPEC NO.	1[2/]	2	3	4[2/]	5[2/]	6	7[2/]	8[2/]	9	10	11[2/]	12[2/]	13[2/]	14	15[2/]	16	17	18
FIELD NO.	P-80-38	P-80-20	P-80-24	P-80-33	P-80-32.	P-80-26	P-80-37	P-25	P-80-9	P-80-41	P-80-36	P-80-39	P-80-42	P-80-8	P-80-40	P-80-44	P-80-45	P-80-43
								MAJOR OXIDE COMPOSITION (WEIGHT PERCENT[3/])										
SiO_2	72.3	71.3	70.3	69.5	68.8	68.5	68.5	68.4	68.2	68.0	67.8	67.7	67.2	67.1	66.4	54.0	54.3	54.8
Al_2O_3	15.3	15.1	16.8	14.6	15.1	15.5	15.3	15.4	15.5	15.2	15.3	15.6	15.8	15.9	15.9	9.7	12.1	19.8
Fe_2O_3	1.0	.3	.8	1.7	1.7	1.8	1.8	1.6	1.5	1.5	1.7	1.4	1.4	1.6	1.6	2.4	2.4	2.1
FeO	.3	2.3	1.4	1.3	1.2	1.0	2.0	1.4	1.1	2.1	1.7	1.9	1.9	1.4	1.5	5.1	5.0	4.3
MgO	.23	.55	.97	1.2	1.4	.74	1.6	.66	.88	1.6	1.4	1.5	1.6	.88	1.3	10.6	8.7	2.8
CaO	1.9	2.2	2.6	3.2	3.4	3.9	3.7	3.3	4.1	3.8	3.5	3.6	4.1	4.3	3.7	14.4	10.4	5.7
Na_2O	3.8	3.6	3.8	3.0	3.4	2.7	3.2	3.7	3.1	3.3	3.2	3.3	3.5	3.4	3.5	1.6	2.0	4.6
K_2O	4.0	3.1	3.0	2.8	2.8	2.8	3.1	3.5	3.6	3.0	3.1	3.2	2.7	3.1	3.2	1.3	2.0	3.0
H_2O+	.55	.65	.70	.50	.57	2.1	.70	.55	1.6	.63	.67	.69	.77	.10	.73	.66	.67	1.1
H_2O-	.29	.16	.17	.29	.28	1.6	.33	.05	1.1	.33	.30	.24	.27	.18	.33	.30	.42	.23
TiO_2	.10	.26	.34	.35	.32	.26	.53	.40	.32	.51	.45	.48	.43	.38	.37	1.0	1.3	1.1
P_2O_5	.04	.11	.19	.13	.11	.11	.21	.15	.11	.19	.15	.20	.14	.19	.13	.22	.39	.71
MnO	.02	.04	.03	.05	.02	.03	.04	.03	.02	.06	.03	.04	.04	.01	.03	.03	1.2	.07
CO_2	.01	.02	<.01	.02	.01	.02	.01	.13	.02	.02	.01	.01	.02	.01	.02	.01	.01	.02
BaO[2/]	.04	.12	.11	.08	.08	.08	.08		.09	.09	.09	.09	.10	.08	.09	--	--	--
SrO	.02	--	--	.05	--	--	.06	--	--	--	.06	.07	.07	--	.06	--	--	--
Total	99.90	99.83	101.21	98.77	99.19	101.40	101.16	99.27	101.24	100.33	99.46	99.62	100.04	98.63	98.86	101.32	100.89	100.33
								MINOR ELEMENT COMPOSITION TRACE ELEMENT ABUNDANCE (PARTS PER MILLION) LARGE CATIONS[4/]										
K[5/]	32200	25700	24900	23200	23200	23200	25700	29000	29900	24900	25700	26600	22400	25700	26600	10792	16603	24904
Rb	165[8/]	111	84	108[8/]	119[7/]	121	98[8/]	100	141	105[7/]	103[8/]	97[8/]	78[8/]	90	100[8/]	38	44	90
Ba	366	1004	981	672	729	704	756	654	723	844	843	847	934	718	800	336	500	1177
Sr	209[8/]	338[7/]	533[7/]	426[8/]	425[7/]	324[7/]	521[8/]	396[8/]	345[7/]	501[7/]	515[8/]	552[8/]	565[8/]	509[7/]	519[7/]	295	407	1045
K/Rb	195	231	296	215	195	192	262	290	212	237	249	274	287	286	266	284	377	277
Ba/Rb	2	9	12	6	6	6	8	7	5	9	8	9	12	8	8	9	11	13
K/Ba	88	26	25	35	32	33	34	44	41	30	30	31	24	36	33	32	33	21
								HIGH-VALENCE CATIONS[4,6/]										
Th	9.7	14.0	11.0	15.8	8.4	9.2	13.6	14.0	12.0	14.4	12.6	15.0	9.6	11.9	10.0	2.2	4.9	16.3
U	4.5	2.2	1.4	7.0	5.2	2.4	1.6	3.0	6.2	1.4	2.9	2.3	1.5	1.9	1.6	.8	2.4	2.6
Zr	82	147[7/]	170[7/]	130	164	103[7/]	200	195[7/]	158[7/]	187	160	202	150	166[7/]	110	153	170	537
Hf	2.0	4.1	4.0	2.8	3.1	2.9	4.4	4.4	4.1	4.6	3.7	4.9	3.6	3.9	3.1	3.9	4.0	10.0
Nb[8/]	10.0	7.5	8.8	12.0	10.0	7.7	13.0	9.7	13.0	12.0	12.0	12.0	7.7	12.0	7.9	6.5	15	22
Ta	1.18	1.16	.60	1.22	.96	.81	1.18	--	1.00	1.08	1.06	.92	.53	1.18	.69	.51	1.05	.76
Th/U	2.2	6.4	7.9	2.3	1.6	3.8	8.5	1.2	1.9	10.3	4.3	6.4	6.2	6.3	6.3	2.75	2.0	6.3
Zr/Hf	44	36	42	46	53	36	45	44	38	41	43	41	42	43	35	39.2	42.5	53.7
Nb/Ta	8.5	<4.	<8.	9.8	10.4	<6.	11	11.3	6.4	11.1	--	11.3	14.5	<4.	11.4	12.7	14.3	28.9

TABLE 4.—*Chemical compositions of granodiorites[1] and inclusions/intrusions[1] of the Ellisville pluton*—Continued

	<------- Granodiorites														------->	Inclusions/Intrusions		
SPEC NO.	1[2]	2	3	4[2]	5[2]	6	7[2]	8[2]	9	10	11[2]	12[2]	13[2]	14	15[2]	16	17	18
FIELD NO.	P-80-38	P-80-20	P-80-24	P-80-33	P-80-32	P-80-26	P-80-37	P-25	P-80-9	P-80-41	P-80-36	P-80-39	P-80-42	P-80-8	P-80-40	P-80-44	P-80-45	P-80-43
										FERROMAGNESIAN ELEMENTS[3]								
Co	1.1	3.6	6.2	6.7	6.4	6.4	9.1	6.5	6.3	8.4	8.0	8.5	8.5	6.2	6.6	24.5	33.5	14.4
Zn	19	44	41	42	40	36	51	72	43	54	44	53	47	42	45	77	79	82
Cr	4.6	5.4	13.0	22.2	23.4	10.6	23.2	14.5	10.9	22.5	20.6	24.4	21.0	12.0	18.1	460	255	14.6
Sc	2.28	4.06	7.34	5.96	5.85	4.92	7.90	7.40	5.89	7.26	7.13	7.63	7.39	6.76	6.28	51.2	43.7	10.5
										RARE EARTH ELEMENTS[4,9]								
La	15	13	32	33	20	15	45	41	32	51	38	47	32	25	33	17	42	102
Ce	24	42	71	52	34	43	71	69	89	84	68	77	56	75	53	35	64	217
Nd	10	8	20	22	16	10	29	27	21	31	26	30	20	19	19	28	42	76
Sm	2.1	1.5	3.2	3.8	2.7	2.1	4.0	4.2	3.6	4.4	3.4	3.8	2.7	3.5	2.7	5.5	8.0	10.8
Eu	.52	.52	.78	.68	.62	.52	.97	.86	.70	1.00	.86	.97	.69	.78	.68	1.27	1.82	2.06
Gd	2.0	1.8	2.8	3.2	2.5	1.8	4.4	3.5	2.5	4.1	3.6	3.2	4.3	3.4	3.1	4.6	5.7	6.4
Tb	.20	.22	.28	.30	.26	.18	.40	.37	.29	.40	.33	.34	.29	.37	.29	.7	1.04	.89
Ho	--	.2	.3	--	.2	--	.3	--	.4	.3	.3	.4	.2	.3	.2	--	--	--
Tm	.13	--	.15	--	.12	--	.19	.20	--	<.20	.14	.19	.10	.10	.07	.28	.37	.36
Yb	.6	.8	.6	.8	.7	.5	.9	.8	.8	.9	.8	.8	.5	.8	.5	1.8	2.0	1.7
Lu	.08	.11	.10	.11	.10	.09	.14	.12	.11	.13	.12	.12	.09	.11	.09	.27	.29	.26
Y[8]	15	13	14	16	14	10	17	10	9	16	14	14	13	13	13	17	20	21
La/Yb	25	16	53	41	29	25	50	--	40	57	48	59	64	31	66	63	21	60
Nb/Y	--	<.4	<.4	--	--	<.5	--	--	.1	--	--	--	--	.1	--	.4	.6	1.0
										OTHER ELEMENTS[7]								
Cs	3.3	2.0	1.4	4.6	2.2	2.7	1.6	2.3	3.5	1.6	2.4	2.1	1.4	1.5	1.5	.6	.8	1.2
Sb	1.1	.7	1.2	1.2	.8	.4	.8	--	.7	2.0	.5	.3	.4	.6	.6	.7	1.6	.8

1/ Rocks are described in table 2.
2/ Samples used in geochronologic studies.
3/ Determined by rapid rock analyses:
a) P-80-32, P-80-33, P-80-36 through P-80-42; E. Campbell, D. Kobilis, analysts.
b) P-80-8, P-80-9, P-80-20, P-80-24, P-80-25, P-80-26; H. Smith, R. Somers, analysts.
4/ Determined by instrumental neutron activation analysis; L.J. Schwarz, analyst; average of two or three measurements per sample; and by X-ray spectroscopy. J. Lindsay, B. McCall, G. Sellers, and R. Johnson, analysts.
5/ Calculated from K_2O whole-rock rapid analyses.
6/ P-80-33, P-80-36, P-80-37, P-80-38, P-80-39, P-80-40, P-80-42, analyzed by isotope dilution mass spectrometry, J.G. Arth, J. Carlson, analysts.
7/ X-ray spectroscopy, H.J. Rose, Jr., J. Lindsay, B. McCall, G. Sellers, and R. Johnson, analysts.
8/ Spectrophotometric analysis:
a) P-80-32, P-80-33, P-80-36 through P-80-42, E. Campbell, analyst.
b) P-80-8, P-80-9, P-80-20, P-80-24, P-80-26, P-25, P. Aruscavage, analyst.
9/ All REE values of La through Lu are averages of two analyses.

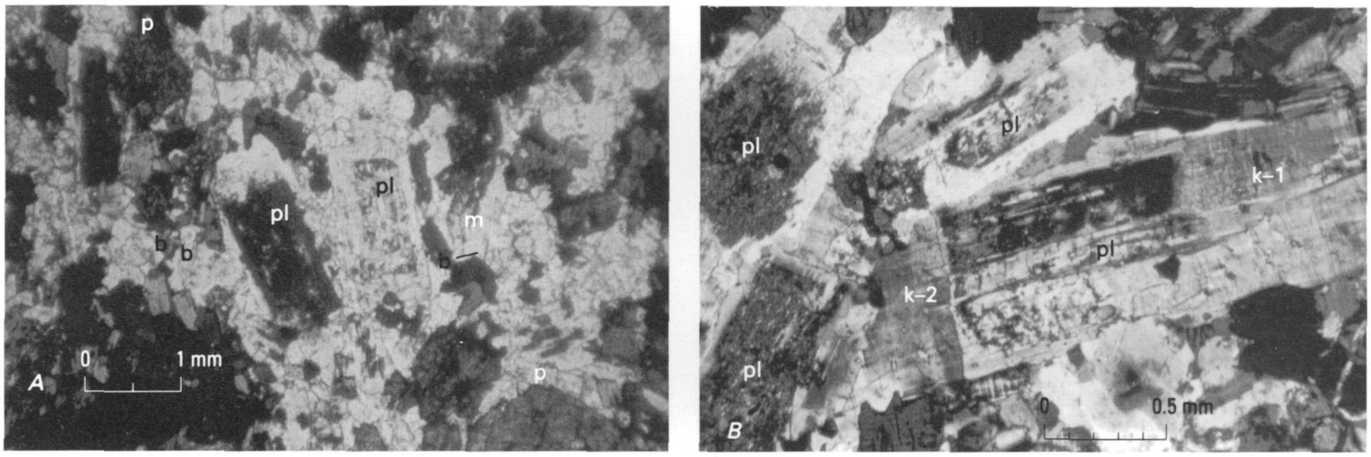


FIGURE 8.—Photomicrographs of pyroxene monzonite (P-81–10) of the Lahore pluton with altered plagioclase. *A*. Calcic core of plagioclase (pl) is moderately to heavily altered to fine-grained epidote. Groundmass contains potassic feldspar, brown biotite (b), and magnetite (m). Pyroxene (p) is megacrystic: plane light. *B*. Heavily to moderately epidote-altered plagioclase (pl) locally being replaced by microcline (k-1), which also is a groundmass constituent (k-2): crossed nicols. Lahore Quadrangle at lat 38°11′07″N. and long 77°56′31″W.

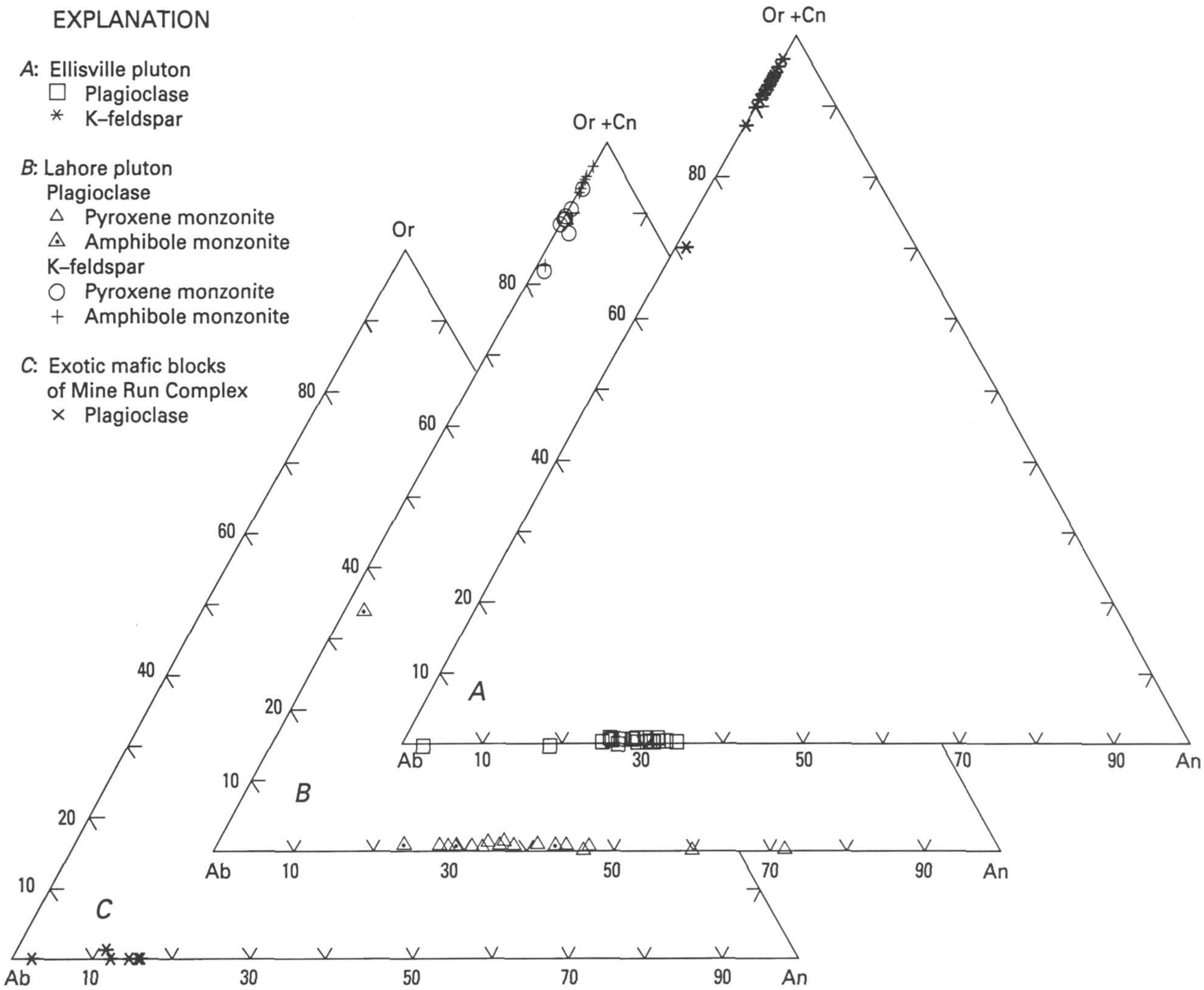


FIGURE 9.—Ternary Or-Ab-An diagram showing compositional range and distribution of feldspars from *A*: Ellisville pluton granodiorite, *B*: the Lahore pluton monzonitic rocks, and *C*: exotic mafic blocks from melange of the Mine Run Complex.

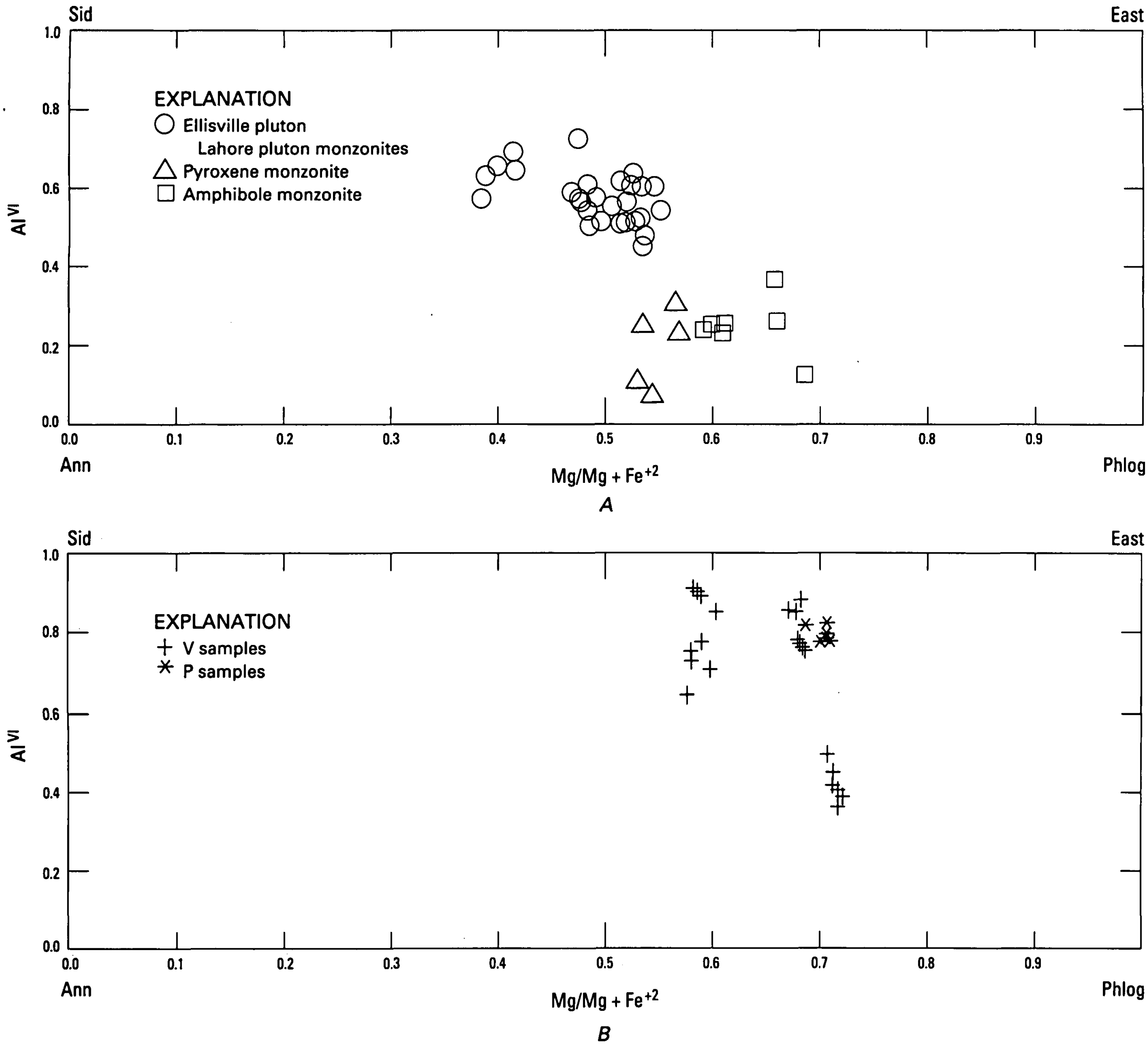


FIGURE 10.—Diagram showing composition range of biotite from: *A*: Lahore pluton monzonites listed in table B-8 and Ellisville pluton granodiorites listed in table C-3 and *B*: contact-metamorphosed rocks of the Chopawamsic Formation listed in table D-1. Diagram is modified from Guidotti (1984, fig. 35).

perthitic potassic feldspar (fig. 12). Potassic feldspar also occurs in smaller grains as a groundmass constituent. Electron microprobe analyses of potassic feldspar from amphibole monzonite are listed in table B-7B. Potassic feldspar of the amphibole monzonites differs a little from that in the pyroxene monzonites in that it contains slightly more molecular orthoclase (Or) and less albite (Ab) (compare average analyses of tables B-7A and B-7B). Potassic feldspars in pyroxene monzonite and amphibole monzonite have generally similar celsian (Cn) contents (table 5).

Quartz: Quartz is a rare-to-sparse groundmass constituent that commonly has undulose extinction. It also occurs as a chadacryst in poikilitic potassic feldspar and amphibole.

Myrmekite: This intergrowth commonly has developed within small grains of plagioclase where such grains occur marginal to potassic feldspar or as bulbous protrusions where small grains of plagioclase are completely enclosed by potassic feldspar. Locally, where in contact with potassic feldspar, some myrmekite has clear albitic(?) rims.

Amphibole and pyroxene: Pleochroic, colorless-to-green amphibole is one of the most abundant constituents of this suite of rocks. Electron microprobe analyses, which only measure total Fe and which is reported as FeO, are listed for this amphibole in table B-10. The cation calculations for this and other amphiboles of this report, as stated in appendix F-1, are made on the basis that all the Fe is present as FeO as listed in table B-10 as well as tables A-5, B-3, C-7, and D-9. However, some of the amphiboles in these tables have also been calculated by the computer program of Freeborn and others (1985), on the basis that they contain both FeO and Fe_2O_3, and these cation formulations (Pavlides, unpublished data) are the basis for the amphibole classification diagrams of figure 3. The amphiboles from the amphibole monzonites of the Lahore pluton, under this classification scheme, are mostly edenitic hornblende (fig. 3). Spectrophotometric and wet chemical analyses by John Marinenko (written commun., 1986) of the U.S. Geological Survey also indicate that Fe_2O_3 is an appreciable chemical constituent in amphiboles of the amphibole monzonites as shown by the analyses (in percent) listed below:

Sample	FeO	Fe_2O_3	FeO_{t1}	FeO_{t2}	F
P-81–12	5.76	12.2	17.96	18.28	.19
P-81–15	5.29	9.4	14.69	14.37	.30

Furthermore, the FeO_{t1} (total FeO calculated from $FeO+Fe_2O_3$) and FeO_{t2} (total FeO analyzed by electron microprobe; table B-10, analyses 82A and 49A) compare favorably. These amphibole analyses are very rich in Fe_2O_3 whereas the whole-rock analyses of these rocks (P-81–12 and P-81–15, table 3) have $Fe_2O_3<FeO$. Apparently, although these rocks formed under generally reducing conditions, an oxidizing environment prevailed at the time of amphibole crystallization. At many places the amphibole has cores or patches of relict pyroxene as in some of the pyroxene monzonites, and such amphibole, as stated earlier, may have formed by alteration from pyroxene during late-stage crystallization of the parent magma. In one rock (P-80–70), amphibole encloses well-formed pyroxene, with sharp contacts (fig. 13). This feature supports a magmatic overgrowth of younger amphibole on older pyroxene and contrasts with the irregular amphibole-after-pyroxene replacement texture of figure 11. The location of electron microprobe analyses of this amphibole and the enclosed pyroxene are shown on figure 13 and are listed, respectively, in tables B-10 and B-5. Pyroxenes enclosed by hornblende in the amphibole monzonite (table B-5, analyses 62–74A) are diopside. Thus, they are distinguishable from augite of the pyroxene monzonites (fig. 7). The amphibole of figure 13 is compositionally an edenitic hornblende (table B-10, analyses 55–69A) as are many of the amphiboles found in other amphibole monzonites (table B-10, analyses 5–15A, 20, 23A-24, 26, 30A, 32, 37A, 42, 45, 48, 50–53A, 70–73) and summarized in figure 3. Small grains of quartz, plagioclase, potassic feldspar, magmatic epidote, apatite, and amphibole are present as inclusions in amphibole.

Biotite: An important and common accessory of these rocks is pleochroic, brown to greenish-brown biotite. The range of biotite composition is shown in figure 10. It occurs as a groundmass constituent in subhedral as well as ragged crystals. In some specimens it is poikilitic and encloses fine-grained euhedral apatite and primary titanite. Locally biotite occurs within clots or clumps, and, in such habit, it is closely associated with subhedral epidote. Electron microprobe analyses of biotite are given in table B-8. Analyses of FeO, Fe_2O_3 and H_2O+ content (in percent) of two biotite concentrates from separate samples of amphibole monzonite by Hezekiah Smith and William d'Angelo of the U.S. Geological Survey (written commun., 1986) are listed below and indicate a fairly homogeneous redox potential during biotite crystallization.

Sample	Fe_2O_3	FeO	H_2O+	H_2O-	FeO_t
P-81–11	5.7	13.8	3.0	.02	18.7
P-81–12	4.9	13.4	2.6	.01	17.8

The total FeO content (FeO_t) of these biotites is generally higher than the FeO content determined by electron microprobe analyses in biotites from other amphibole monzonites (compare FeO_t with FeO of analyses 1–10 of table B-8B).

Epidote: In these rocks, epidote and clinozoisite(?) occur mostly as fine-grained granular alteration minerals within plagioclase. Less commonly, epidote occurs as large subhedral grains. Some of this epidote has a light-yellow pleochroism; it has a high iron content and compositionally is Ps_{28} (table B-9B).

Magnetite: The principal fine-grained, opaque oxide is magnetite and imparts a noticeable magnetic susceptibility to this suite of rocks. It ranges from euhedral to subhedral in habit. Some opaque oxide locally is rimmed by titanite.

Titanite: This minor fine-grained constituent occurs in diamond-shaped euhedra and as rounded grains. As stated above, in some rocks it mantles opaque oxides. Locally, titanite has undergone partial alteration to "leucoxene." Titanite is an inclusion in many poikilitic minerals.

Apatite: A sparse fine-grained prismatic mineral, apatite generally occurs as an inclusion within poikilitic minerals.

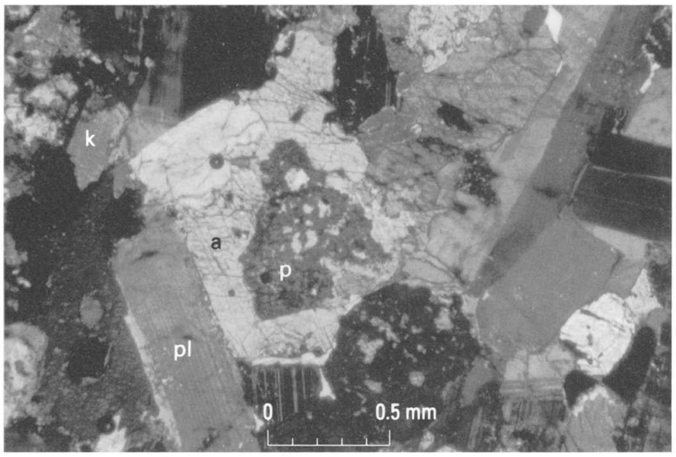


FIGURE 11.—Photomicrograph of monzonite (P-80–67) of the Lahore pluton with poikilitic augite (p), irregularly enclosed by amphibole (a). Other minerals in section include plagioclase (pl) and potassic feldspar (k). Crossed nicols. Lahore Quadrangle at lat 38°11′46″N. and long 77°57′22″W.

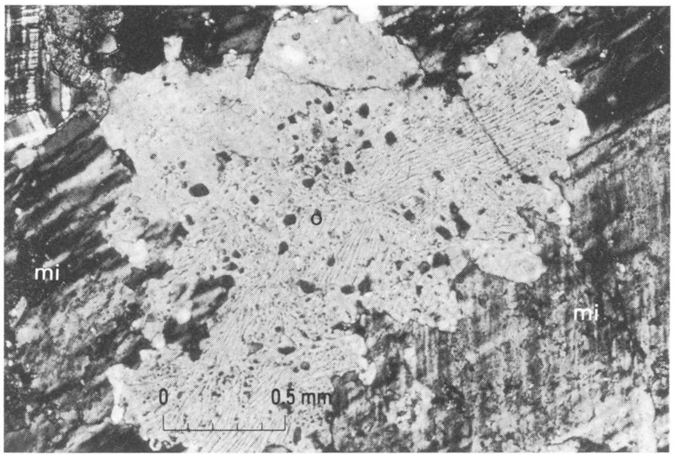
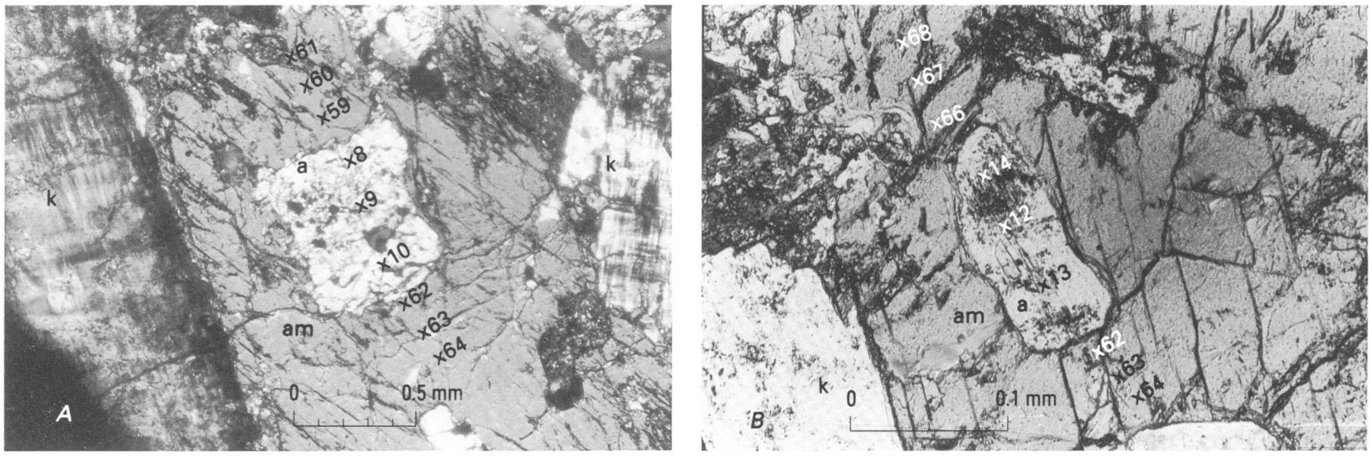


FIGURE 12.—Photomicrograph of perthitic (string) orthoclase (o) enclosed by Carlsbad twinned microcline (mi) megacryst in amphibole monzonite (P-81–11) of the Lahore pluton. Crossed nicols. Lahore Quadrangle at lat 38°10′09″N. and long 77°57′36″W.



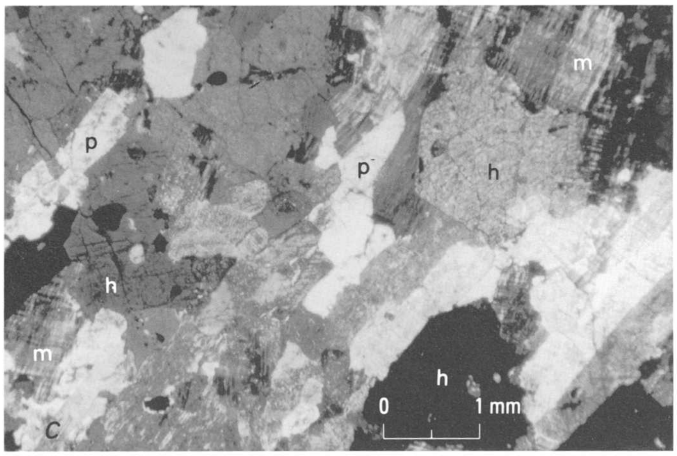


FIGURE 13.—Photomicrographs of amphibole monzonite of the Lahore pluton containing magmatic(?) amphibole enclosing augite. Points represent electron probe analyses listed in tables B-5 (pyroxene) and B-10 (amphibole). *A*. Subangular poikilitic, altered augite (a) enclosed in sharp contact by amphibole (am). Other major mineral is potassic feldspar (k). Specimen P-80–70. *B*. Oval-shaped slightly altered poikilitic augite (a) enclosed by and in sharp contact with amphibole (am); k is potassic feldspar: plane light. Specimen P-80–70. Lahore Quadrangle at lat 38°11′22″N. and long 77°57′14″W. *C*. Amphibole monzonite (P-81–15) of the Lahore pluton from which an Ar release spectrum was obtained (fig. 38 and table 9). Coarse-grained, green, poikilitic, amphibole (h) (see table B-10, analyses 27–49) is intergrown with foliation-aligned perthitic microcline (m) and plagioclase (p). Crossed nicols. Lahore Quadrangle at lat 38°11′37″N. and long 77°57′37″W.; also see plate 2*B* for location.

TABLE 5.—*Percentage of barium oxide (BaO) content, celsian (cn), and orthoclase (or) molecular proportions in feldspars of monzonites of the Lahore pluton and granodiorites of the Ellisville pluton. Whole-rock content of Ba and Sr (ppm) for each specimen taken from text table 3 (monzonites) and table 4 (granodiorites)*

Spec. No.	BaO	Feldspar cn	or	Appendix table: Analyses No.	Whole rock Ba	Whole rock Sr
			1. Lahore monzonites			
			A. Amphibole quartz monzonite			
			Plagioclase			
P-81–15	.02	.03	.02	B-6 : 24	1725	1260
	.04	.08	.86	do : 28		
	.03	.05	.90	do : 32		
	.05	.10	1.21	do : 38		
	.02	.03	.87	do : 41		
	.03	.05	1.09	do : 47		
Average	.03	.06	.82			
			Potassic feldspar			
P-81–15	.67	1.27	92.95	B-7 : 4	1725	1260
	.39	.73	82.12	do : 8		
	.59	1.15	95.06	do : 12		
Average	.55	1.05	90.04			
			B. Amphibole monzonites			
			Potassic feldspar			
P-80–70	.80	1.54	93.25	B-7 : 16	2170	1670
	.76	1.47	92.21	do : 20		
	.97	1.86	92.64	do : 24		
Average	.84	1.62	92.70			
			C. Pyroxene monzonites			
			Potassic feldspar			
P-81–10	.67	1.28	87.69	B-7 : 5	1881	1194
	.82	1.53	87.34	do : 9		
	.76	1.41	87.69	do : 13		
	.74	1.38	80.81	do : 17		
Average	.75	1.40	85.88			
P-78–53	.85	1.58	87.00	B-7 : 21	2060	1330
	1.00	1.87	94.48	do : 25		
	.97	1.78	88.69	do : 29		
Average	.94	1.74	90.05			
			2. Ellisville granodiorites			
			Plagioclase			
P-80–39	.03	.05	.54	C-1 : 26	847	552
	.01	--	.93	do : 30		
	.01	--	.60	do : 35		
Average	.02	.02	.69			
P-25	--	--	.88	C-1 : 42	654	396
	--	--	.92	do : 46		
	.03	.05	.90	do : 50		
	--	--	.67	do : 54		
Average	.01	.01	.84			
			Potassic feldspar			
P-80–8	.27	.49	92.77	C-2 : 5	718	509
	.35	.62	92.69	do : 10		
Average	.31	.56	92.73			
P-80–32	.51	.92	93.95	C-2 : 14	729	425
	.40	.73	89.01	do : 21		
Average	.46	.82	91.48			
P-80–19	.84	1.53	91.22	C-2 : 25	--	
P-80–20	.92	1.66	84.14	do : 36	1004	338
	.86	1.55	91.23	do : 40		
Average	.89	1.60	88.68			

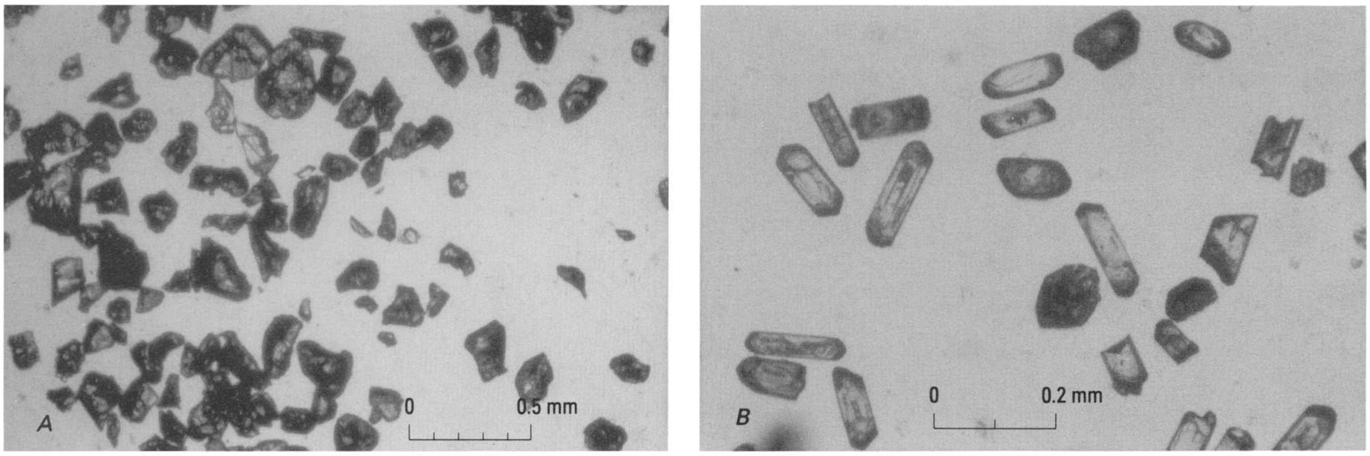


FIGURE 14.—Photomicrographs of zircon concentrates from *A*: Lahore pluton monzonite (P-81–12); this zircon concentrate is composed of anhedral fragments ranging up to 0.4 mm in size. *B*: Ellisville pluton granodiorite (P-80–32); zircons are mainly euhedral with inclusions and smaller in grain diameter as compared to the Lahore monzonites. This Ellisville granodiorite sample has a concordant uranium-lead age of 433 m.y. (see table 7 and fig. 37B).

Chlorite: A minor mineral, chlorite mostly occurs as a pseudomorph of biotite and, less commonly, of amphibole.

Zircon: Only a few grains of zircon were noted in thin sections, but this mineral is probably of greater abundance than microscopically recognized because sufficient quantities have been separated from these rocks for purposes of dating by the U/Pb method, and these zircons are generally anhedral (fig. 14).

Allanite: This is a rare, fine-grained metamict constituent in several monzonites.

MAFIC PLUTON

The Lahore Complex includes a very poorly exposed mafic pluton at its north end (pl. 2*A*), which has been described elsewhere (Pavlides, 1989). It apparently is composite, as suggested by the few available bedrock exposures. It contains partially serpentinized pyroxenite consisting of well-formed diopside (table B-1, and fig. 7) that is rimmed by antigorite (table A-1, and fig. 2, nos. 11–13). Amphibolitic, diopside-metapyroxenite is also present in this ultramafic mass. It occurs as a medium-grained rock with cores of diopside enclosed by tremolite that apparently has replaced the margins of diopside (Pavlides, 1989, fig. 7*E*). Electron microprobe analyses of the tremolite are listed in table B-3 and fig. 3 I*A*. Thin, gash veinlets of chlorite (table B-4) locally are present in parts of the ultramafic mass. The ultramafic mass is inferred to be intruded by the granitoids of the Lahore pluton on its south side although this intrusive relationship cannot be demonstrated unequivocally because of poor exposure. Although originally interpreted as an olistolith (Pavlides, 1989), this mass is now considered to be an early mafic intrusion that preceded emplacement of the Lahore pluton.

DIKES OF THE LAHORE COMPLEX

Tonalite: Thin (7.6 cm wide) tonalitic dikes cut the Lahore pluton locally. They are finely porphyritic leucocratic rocks composed predominantly of plagioclase and quartz with only minor amounts of potassic feldspar. Fine-grained, brown biotite with a pronounced orientation imparts a strong foliation to the rocks. Abundant, subhedral epidote, in part, may be of magmatic origin. Granular to crystalline titanite is a common accessory as is subhedral apatite. White mica is locally present in fairly large amounts. Green, locally poikilitic amphibole is the coarsest mineral present and also occurs as phenocrysts. These intrusive epidote- and titanite-bearing tonalite dikes are interpreted as having been derived from the Ellisville pluton.

Aplitic dikes composed of fine-grained quartz and feldspar are also locally present in the mafic mass of the Lahore Complex.

ELLISVILLE PLUTON

The Ellisville pluton is composed almost exclusively of granodiorite under the Streckeisen (1976) modal classification system (fig. 4*A*) as well as the chemical classification system (fig. 4*B*) of De La Roche and others (1980). Modal analyses are given in table 2. The Ellisville granodiorites typically are coarse- to medium-grained, commonly mesocratic, equigranular to porphyritic in texture and include massive to strongly foliated biotitic rocks. Foliation is imparted mostly by the biotite and, in some places, also by the dimensional orientation of felsic minerals. Foliated, porphyritic rocks locally have well-developed trachytoid textures (fig. 15). The dominant felsic minerals of these rocks are quartz, plagioclase, and potassic feldspar; biotite is invariably the characteristic accessory mineral (table 2). White potassic feldspar commonly forms the megacrysts in porphyritic varieties. The megacrysts have a wide range in size, with 1.5 cm being their average length and 1.0 cm their average width.

MINERALOGY AND PETROGRAPHY

Plagioclase: The compositional range of plagioclase is shown on figure 9 and listed in table C-1. It is locally zoned (fig. 16), and in some zoned crystals the core of the plagioclase is altered in varying amounts to white mica or granular epidote-zoisite or both. Polysynthetic twinning of plagioclase in some granitoids is not continuous; in places it may be partial or enclosed (Spry, 1969, fig. 24, p. 69–72). Some granitoids contain plagioclase that is poikilitic and encloses smaller, randomly oriented, earlier formed plagioclase. Not uncommonly, plagioclase is locally myrmekitic (fig. 17). The zoned plagioclase grains have cores that range from An_{37-28} (table C-1, analyses 47 and 39) to rim compositions of An_{33-16} (table C-1, analyses 31 and 27). In general, the zoning ranges from a core of sodic andesine to an edge composition of oligoclase (table C-1). This more sodic core composition in zoned plagioclase contrasts with the more calcic plagioclase cores of the pyroxene monzonites of the Lahore pluton (compare table C-1, with table B-6). Plagioclase grains analyzed at random within some rocks compare, in general, to the average analyses for the zoned plagioclase (compare table C-1, nos. 1–8, 12, 18, and 19–21 with nos. 26, 30, 35, 36, 37, 38, 42, 46, 50 and 54). Plagioclase in both the Ellisville granodiorites and the amphibole monzonites of the Lahore pluton, in general, are compositionally similar (compare table C-1, with table B-6B). Carlsbad and polysynthetic twinning are common, but some plagioclase is untwinned; it can be distinguished by the white mica and epidotic alteration it has undergone. In rocks that have undergone incipient weathering, plagioclase is clearly the first of the felsic minerals to break down. Such weathered plagioclase is cut by a mosaic of fractures confined to plagioclase, whereas the adjoining and enclosing quartz and potassic feldspar grains commonly are fresh.

Potassic feldpar: Orthoclase and microcline constitute the potassic feldspars of the Ellisville pluton granodiorites; the compositional range of potassic feldspars is given in table C-2, and shown in figure 9. The K_2O content of these feldspars is generally high, in the range of 15 to 16 weight percent. The CaO content is in trace amounts. The Ab content of potassic feldspars in Ellisville granodiorites is similar to that in amphibole monzonites of the Lahore Complex, but the average is less than the Ab contents of plagioclases in the pyroxene monzonites. The BaO contents of the potassic feldspars of the Ellisville granodiorites, as expected, exceed that of the associated plagioclases (compare tables C-1 and C-2, also see table 5). However, potassic feldspars of the Ellisville granodiorites generally contain less BaO than the potassic feldspars of the monzonites of the Lahore Complex (compare table C-2, with tables B-7A and B-7B). This may be because biotite, which also is a sink for Ba, is more abundant in the Ellisville granodiorites. In many rocks, potassic feldspars are perthitic, with string and flame perthite being common types. Perthitic microcline generally is the most common potassic feldspar and is petrographically differentiated from orthoclase by its gridiron twinning. In contrast, only orthoclase has Carlsbad twinning. In many granodiorites potassic feldspar occurs as a groundmass constituent as well as poikilitic megacrysts. Where poikilitic, potassic feldspar commonly encloses small crystals of plagioclase. Plagioclase inclusions may be myrmekitic, and some may simply have clear sodic rims (fig. 16). Plagioclase inclusions in a few potassic feldspar host grains are dimensionally aligned along the margins of the potassic feldspar (fig. 18). In many places, however, potassic feldspars contain randomly aligned inclusions of plagioclase as well as of epidote and biotite.

Myrmekite: Myrmekite is a ubiquitous fine-grained minor constituent of the Ellisville granodiorites. Where it has developed, it is invariably associated with potassic feldspar. It may be entirely enclosed by potassic feldspar, or it may be marginal to the potassic feldspar crystals, and in such cases it commonly forms bulbous protrusions into the potassic feldspar (fig. 17). Some myrmekite contains relict polysynthetic twinning of plagioclase, and plagioclase crystals only partially enclosed by potassic feldspar are myrmekitic at the end enclosed by the potassic feldspar; the part of the plagioclase not enclosed by potassic feldspar remains as unmodified plagioclase. Myrmekite also occurs as a groundmass constituent but in all cases was formed in contact with groundmass potassic feldspar. The origin of myrmekite is controversial in the geologic literature and will not be discussed at length here. However, judging by the relationships observed in the Ellisville granodiorites and the relationships described by Phillips and Carr (1973) in deformed and undeformed felsic rocks from New South Wales, a striking similarity in myrmekite morphology and localization exists between the two areas. It is also concluded, in agreement with Phillips and Carr, that such myrmekite formed principally through a process of

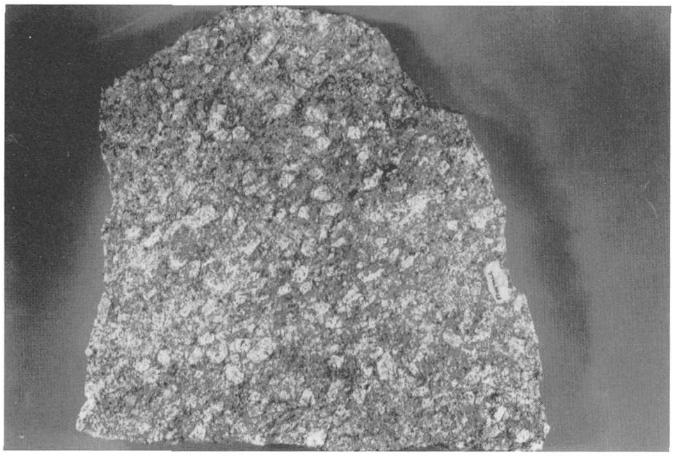


FIGURE 15.—Photograph of hand specimen of granodiorite (P-84–29) of the Ellisville pluton with trachytoid texture of poikilitic feldspar phenocrysts. Biotite locally visible as thin black tabular grains has same alignment as feldspar phenocrysts. Painted label on slab is 3.0 cm long. Mineral Quadrangle at lat 38°04′33″N. and long 77°58′15″W.

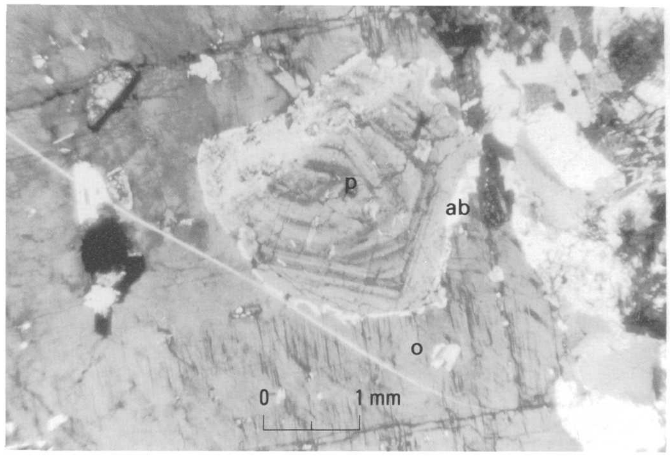


FIGURE 16.—Photomicrograph of granodiorite (P-80–8) of the Ellisville pluton with zoned plagioclase (p) and with exsolved albitic margin (ab) along outer rim and large orthoclase (o) phenocryst. Crossed nicols. Mineral Quadrangle at lat 38°06′59″N. and long 77°54′49″W.

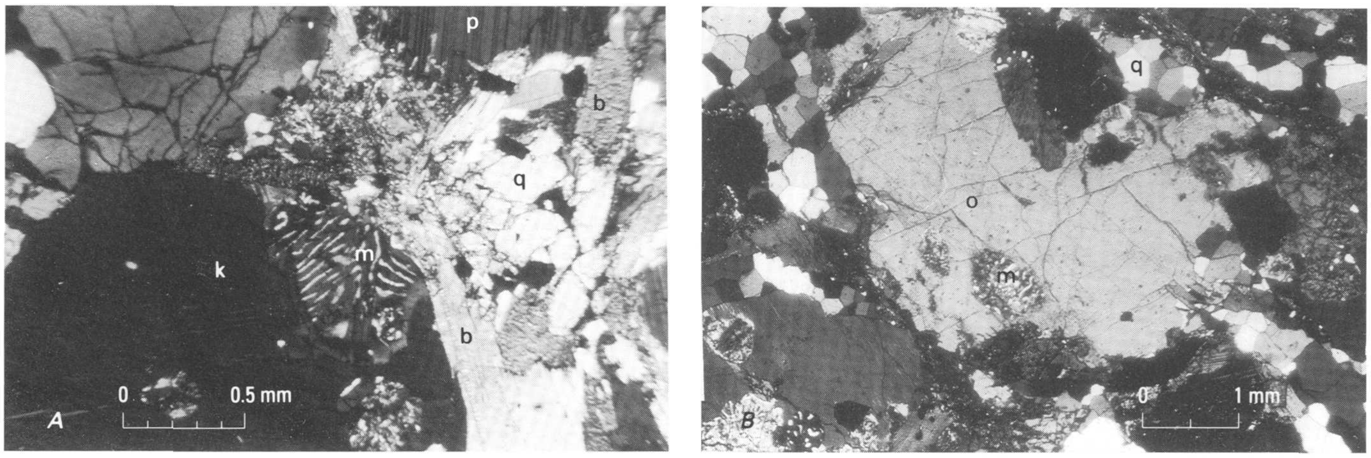
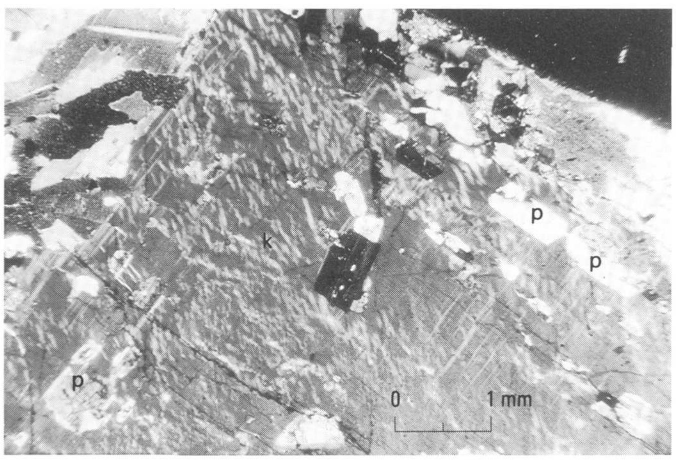


FIGURE 17.—Photomicrographs of myrmekite in granodiorite (P-80–6) of the Ellisville pluton. *A*:Bulbous myrmekite (m) embaying large potassic feldspar grain (k). Immediately above myrmekite is an intergrowth of biotite and epidote. Other minerals include plagioclase (p), biotite (b) and quartz (q): crossed nicols. *B*:Myrmekite (m) entirely enclosed within orthoclase (o). Granoblastic textured quartz (q) is groundmass constituent: crossed nicols. Mineral Quadrangle at lat 77°56′32″N. and long 38°05′17″W.



◀ FIGURE 18.—Photomicrograph of granodiorite (P-80–8) of the Ellisville pluton showing plagioclase (p) inclusions dimensionally aligned along outer parts of perthite (k) megacryst: plane light. Mineral Quadrangle at lat 39°06′59″N. and long 77°54′49″W.

solid-state exsolution of quartz from plagioclase, possibly also influenced locally by metasomatic processes.

Quartz: In foliated samples, quartz normally has a granoblastic-polygonal texture and may form large aggregate masses that in hand specimen may have the outline of single grains. In the massive samples, quartz occurs as large individual groundmass grains and in some rocks such quartz has strain-induced undultory extinction. Quartz is, of course, the fine-grained vermicular constituent of myrmekite. Fine-grained quartz also occurs in symplectic intergrowths with epidote and, rarely, with biotite.

Biotite: Brownish-green, strongly pleochroic medium-grained biotite is an ever-present accessory in the Ellisville granodiorites. Electron microprobe analyses of biotite are given in table C-3, and their compositional range is shown on figure 10. Spectrophotometric and wet chemical analyses of a biotite concentrate from sample P-80-41 indicates that it contains 4.5 percent Fe_2O_3, 15.9 percent FeO, 3.2 percent H_2O+, and .02 percent H_2O-. The total Fe content of this sample when calculated as FeO is 19.9 percent and is in the general FeO range for other biotites from different granodiorites analyzed by the electron microprobe (see table C-3). In foliated rocks, biotite is dimensionally oriented and occurs generally in discontinuous wavy folia. However, within such folia individual biotite laths may diverge by appreciable amounts from the general trend of the rock foliation. In some rocks that clearly have been deformed, the biotite is broadly bent and in places is strongly kinked. Commonly, biotite is closely associated with epidote, titanite, allanite, and apatite, all of which it locally may enclose poikilitically. In massive rocks, it occurs in randomly oriented clots or as single randomly oriented crystals. Foliation along the margins of the Ellisville pluton is aligned parallel to its country rock contact and is considered to be a flow-foliation (pl. 2*A*).

Epidote and allanite: Two generations of epidote are present in the Ellisville granodiorites. The most common is the fine- to medium-grained well-crystallized variety (fig. 19*A* and 19*B*) that is closely associated with biotite or occurs as a groundmass constituent. Electron microprobe analyses of subhedral epidote (table C-4) indicate that generally it is compositionally comparable with the epidote of the monzonites of the Lahore pluton (compare table C-4 and table B-9). Compositionally it is Ps_{28-32} (Fe-epidote); one analysis is Ps_{14} (Al-epidote). In many biotites within which it is enclosed, epidote has nucleated on allanite, which, locally, it completely encloses. In such cases the enclosing epidote has radiation-damage radial cracks developed around the allanite (fig. 19*C*). Although closely associated with epidote, allanite also occurs as discrete well-formed grains in the felsic groundmass (fig. 19*D*). These textural features of allanite demonstrate it is a pre-epidote magmatic mineral. Commonly it is strongly zoned (fig. 19*C*) and, where unaltered, it is pale brown and somewhat pleochroic. It is, however, commonly altered to an metamict state. A three point average of a partial electron microprobe analysis of allanite from a grain enclosed in epidote yielded 4.93 percent La_2O_3, 9.13 percent Ce_2O_3, and 0.25 percent Y_2O_3. The origin of epidote in subhedral grains with straight crystal faces in sharp contact with biotite or other juxtaposed minerals (fig. 19*A*) is considered evidence for magmatic origin (Zen and Hammarstrom, 1984). The symplectic intergrowth of epidote and quartz (fig. 20*B*) may also support such an interpretation. Epidote also encloses euhedral magmatic titanite (fig. 20*A*) further supporting the conclusion that epidote is a late magmatic mineral. The epidote has a range of Ps composition (28-32) that is common to magmatic edipdote. Epidote in small amounts also occurs less abundantly as fine-grained, granular, saussuritic alteration within plagioclase. Clinozoisite may also occur with, or independently from, such granular aggregates with altered plagioclase.

Titanite: Well-formed crystalline titanite is an ubiquitous but minor constituent of these rocks. Chemical analyses of titanite are listed in table C-5. In many places, unaltered titanite occurs as a well-crystallized overgrowth around an earlier rounded, generally oval-shaped alteration-clouded seed crystal of titanite (fig. 20*A*). In a few places some of the well-formed titanite is partly altered to "leucoxene-like" material, which is characterized in thin section under incident light by its opaque, white reflectance.

Apatite: This mineral occurs as small prismatic crystals. It is commonly enclosed in biotite.

Amphibole: In a few granitoids well-crystallized pleochroic green amphibole occurs as a minor groundmass constituent and is probably of magmatic origin. Microprobe analyses of two such amphiboles are given in table C-6 and generally fall in the compositional range of hastingsitic hornblende to magnesian hastingsitic hornblende (table C-6, and fig. 31*B*). The classification scheme for amphiboles has been described earlier for amphiboles from amphibole monzonites of the Lahore pluton.

White mica: Plagioclase feldspars are locally crowded by or sparsely altered by fine grains of white mica. Well-formed muscovite, however, occurs in some of the granitoids as a primary groundmass constituent.

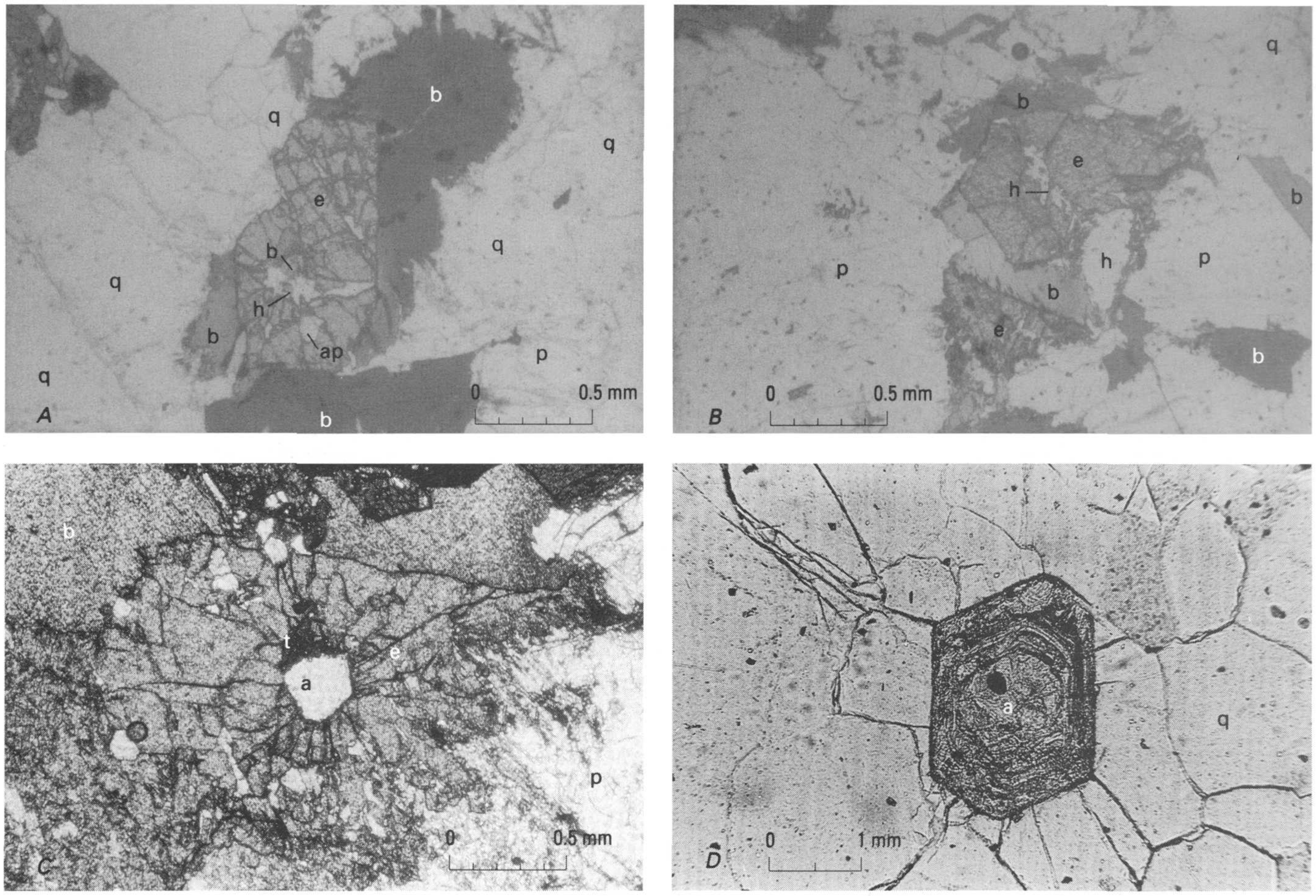


FIGURE 19.—Photomicrographs of epidote and allanite from the Ellisville pluton. *A* and *B*: Well-formed magmatic(?) epidote with straight crystal faces in contact with biotite (b). Centers of A and B have holes (h) due to plucking when slides were made. Epidote (e) in A contains allanite and encloses apatite (ap) as well as small grain of biotite (b). These subhedral epidotes are enclosed by quartz (q) and plagioclase (p). Anhedral epidote occurs in contact with biotite in lower center of *B*. Plane light. *A* (P-80–19) and *B* (P-80–15) are located in the Mineral Quadrangle, respectively at lat 38°05′17″N. and long 77°56′31″W. and at lat 38°05′04″N. and long 77°56′28″W. *C*: Epidote (e) with radial cracks emanating from a core crystal of allanite (a). Titanite (t) and apatite also are enclosed within epidote. Epidote is in contact with biotite (b) and plagioclase (p), specimen P-80–39: plane light. Lahore Quadrangle at lat 38°08′12″N. and long 77°56′59″W. *D*:Zoned metamictic allanite (a) in granoblastic textured quartz (q) matrix, specimen P-80–6: plane light. Mineral Quadrangle at lat 38°06′37″N. and long 77°55′01″W.

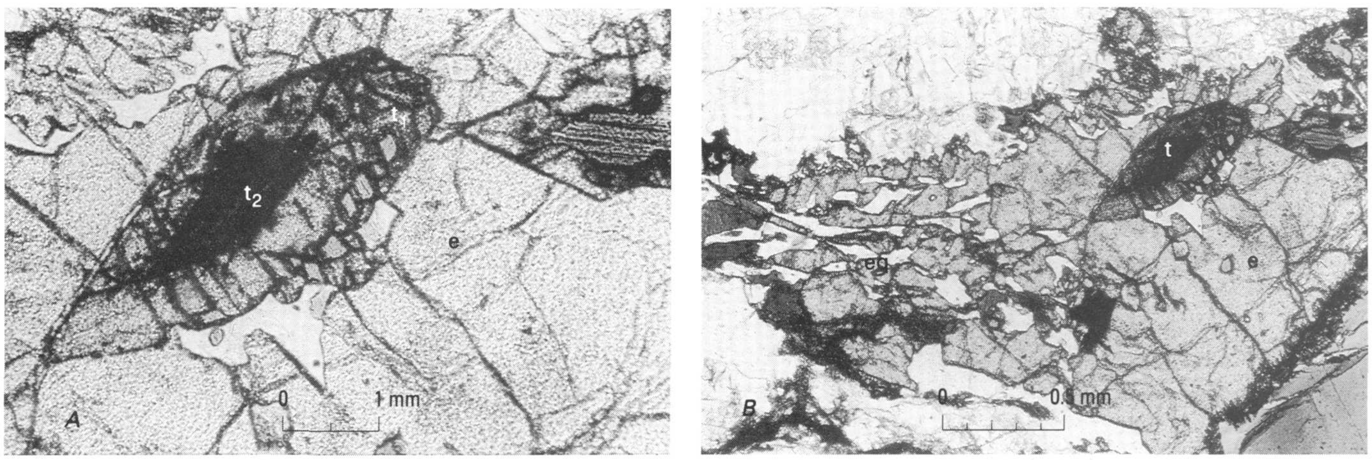


FIGURE 20.—Photomicrographs of titanite in granodiorite (P-80–10) of the Ellisville pluton. *A*:Euhedral titanite (t_1) overgrowth on dusty seed crystal of earlier titanite (t_2) enclosed in epidote (e): plane light. *B*.Same as fig. 20*A* showing titanite (t) enclosed in epidote (e) that at one end is in symplectic intergrowth with quartz (eq): plane light. Mineral Quadrangle at lat 38°06′04″N. and long 77°53′57″W.

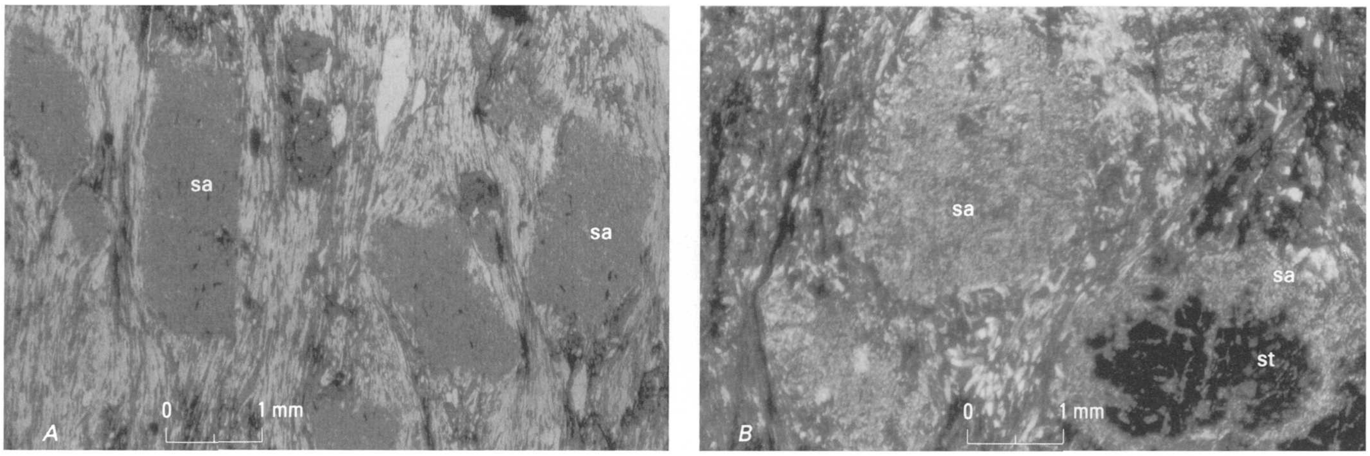


FIGURE 21.—Photomicrographs of mica schist with staurolite. *A*:Tabular and subtabular shimmer aggregate pseudomorphs of staurolite (sa); specimen P-72–88 *B*:Shimmer aggregate pseudomorphs of staurolite (sa) with unreplaced staurolite (st) in core of pseudomorph: crossed nicols; specimen P-72–102. Richardsville Quadrangle at lat 38°24′46″N. and long. 77°43′50″W.

Zircon: This mineral has not been recognized in thin section but is abundant enough to yield concentrates for U/Pb isotopic dating. The anhedral stubby zircon from the Lahore monzonites differ morphologically from the euhedral prismatic zircon crystals found in the Ellisville pluton (compare figs. 14*A* and 14*B*).

Opaque: Very sparse ilmenite(?) is locally present and may have "leucoxene" alteration.

METAMORPHISM

REGIONAL METAMORPHISM

With local exceptions, the metavolcanic rocks of the Chopawamsic Formation and the melange deposits of the Mine Run Complex in the central Virginia Piedmont are at greenschist grade of regional metamorphism and had been metamorphosed prior to the emplacement of the Lahore and Ellisville plutons.

An area of retrograded staurolite schist surrounded by greenschist-facies phyllites occurs near Richardsville within melange zone III of the Mine Run Complex (Pavlides, 1990). Here, staurolite for the most part has been completely retrograded to a shimmer aggregate of fine-grained mica (fig. 21*A*). In a few places, such pseudomorphs contain relict cores of staurolite (fig. 21B). Fine-grained, well-formed crystals of chloritoid are present locally in some of the pseudomorphic shimmer aggregates. Thus, this localized area was initially prograded through regional metamorphism (staurolite grade) followed by retrogression that formed chloritoid and micaceous shimmer aggregate pseudomorphs of staurolite. A later prograding metamorphic event may have formed, through recrystallization, the coarse-grained muscovite and well-formed chloritoid associated with the shimmer aggregates. The abundant euhedral magnetite that truncates foliation throughout this melange zone and produces the large, linear, aeromagnetic anomalies (pl. 1*A*) may also have formed during the late regional prograde event.

The reason for the staurolite retrogression in this area is not clear but it may have been related to the thrust faulting that affected this region (Pavlides, 1990).

Except where contact metamorphism around the Lahore and Ellisville plutons has locally prograded the affected rocks the regional grade is at greenschist facies (Pavlides, 1989). Rocks to the east of the Chopawamsic Formation, that is, the Quantico Formation and all the rocks to its east, are in thrust contact with the Chopawamsic along the Long Branch thrust (Pavlides, 1990) and are at amphibolite and higher grade of regional metamorphism. They were last metamorphosed during the Alleghanian orogeny. The reasons for these conclusions are summarized later.

TACONIAN OR OLDER METAMORPHISM

As described elsewhere (Pavlides, 1989), the rocks of the Mine Run Complex had been deformed and regionally metamorphosed to greenschist facies prior to the emplacement of the Lahore and Ellisville plutons. The Ellisville, whose magmatic age is placed at about 440 Ma (described in the Geochronology section), is now known to have a contact metamorphic aureole that includes nearby rocks of both the Chopawamsic Formation and the Mine Run Complex (pl. 2). The older Lahore Complex, about 450 Ma (see Geochronology), also has locally metamorphosed some of the schists enclosing it. Thus the deformation and regional metamorphism of these rocks is older than 450 Ma. Pavlides (1989) concluded that the Mine Run Complex rocks probably underwent deformation and regional metamorphism from Cambrian time (Penobscot orogeny) to just prior to the intrusion of the Ellisville pluton. Because the Ellisville contains magmatic hornblende with undisturbed plateau ages of about 430 Ma (described later), it is clear that no major thermal event has affected the Chopawamsic and the rocks to its west, including the Ellisville and Lahore plutons, since about 430 Ma.

ALLEGHANIAN METAMORPHISM

The Quantico Formation, in fault contact with the Chopawamsic Formation (pl. 1*A*), is at higher regional grade than the rocks west of the Long Branch thrust and locally contains staurolite, kyanite, and fibrolite (Pavlides, 1980, p. 15). The Quantico in the Fredericksburg area of Virginia (Pavlides, 1990) is folded with rocks that have been metamorphosed during the Alleghanian (Sutter and others, 1985a) along a west-to-east increasing metamorphic gradient and from which hornblende $^{40}Ar/^{39}Ar$ plateau ages (interpreted as times of cooling from maximum metamorphic temperatures to argon closure temperatures) of 321 Ma at staurolite grade to 307 Ma at fibrolite grade were obtained. In addition, thermobarometric studies of the folded Quantico within the same area near Fredericksburg (Flohr and Pavlides, 1986) support an Alleghanian metamorphic event for the Quantico there.

Thus, the Quantico that was deformed and metamorphosed during the Alleghanian was also juxtaposed by faulting against the deformed rocks of the Chopawamsic after 321 Ma, during the Alleghanian orogeny. Prior to the availability of Ar/Ar cooling ages of about 430 Ma for amphibole in the Ellisville, the Chopawamsic-Quantico contact was considered to be entirely an unconformity. Although the stratigraphic contact between these two units is an unconformity at Dale City, Va. (Pavlides and others, 1980), it is now believed that this unconformity became a thrust to the south of the latitude of Stafford, Va., in the later phases of the Alleghanian orogeny. Physical evidence for faulting along the Chopawamsic-Quantico contact is present at a few places, including mylonite along this contact near the Rappahannock River (Pavlides, unpublished data) and about 13 km northwest of Fredericksburg near the headwaters of the Long Branch Reservoir (Pavlides, 1976, figs. 2 and 3) for which the fault was named. The Long Branch thrust transported westward Quantico Formation and Ta River Metamorphic Suite rocks that had been deformed and metamorphosed farther to the southeast. The rocks west of the Long Branch thrust were apparently not covered by a sufficiently thick stack of allochthonous rocks to thermally disturb the K-Ar isotopic system of Ellisville amphibole, which yield nearly concordant $^{40}Ar/^{39}Ar$ age spectra of about 430 Ma (see fig. 40).

CONTACT METAMORPHISM

A locally narrow and irregular aureole of contact-metamorphosed rocks was first described around the Ellisville pluton by Pavlides (1989). It is now known that less well-defined contact metamorphism occurred along the northeast side of the older, pyroxene monzonite of the Lahore pluton. These contact-metamorphosed rocks formed when the plutons were emplaced into the regionally metamorphosed (greenschist facies) and deformed rocks of the Chopawamsic Formation and Mine Run Complex (pl. 2A). The mineralogy of the contact metamorphosed rocks (see below) and the narrowness of the high-grade part of the aureoles suggest that the plutons were emplaced at mesozonal (Buddington, 1959) or intermediate depths within the Earth's crust.

Ar/Ar GEOCHRONOLOGY

The various isotope geochronologic studies, as they pertain to the Ellisville and Lahore plutons, will be described in later sections of this report. Some of the isotopic results, however, are discussed now because they pertain to contact metamorphism. Of specific pertinence to discussion of contact metamorphism are some of the $^{40}Ar/^{39}Ar$ dates obtained for amphibole within the Lahore monzonites. Similar discussion of $^{40}Ar/^{39}Ar$ dates of amphiboles from some of the country rocks relate to the 440 Ma age of the Ellisville pluton (discussed under Geochronology). The location of the samples used to obtain isotopic data in the terrane of interest are compiled on plate 2*B*. $^{40}Ar/^{39}Ar$ ages have been obtained for amphiboles from two different hornblende-bearing monzonites of the Lahore pluton (samples 7 and 14, plate 2*B*). Sample 7 (P-81-12) is the more proximal of the two to the exposed contact of the Ellisville pluton, and amphibole from it has an $^{40}Ar/^{39}Ar$ plateau "age" of 441.4±2.2 Ma (table 9). In contrast, sample 14, (P-81-15) the more distal from the exposed contact of the Ellisville pluton, has a near-plateau preferred age of 448.2±2.2 Ma (table 9) and an Ar/Ar isochron age of 445.1±2.0 Ma (table 10). The Lahore pluton, as stated earlier, is older (450 Ma) than the Ellisville pluton (440 Ma), which intrudes it. The apparent age difference between amphiboles from samples 7 and 14 of the Lahore pluton may reflect differences in the intensity of heating of these samples during intrusion of the Ellisville. Amphiboles from sample 7 (P-81-12), the more proximal to the exposed contact of the Ellisville, may have lost nearly all of their radiogenic ^{40}Ar at the time of Ellisville emplacement, whereas amphiboles from sample 14 (P-81-15) may have lost virtually none of their radiogenic ^{40}Ar.

FIGURE 22.—Photograph of polydeformed schist containing mesoscopic folds from within the contact-metamorphic aureole of the Ellisville pluton. Such folds generally are present also as microscopic features in the rocks intruded by the Ellisville but due to pre-Ellisville deformation (Pavlides, 1989). Length of knife is 7 cm. Orange Quadrangle at lat 38°08′58″N. and long 78°01′30″W.

It was stated earlier, chiefly on the basis of geophysical data, that the Ellisville pluton probably occurs as an unexposed, subsurface intrusion in the region immediately east of the Lahore pluton. In further support for this interpretation are the amphibole $^{40}Ar/^{39}Ar$ ages of 434.8±2.2 and 437.5±2.2 Ma (figs. 41*A* and 41*B*) obtained from two greenschist blocks within melange zone III of the Mine Run Complex east of the Lahore pluton (pl. 2*B*). These ages approximate the crystallization age of the Ellisville, which intrudes melange zone III. The amphibole ages for the melange zone III greenschist blocks, therefore, are interpreted as reset ages due to heating from an unexposed near-surface part of the Ellisville. Two amphibole $^{40}Ar/^{39}Ar$ age spectra from other greenschist blocks within melange zone III at a considerable distance from the Ellisville pluton (see footnotes of pl. 2*B*) are discussed under Geochronology. Although these age spectra are extremely discordant and therefore difficult to interpret, they are compatible with the suggestion that some of the blocks (olistoliths) may have been metamorphosed in the Late Proterozoic or early Paleozoic. Such timing is consistent with the model that some of the melange zone III blocks were derived from the floor of a back-arc basin present at that time (Pavlides, 1989).

STRUCTURAL FEATURES

Locally, metasedimentary rocks of various types that comprise the matrix host rocks for the exotic blocks of the melange zones of the Mine Run Complex (Pavlides, 1989), are converted to complexly folded schists and gneisses (fig. 22) within the contact metamorphic aureole of the Ellisville pluton and on the east side of the Lahore pluton. Strain slip or fracture cleavage that crinkles earlier foliation is well-developed locally in some of the rocks proximal to the Ellisville pluton. This is evident, for example, along the east side of the pluton in rocks of the Chopawamsic Formation (pl. 1*A*). Such structural features in contact-metamorphosed rocks adjacent to the pluton are interpreted to have formed due to ductility increase of the country rocks within a narrow zone surrounding the pluton. The increased ductility probably resulted because of the temperature rise during contact metamorphism. Folds (fig. 22) and crinkled foliation within such ductile zones are interpreted to have formed from the stresses generated by the forceful intrusion of the plutons. The shouldering effect of the Ellisville pluton is reflected by the warping of the regional foliation of the country rocks into parallelism with the contact of the pluton. This structural relationship is apparent at the northeast part of the pluton (pl. 1*A*). Here the northeast-trending regional foliation is deflected west and northwest generally parallel to the convex northward trend of the contact of the Ellisville pluton. Similarly, regional foliation has apparently been rotated from its northeast trend to a north trend where the contact of the Ellisville pluton trends north in several places in the Louisa quadrangle (pl. 1*A*). As stated earlier, the warping of the regional northeast trend of aeromagnetic anomalies around the western margin of the pluton (pl. 1*A*) reflects the shouldering effect of the pluton when emplaced into the magnetite-bearing metamorphosed terrane.

TEXTURAL FEATURES

One of the characteristic textural features of the contact-metamorphosed rocks is the presence of granoblastic quartz (fig. 23). This contrasts with the subround to irregular shapes of the quartz in the regionally metamorphosed phyllite and schist country rocks and reflects recrystallization by contact metamorphism. These include a variety of metasedimentary (Pavlides, 1989, figs. 4*B* and 4*F*) and metavolcanic rocks (Pavlides and others, 1982c, figs. 4*A* and 4*C*). Textural modification also involves local coarsening of grain size thereby converting phyllite and fine-grained schist to typical schist and gneiss.

Textural modification in the sulfide ores is more difficult to document. Some ores within the thermal aureole of the Ellisville pluton are foliated (Katz, 1961, fig. 20; Sandhaus, 1981, fig. 10*B*), and this may reflect the earlier regional metamorphism they underwent prior to contact metamorphism. The presence of granoblastic-polygonal textures resulting in minerals with polygonal shapes and generally straight boundaries that meet at triple points may indicate contact (thermal) metamorphism (Spry, 1969, p. 186–197). Such textures are present in some ores from the Mineral district (Cox, 1979, figs. 8 and 9; and Pavlides and others, 1982c, figs. 12*A* and 12*B*). Sulfide mobility also is common under conditions of contact metamorphism (Vokes, 1969, p. 106 and 134). A sulfide vein that crosscuts earlier formed ores is present in the Cofer deposit, and this may also reflect sulfide mobility during contact metamorphism. Miller (1978, p. 24-25) has discussed textural features of ore minerals in the Cofer deposit that he attributes to thermal rather than regional metamorphism. Among these features are (1) optical and chemical homogeneity of sphalerite and tennantite, tetrahedrite, and freibergite; minerals that are normally zoned in volcanogenic deposits (Yui, 1970, and Shimazaki, 1974); (2) the presence of thin films and small grains of chalcopyrite that adhere to crystals of pyrite, features that Mookherjee (1976) interpeted as features of contact metamorphism; and (3) lack of preferred orientation of twins in sphalerite. Sphalerite within dynamically metamorphosed deposits show parallel deformation twins (Vokes, 1969).

Because of limited bedrock exposure and extensive saprolitization in the region, a precise delineation of isograds related to contact metamorphism has not been attempted.

MINERALOGY

Previous studies of the mineralogy of the volcanogenic massive sulfide deposits have recognized and briefly described some of the metamorphic silicate minerals found in the volcanogenic massive sulfide deposits of the Mineral district of Virginia (Pavlides and others, 1982c, p. 241-243). Silicates of metamorphic origin include poikiloblastic amphibole and biotite as well as sieved and massive staurolite and chloritoid, kyanite, and anthophyllite (Pavlides and others, 1982c, fig. 4). Aluminous minerals, such as chloritoid and staurolite, found within quartz-eye felsites are interpreted to have formed through metamorphism in metavolcanic rocks that had undergone a prior hydrothermal event that residually enriched them in Al_2O_3 (Pavlides and others, 1982c, p. 243). Pavlides (1989) reported that some aluminous silicate minerals including kyanite and fibrolite formed through contact metamorphism within the thermal aureole of the Ellisville pluton.

In this report, some additional details about contact metamorphism as well as new mineral identifications from samples taken within the contact-metamorphic aureole of the Ellisville and Lahore plutons will be discussed.

Neomineralization and recrystallization of minerals attributable to contact metamorphism include biotite, muscovite, margarite, chloritoid, staurolite, kyanite, and fibrolite. Well-crystallized gahnite and tourmaline probably formed from earlier processes, but the gahnite may have undergone some textural modification during contact metamorphism.

MUSCOVITE AND BIOTITE

Coarse-grained muscovite and biotite occur in the contact-metamorphic aureole, and megacrystic muscovite encloses earlier formed minerals. Figure 24*C*, for example, shows large megacrystic muscovite that encloses two foliations. One foliation (S_1) in the photomicrograph, is fine-grained biotite (b-1) aligned "east-west." The other is the northeast aligned fine-grained biotite (b-2), which is the foliation (S_2) in the surrounding groundmass. The S_2 plane is also the one in which the muscovite megacrysts are dimensionally and crystallographically aligned. S_1 within one such muscovite megacryst is sensibly parallel with the sigmoidally entrained fibrolite (fig. 24*A*). Fine-grained S_1 biotite essentially parallel with the S_1 fibrolite is also present in figure 24*A*. Metacrystic muscovite like that shown in figures 24*A*, *B*, and *C* therefore formed after S_1. Such megacrystic muscovite is interpreted as forming through potassic metasomatism from late kinematic fluids eminating from the Ellisville and Lahore plutons as described below when discussing fibrolite.

Poikiloblastic biotite in the Ellisville thermal aureole contrasts with biotite in regionally metamorphosed schist, which occurs as homogenous elongate crystals that form the foliation. Such muscovite and biotite locally are kinked, probably by deformation related to the emplacement of the plutons. Electron microprobe analyses of muscovite and biotite within contact-metamorphosed rocks are listed in tables D-2 and D-1, respectively. Biotite in the Chopawamsic Formation from within the contact-metamorphic zone of the Ellisville pluton is more sodic (0.36–0.53 weight percent Na_2O; table D-1) than biotite in the Lahore and Ellisville plutons (.02-.06 weight percent Na_2O; tables B-8 and C-3).

FIBROLITE

In many places, coarse-grained, metacrystic muscovite in contact-metamorphosed schists contains dimensionally aligned fibrolite in a variety of orientations. Most oriented fibrolite is not parallel with the dominant rock foliation. Commonly, fibrolite needles form aligned swarms that cut across crystallographic axes of muscovite (fig. 24*A*). They also locally parallel the (001) cleavage of muscovite. Fibrolite occurs less commonly in biotite. It also occurs in random alignment or in small concentration in quartz (fig. 24*B*).

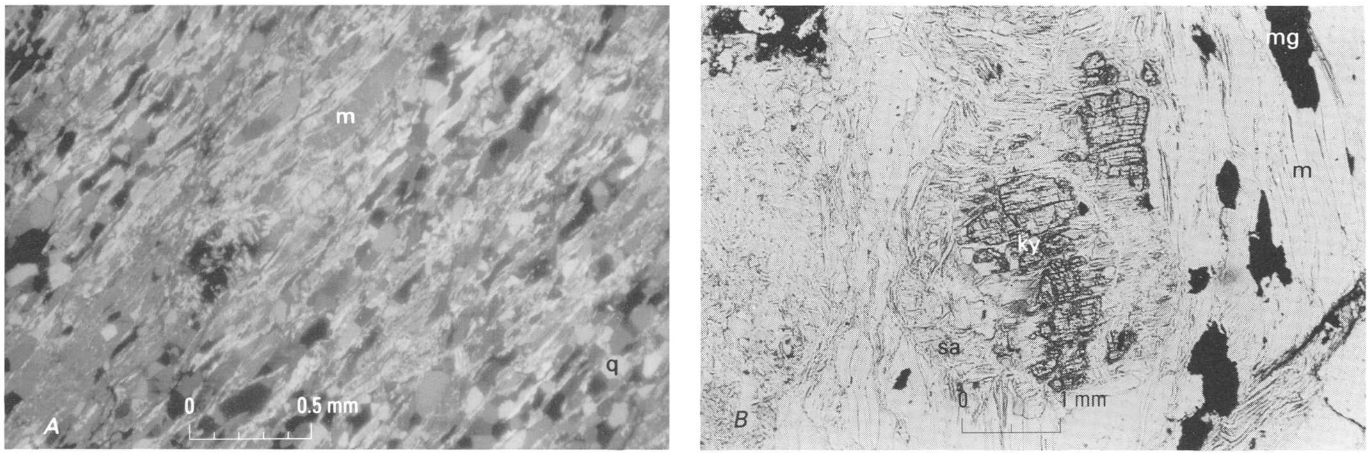
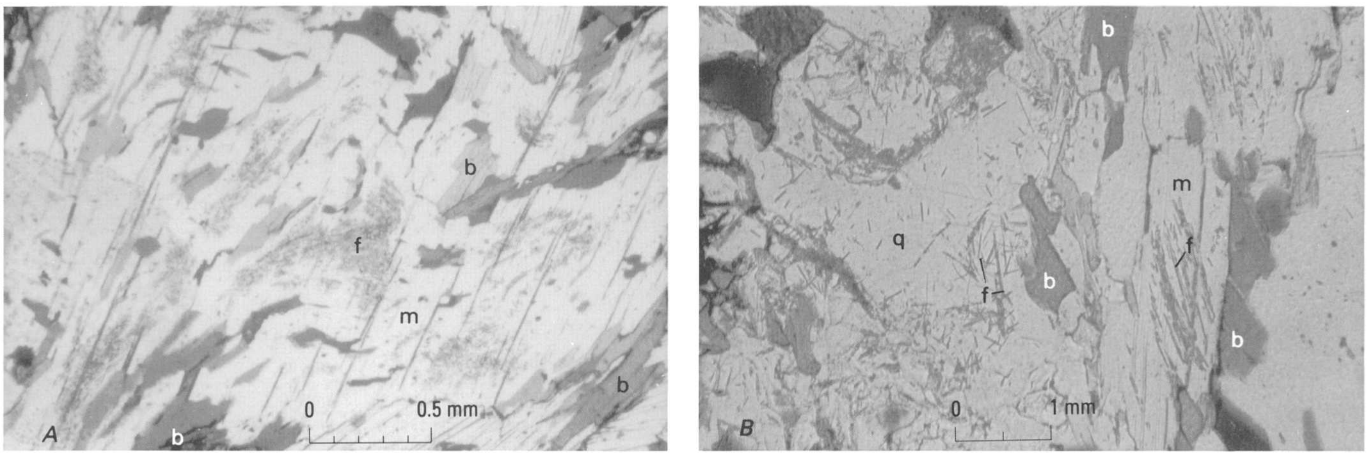


FIGURE 23.—Photomicrographs of foliated muscovite-quartz-kyanite schist (P-80–12). *A*. Granoblastic textured quartz (q) occurs between muscovite (m) folia: crossed nicols. *B*. Kyanite (ky) in part altered to shimmer aggregate of white mica and chlorite (sa) in a groundmass of mica (m) and magnetite (mg): plane light. Mineral Quadrangle at lat 38°05′46″N. and long 77°53′57″W.

Metacrystic muscovite, considered as of late metasomatic origin, has overprinted the foliations shown in figure 24*C*. Fibrolite has been reported as inclusions in muscovite from the inner parts of contact-metamorphic aureoles elsewhere, as, for example, in the Donegal region of Ireland (Pitcher and Berger, 1972, fig. 14–5). It has been suggested that muscovite and fibrolite may form contemporaneously (Pitcher and Reed, 1963; Pitcher and Berger, 1972). Alternately, it has been proposed that fibrolite forms from the breakdown of



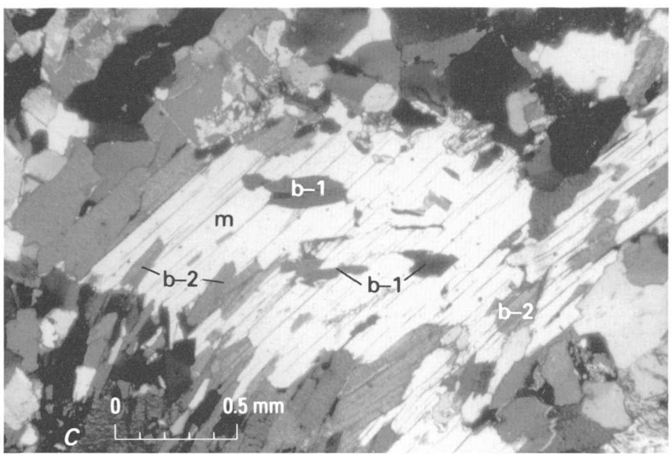


FIGURE 24.—Photomicrographs of fibrolite and micas in contact-metamorphosed schists. *A*. Fibrolite (f) entrained in sigmoidal pattern in large muscovite grain (m) that occurs along the limb of folded folia near the axial surface of the fold. Rock (P-80–85) is an amphibole-fibrolite(f)-muscovite-biotite(b)-plagioclase-quartz schist: plane light. Lahore Quadrangle at lat 38°13′19″N. and long 77°56′17″W. *B*. Fibrolite (f) entrained in quartz grains (q) and aligned in muscovite (m) associated with minor biotite (b), specimen P-78–44: plane light. Lahore Quadrangle at lat 38°13′18″N. and long 77°54′32″W. *C*. Large megacrystic muscovite (m) that encloses fine- grained biotite (b-1) aligned east-west or across the photomicrograph and fine-grained biotite (b-2) aligned northeast with respect to the photomicrograph, which is the foliation direction in the surrounding ground mass; crossed nicols; Specimen P-80–85.

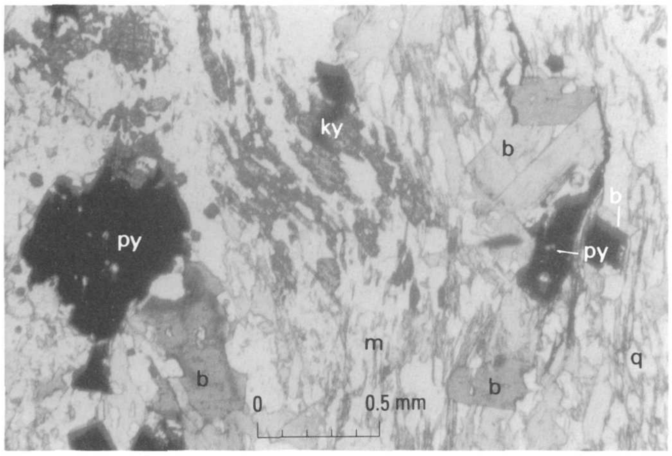


FIGURE 25.—Photomicrograph of muscovite (m)-kyanite (ky)-biotite (b) polygonized-quartz (q)-euhedral pyrite (py)-schist (P-77-99) of the Chopawamsic Formation within the thermal aureole of the Ellisville pluton. Plane light. Mineral Quadrangle at lat 38°03′54″N. and long 77°52′47″W.

biotite by acidic emanations from a nearby pluton (Kerrick, 1987). Acidic emanations from granitic plutons have been described by Eugster (1985). The east-west aligned S_1 biotite and the similarly oriented sigmoidal fibrolite of figure 24*A* may represent replacement by the muscovite porphyroblast of an early biotite containing S_1 fibrolite. The fibrolite randomly oriented in quartz grains (fig. 24*B*) may have formed from the groundmass of the rock and became enclosed by quartz from silica released by various metamorphic reactions within the rock.

The recognition of fibrolitic muscovite in highly deformed schist at the northeast end of the Lahore Complex (pl. 2*C*) is the basis for considering the Lahore an intrusion rather than an olistolith, as previously interpreted by Pavlides (1989).

KYANITE

Locally, kyanite is present within the innermost part of the thermal aureole as in the strongly foliated muscovite-quartz schist of figure 23*B*. Kyanite, in combination with staurolite is present in some of the metapelites as well as in some of the metavolcanic rocks of the Chopawamsic Formation (Pavlides and others, 1982c, fig. 4*B*). As discussed earlier, in order to form aluminosilicates in the volcanic rocks of these deposits, it is assumed that the rocks underwent hydrothermal alteration and were residually enriched in Al_2O_3 and SiO_2 prior to regional and (or) contact metamorphism. Kyanite also occurs with chloritoid on the east side of the Ellisville pluton (pl. 2*B*). There, within the Chopawamsic Formation, it is present in fine-grained sulfidic schist composed of the mineral assemblage muscovite-chlorite-pyrite-kyanite-biotite-quartz (fig. 25). This kyanitic schist is apparently interlayered with metafelsite and with chloritoid-bearing phyllite and schist described below. Microprobe analyses of kyanite are listed in table D-4. Small amounts of ferric iron can be incorporated in kyanite (Deer and others, 1962, p. 138 and table 24). Thus the iron reported as FeO (.35 to .41 weight percent) in table D-4, is probably real rather than an artifact of the probe analyses or of random inclusions.

STAUROLITE

Staurolite occurs within the contact-metamorphosed schists surrounding the Ellisville pluton (pl. 2*B*). It forms euhedral as well as subhedral crystals, which, in thin sections, have characteristic yellow pleochroism. In one thin section, euhedral staurolite occurs in a compositional layer in direct contact with a layer containing anhedral, sieved staurolite (fig. 26). These two juxtaposed but morphologically different staurolites have similar chemical compositions. In table D-5, analyses 1 and 2 and 3 through 9 are, respectively, from subhedral and euhedral staurolite in the juxtaposed layers shown in figure 26. Staurolite from the ore zone of the Arminius deposit (pl. 2*B*) contains as much as 7 percent zinc (Cox, 1979, p. 57). Zincian staurolite presumably related to the ore zone from the Sulfur deposit (pl. 2*B*) contains up to 4.73 percent zinc oxide (ZnO) (table D-5, analyses 15). However, ordinary schist from the Sulfur deposit contains staurolite with only 1.7 to 1.9 percent ZnO (table D-5, analyses 1 to 9). Metafelsite(?) schist within the Chopawamsic Formation farther removed from the ore deposits carries staurolite that contains only .05 to .15 percent ZnO (table D-5, analyses 25 through 30).

CHLORITOID

Chloritoid occurs within the thermal aureole of the Ellisville pluton, generally at greater distances from the pluton contact than the fibrolite-bearing schist described above. Such chloritoid-bearing rocks commonly are phyllite and semischist and lack the close folding of the polydeformed fibrolitic schists of the innermost part of the contact aureole. Chloritoid in the phyllites and semischists is typically poikiloblastic and encloses fine-grained groundmass quartz grains (fig. 27). Commonly it is polysynthetically twinned. Electron microprobe analyses of chloritoid from one specimen are listed in table D-6. In some aureole rocks, poikiloblastic chloritoid encloses fine-grained entrained quartz that lies at an angle to the rock foliation, suggesting preservation of an earlier, overprinted foliation. Whether the chloritoid was rotated after overprinting the early foliation, however, is not certain. Some chloritoid-bearing contact-metamorphosed rocks, possibly meta-quartz wackes, also contain small amounts of well-formed fine-grained

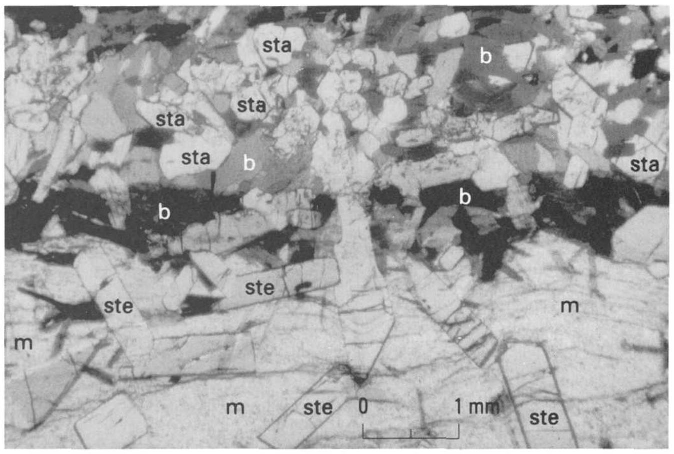


FIGURE 26.—Photomicrograph of staurolite schist from the Sulfur deposit in the Mineral district, Virginia. Tabular euhedral zincian staurolite (ste) occurs in random orientation within a very-fine grained mat of muscovite (m). Anhedral to subhedral stubby zincian staurolite (sta) occurs in a juxtaposed layer composed essentially of green biotite (b). Electron microprobe analyses of the two types of staurolites are given in table D-5: analyses 1 and 2 are of anhedral to subhedral staurolite (sta); analyses 4 through 9 are of tabular, euhedral staurolite. See plate *2B* for location of Sulfur deposit. Specimen V1884d is from the collection of A.S. Katz (Katz, 1961), stored at the University of Virginia and collected from the dump of Sulfur mine.

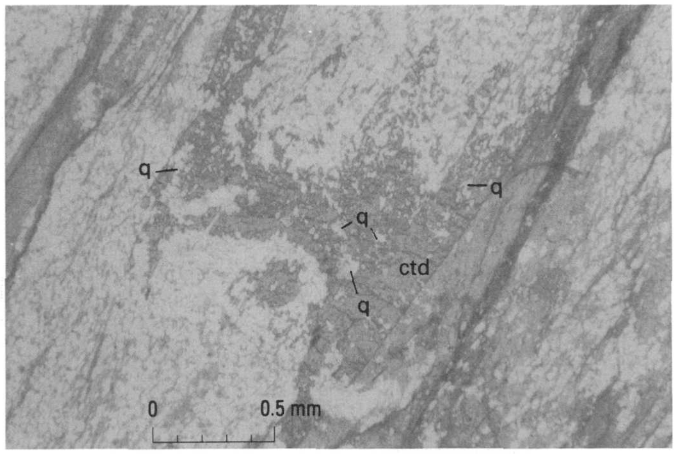


FIGURE 27.—Photomicrograph of phyllite (P-77-86) of the Chopawamsic Formation within the thermal aureole of the Ellisville pluton with poikiloblastic chloritoid (ctd) enclosing finer grained quartz (q). Plane light. Mineral Quadrangle at lat 38°03′51″N. and long 77°52′51″W.

staurolite and subhedral to anhedral garnet. Chloritoid also occurs with kyanite or with kyanite and staurolite. Fine-grained intergranular chlorite whose electron probe analyses are given in table D-7, is locally abundant in chloritoid phyllites. Brown biotite and subhedral to euhedral poikiloblastic chloritoid also form irregular folia in schistose rocks. In outcrop, such rocks locally have foliation planes containing chloritoid arranged in fascicular aggregates.

OTHER MINERALS

A number of minerals occur in the Chopawamsic Formation that may or may not have formed directly from contact metamorphism but which none-the-less are found within the thermal aureole of the Ellisville pluton and are discussed here for the sake of convenience. Among these is green gahnite, which generally occurs in regionally metamorphosed volcanogenic sulfide deposits. In the Mineral district of Virginia, it has been found in the Arminius, Cofer, Julia, and Sulfur deposits (pl. *2C*) by Katz (1961), Miller (1978), Cox (1979), and Sandhaus (1981). These authors have extensively described such gahnite, and no further treatment is attempted herein.

MARGARITE

Margarite, a heretofore unrecognized mineral in the Chopawamsic Formation of the Mineral district in Virginia was found in one schist specimen from the Sulfur mine dump (pl. *2B*). We are grateful to the late Professor R.S. Mitchel of the University of Virginia who made available to us this and other samples (as credited under the appropriate electron microprobe analyses in Appendix A) from the Sulfur mine collected during a study of this mine by A.S. Katz (1961). The margarite occurs as fine-grained bundles of radiating crystals enclosed within biotite and also intergrown as thin plates within very fine-grained muscovite mats (fig. 28). Electron microprobe analyses of such margarites are listed in table D-3. These analyses clearly indicate that a small amount of

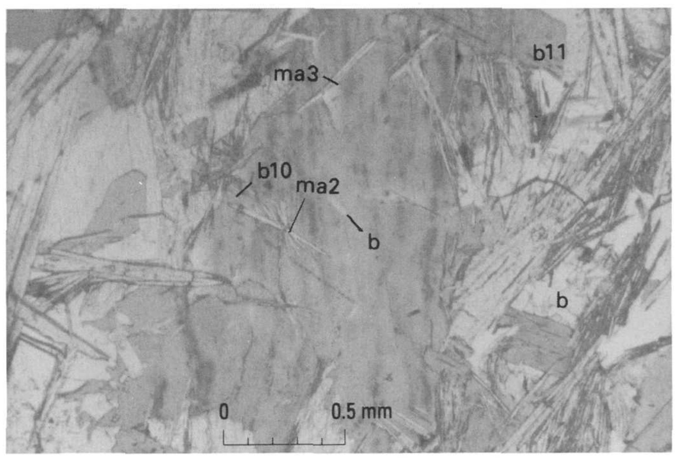


FIGURE 28.—Photomicrograph of margarite-bearing schist (V1810) from the Sulfur mine from within the thermal aureole of the Ellisville pluton. Fine-grained, bladed margarite (ma) enclosed by biotite (b). Numbers shown for margarite (nos. 2 and 3) refer to electron microprobe analyses listed in table D-3; biotite (b - nos. 10 and 11) microprobe analyses are listed in table D-1. Specimen is from the collection of A.S. Katz (Katz, 1961) stored at the University of Virginia and collected from the dump of the Sulfur mine.

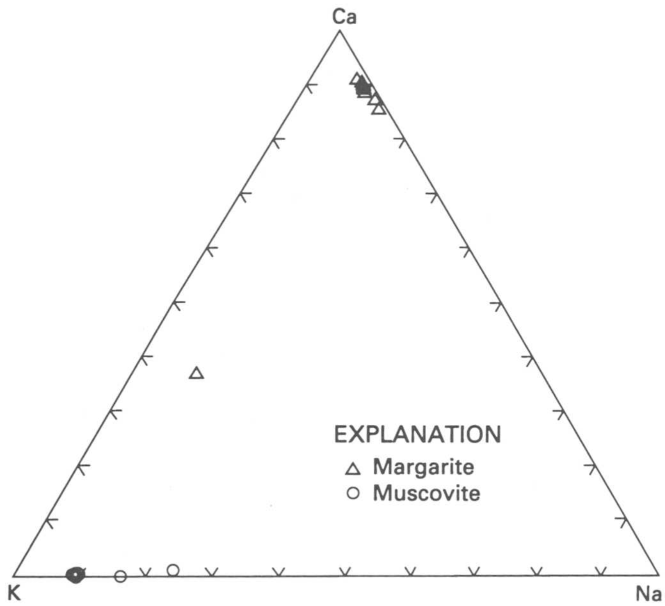


FIGURE 29.—Plot of muscovite and margarite from the Sulfur mine (plate 2*B*) on a K-Na-Ca diagram. Modified from Guidotti (1984, fig. 3).

isomorphism with paragonite is attained as shown on the K-Na-Ca diagram (fig. 29) where the analyses fall along the Ca-Na join. Analysis 8 (table D-3) probably represents submicroscopic intergrowths of muscovite and margarite rather than an isomorphous mixture because of the miscibility gap between muscovite and margarite. There is no carbonate recognized within the rock thin section containing margarite. However, carbonate, if present in the past, may have broken down during a hydrothermal or regional metamorphic event and so supplied the necessary calcium needed to produce margarite. The rock sequence in which the margarite of the Sulfur deposit occurs probably originally contained metalimestone. An alternative source for Ca needed to make margarite may have been from saussuritization of plagioclase, but plagioclase has not been recognized in margarite-bearing rock. However, clinozoisite enclosing allanite is present (fig. 30). Calcium, to form margarite and clinozoisite, may have been introduced selectively into some stratigraphic levels in the Sulfur deposit during an exhalative phase of the Ellisville pluton.

Margarite is commonly considered a metamorphic mineral that occurs within rocks subjected to greenschist and amphibolite grade metamorphism. Its occurrence in schist rather than phyllite at the Sulfur mine may suggest origin during early contact metamorphism rather than during the preceding regional metamorphism.

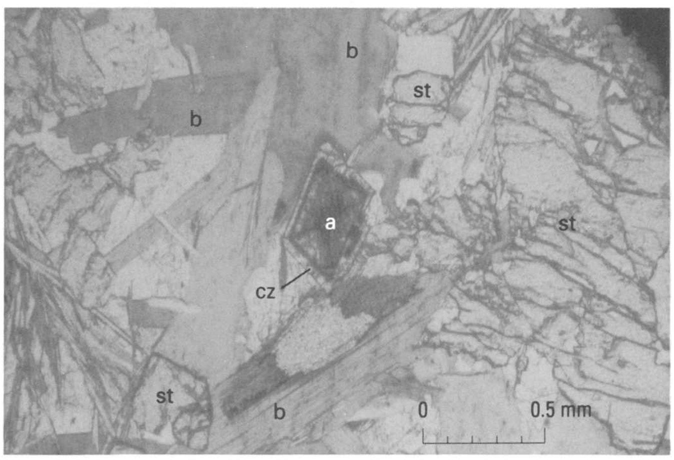


FIGURE 30.—Photomicrograph of euhedral composite grain of altered allanite (a) enclosed by clinozoisite (cz). Also present are staurolite (st) and biotite (b): plane light. Specimen 1810d is from the Sulfur mine dump (plate 2*B*). It is from the collection of A.S. Katz (Katz, 1961) stored at the University of Virginia.

TOURMALINE

Tourmaline was first reported from the Sulfur mine (pl. 2*B*) by Katz (1961, p. 73–75) who describes it as occurring mostly in massive vein quartz. However, in a probe thin section cut from Katz's specimen V-1810 D, well-formed zoned and unzoned green tourmaline occurs scattered in the groundmass (fig. 31) as well as in massive semilayers. Slack (1982) has pointed out that

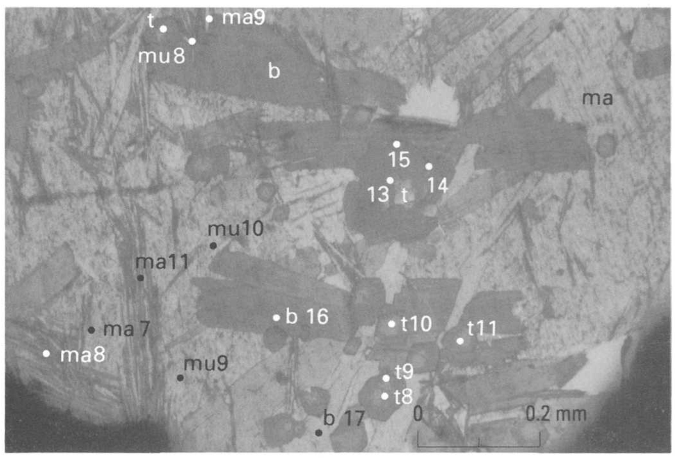


FIGURE 31.—Photomicrograph of euhedral, weakly zoned, widely dispersed tourmaline (t) enclosed by biotite (b) and a groundmass of finely divided muscovite (mu). Muscovite (mu) and margarite (ma) also occur as bladed crystals in the muscovite mat. Numbers given with biotite (16 and 17), muscovite (8, 9, and 10), margarite (7, 8, and 9), and tourmaline (8–11, 13–15) refer to electron microprobe analyses listed respectively in tables D-1, D-2, D-3, and D-10. Microprobe thin section made from specimen V1810 which was supplied by the University of Virginia from the collection of Katz (1961) from the Sulfur mine dump. See plate 2*B* for location of Sulfur mine.

tourmaline is found as a disseminated mineral or that it forms stratiform masses (tourmalinites) in various stratabound mineral deposits, particularly in massive base-metal sulfide deposits. He proposed that the tourmaline in stratabound deposits, particularly in volcanic settings, formed by submarine-exhalative processes when such ores were deposited. Tourmaline present in disseminated and quasi-layered habit in the Sulfur mine within the volcanogenic terrane of the Chopawamsic Formation may have formed syngenetically with the sulfide deposits. However, the proximity of the Ellisville pluton and the Sulfur mine's location within that pluton's thermal aureole pose the alternative possibility that the tourmaline may have been deposited by fluids emanating from the Ellisville pluton.

Electron microprobe analyses of zoned and unzoned tourmaline from the Sulfur deposit are listed in table D-10. Zoned tourmalines have higher MgO at their rims than at their centers (compare analyses 9 with 8 and 10, and 15 with 13, and 18 with 17 of table D-10). Henry and Guidotti (1985) evaluated the chemical features of tourmaline formed in various tectonic environments and constructed discriminant diagrams to help recognize the environment of tourmaline formation. These discriminant diagrams were further refined by Taylor and Slack (1984). The ternary Fe-Ca-Mg and Fe-Al-Mg ratios of all tourmaline analyses from the Sulfur deposit are plotted on the discriminant and classification diagrams of Taylor and Slack (1984), as A and B respectively, in figure 32. Both the zoned and unzoned tourmaline fall in the field of Ca-poor metapelites, metapsammites, and quartz-tourmaline rocks (fig. 32*A*) and both types of tourmaline are of intermediate schorlite-dravite composition (fig. 32*B*) but are richer in Mg rather than Fe (table D-10). Of particular relevance with respect to these compositions is the conclusion of Taylor and Slack (1984) that "Dravite and Mg-rich dravite-schorl compositions are the characteristic tourmalines of massive sulfide associations." However, the tourmalines from the Sulfur deposit plot mostly in the field of Fe^{+3}-rich quartz-tourmaline rocks.

The chemical data cited above support the interpretation that the tourmaline of the Sulfur deposits listed in table D-10, and shown in figure 31 was formed originally by submarine-exhalative processes at the time of massive sulfide deposition within the volcanic rocks that comprise the Chopawamsic Formation. Further support for a volcanic-hydrothermal origin is the presence of tourmalinites in the same volcanic terrane south of the Mineral district near Dillwyn, Va. (Pavlides and others, 1982c, p. 243), where plutonism is not known to have affected these tourmalinites. However, the presence of quartz veins with tourmaline that has been recognized both near Dillwyn (Pavlides and others, 1982c, p. 243) and in the Sulfur deposit (Katz, 1961) are puzzling. They may be quartz-tourmaline sweat-outs during metamorphism, but the possibility that such quartz-tourmaline veinlets are related to boron-rich solutions emanating from the Ellisville pluton in the Mineral district cannot be ruled out at this time. The genetic relationship of the quartz-tourmaline associations awaits chemical and related study.

Allanite-Clinozoisite

Epidote group minerals are common in many of the metavolcanic rocks of the Chopawamsic Formation. An unusual occurrence of this mineral group from the Sulfur mine was noted and described by Katz (1961, p. 68–73, figs. 46–64). This occurrence is the association of metamict allanite as the crystal core, surrounded by a thin rim of clinozoisite (fig. 30), which in turn may locally be enclosed by epidote. The petrographic features of the allanite group in the Sulfur deposit have been well described by Katz (1961) and will not be further described herein. Clinozoisite and the earlier described margarite may have formed during contact metamorphism whereby Ca was selectively added to certain structural or stratigraphic horizons within the Chopawamsic Formation, particularly in parts of the Sulfur deposit. Such minor Ca metasomatism may have occurred concomitant with the potassium metasomatism described earlier that formed muscovite megacrysts that overprint early formed fibrolite-biotite (fig. 24) fabric. Alternately, the Ca may have been derived from the metalimestone found within this deposit as discussed earlier.

Chlorite

Green, pleochroic chlorite, some of which occurs in well-formed, polysynthetically twinned crystals is locally present in the thermally metamorphosed rocks from the Sulfur mine and nearby schist. Electron microprobe analyses for some of these chlorites are given in table D-7 and these are characteristically ripidolites (fig. 4).

MINERAL DISTRIBUTION

The region discussed in this report contains regionally metamorphosed rocks of two distinct generations. As described earlier, the terrane west of the Long Branch thrust fault (pls. 1 and 2*A*) was polydeformed and regionally metamorphosed prior to the intrusion of the granitoids of the Lahore and Ellisville plutons. In the terrane east of this fault the rocks underwent Alleghanian metamorphism somewhere east of their present location and were juxtaposed against the rocks to their west after the Alleghanian metamorphism. These Alleghanian polymetamorphosed rocks, therefore,

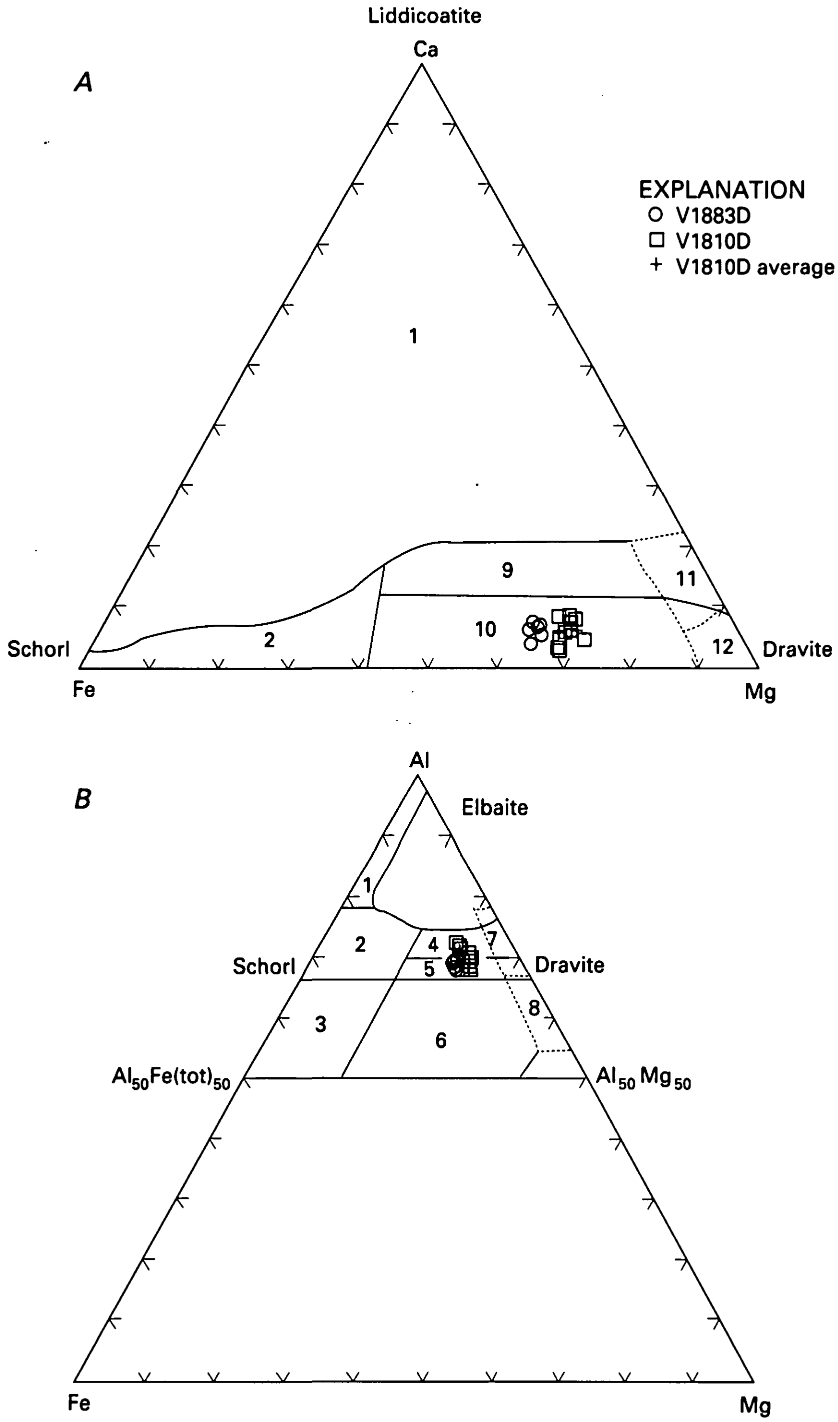


FIGURE 32.—Plots of tourmaline from the Sulfur mine (see plate 2*B*) of the Mineral district, Virginia (table D-10) shown on the diagram of Taylor and Slack (1984, fig. 10) as modified from Henry and Guidotti (1985) and Vladykin and others (1975). Fields of A and B represent: (1) Li-rich granitoid pegmatites and aplites; (2) Li-poor granitoid pegmatites and aplites; (3) hydrothermally altered granitoid rocks; (4) metapelites and metapsammites with an Al-saturating mineral (for example, staurolite); (5) as in (4) but without Al-saturating mineral; (6) Fe^{+3}-rich quartz-tourmaline rock; (7) low-Ca ultramafics and Cr- and V-rich metasediments and somewhat generalized; (8) metacarbonates and metapyroxenites; (9) Ca-rich metapelites; (10) Ca-poor metapelites, metapsammites quartz-tourmaline rocks; (11) metacarbonates; and (12) meta-ultramafics.

were not affected by the contact metamorphism related to the emplacement of the Lahore and Ellisville granitoids and will not be further discussed here.

Suites of characteristic metamorphic mineral assemblages generally form a thermal aureole about rocks invaded by intrusions. Ideally, such aureoles are zoned, with the innermost zone, closest to the intrusive contact, containing the highest grade mineral assemblages. The metamorphic grades of the mineral assemblages decrease successively outward from the intrusion up to the outer limits of the aureole, where the mineral assemblages merge with those of the country rocks.

Mineral zonation was not recognized with the contact-metamorphic rocks associated with the emplacement of the Lahore and Ellisville plutons (pl. 2*B*). However, fibrolitic muscovite occurs very close to the pluton contacts. Fibrolite has only been recognized in contact-metamorphosed matrix rocks of the Mine Run Complex melange units (pl. 2*C*). The origin of fibrolite in the contact-metamorphosed schists through the breakdown of biotite by acid fluids derived from the pluton and the eventual replacement of such biotite by muscovite through K-metasomatism has been discussed above.

A similar situation applies to the fibrolite associated with the Ardara pluton of the composite Donegal batholith of northern Ireland. There, fibrolite also occurs close to the Ardara pluton contact and is believed to have formed, in part at least, by "hydrothermal" alteration (Pitcher and Berger, 1972, p. 305) or through acidic volatiles emanating from the Ardara pluton and decomposing biotite (Kerrick, 1987). Other similarities between the Donegal area (Kerrick, 1987, p. 245) and the Ellisville-Lahore area is that the plutons in both areas forcefully intruded terranes that earlier had been regionally metamorphosed to the greenschist facies.

Kyanite also occurs in the Ardara pluton aureole but in a more distal position to the intrusive contact than fibrolite (Kerrick, 1987, fig. 1). However, kyanite is more randomly distributed within the thermal aureole of the Ellisville pluton. It occurs in muscovite-quartz schist very close to the contact of the Ellisville along State highway 522 just south of the southern arm of Lake Anna (pl. 2*B*). Here the kyanite has undergone alteration along its margins and has a carapace of fine-grained micaceous material (fig. 23). This alteration obviously took place after the kyanite had formed and is ascribed to fluids emanating from the Ellisville pluton. These fluids may have been, in part, those that formed fibrolite from biotite. Subsequently, through potassium metasomatism of such fibrolitized biotite, the fibrolitic muscovite porphyroblasts of figure 24*A*, discussed earlier, were formed. Under this interpretation, the paragenetic sequence summarized above for the contact-metamorphic minerals is interpreted to be

1. The formation of kyanite through contact metamorphism when the Ellisville pluton was emplaced;
2. The local, penecontemporaneous alteration of the kyanite (fig. 23*B*) and the formation of fibrolite in biotite by acidic fluids emanating from the Ellisville;
3. The conversion of fibrolitic biotite into muscovite and the incorporation of such fibrolite as part of the muscovite porphyroblasts formed by late-stage potassic metasomatism by fluids emanating from the Ellisville pluton as discussed above. Some of the potassium needed to form muscovite may have been released during fibrolitization of the biotite. Such late-stage metasomatic potassium-bearing fluids may also have partially altered plagioclase to potassic feldspar within some of the monzonites of the Lahore pluton (fig. 8*B*).

Kyanite that formed through contact metamorphism in the Chopawamsic Formation east of the Ellisville pluton in close proximity to it is not altered. In contrast, kyanite near the Ellisville contact described above is altered. Unaltered kyanite commonly occurs along wavy foliation (fig. 25). It may have formed through mimetic crystallization along previously formed schistosity when this schistosity was being deformed by forces active when the Ellisville pluton was emplaced.

Kyanite formed by contact metamorphism around plutons within terranes of greenschist-facies regional metamorphism has been reported from a number of places, for example, the Donegal batholith (Pitcher and Reed, 1963; Naggar and Atherton, 1970; Pitcher and Berger, 1972; Kerrick, 1987) and Ghana (Lobjoit 1964). Kyanite in such aureoles, according to Atherton and others (1975), may not require great pressures for its formation, but this interpretation is not applicable to the Lahore-Ellisville pluton area as discussed later.

Staurolite is also randomly distributed in the eastern part of the Ellisville aureole. In the aureole on the west side of Ellisville, it occurs more distally from the pluton contact than does fibrolite. It occurs with biotite at the pluton contact along State Route 522 on the south side of the southern arm of Lake Anna (pl. 2*B*) and is zincian in the southeast part of the aureole within the base metal-bearing Mineral district where it has been found more removed from the contact than fibrolitic muscovite in a variety of contact-metamorphic mineral associations.

Chloritoid is widely distributed within the aureole on the southeast side of the Ellisville pluton and occurs in a variety of assemblages (pl. 2*B*). Where the Ellisville pluton has narrowed down considerably, the thermal flux may have been small, and chloritoid formed near the Ellisville pluton contact (pl. 2*B*).

As can be seen on plate 2*B*, the thermal aureole on the southeast side of the Ellisville pluton contains a variety of contact-metamorphic assemblages in an irregular distribution pattern. Among these assemblages are

1. Staurolite-biotite-carbonate,
2. Biotite-chloritoid-staurolite-kyanite-muscovite,
3. Staurolite-biotite-garnet,
4. Garnet-kyanite-biotite-staurolite (Pavlides and others, 1982c, fig. 4*B*),
5. Staurolite-anthophyllite-biotite-chlorite (Pavlides and others, 1982c, fig. 4*F*).

Some of these mineral assemblages, such as 2, 4, and 5, are unusual because of the four coexisting AFM phases. Normally, during progressive metamorphism, chloritoid breaks down to form staurolite. The presence of staurolite in assemblages 2, 4, and 5 may result from the high Zn content of the rock, which stabilized the staurolite through substitution of Zn for Fe in the staurolite structure. The stabilizing effect of zinc in staurolite has been described by Ashworth (1975). Alternatively, it is possible that these unusual assemblages are in that part of the aureole that lies over a near-surface cupola or extension of the Ellisville pluton. Rapid heating during pluton emplacement combined with the sluggish nature of mineral conversions may have allowed metastable associations to form. That a near-surface extension of the Ellisville pluton exists on its east and north sides was discussed in the earlier sections on geophysics as well as by consideration of the resulting resetting of the K-Ar isotopic system of amphiboles in exotic blocks on its north side.

GEOCHEMISTRY

Plutonic rocks of the Lahore and Ellisville plutons were analyzed for their major and trace-element composition in order to characterize them, to better understand magmatic relations within and between the two bodies, and to provide a basis for comparison with analyzed rock suites elsewhere.

LAHORE COMPLEX

LAHORE PLUTON

MAJOR ELEMENTS

Samples analyzed from the Lahore pluton (table 3) include pyroxene monzonites, amphibole monzonites, and amphibole quartz monzonites (table 1). These samples have a limited range of SiO_2 content of 50.3 to 57.1 weight percent. Their Al_2O_3 content ranges from 13.9 to 16.1 percent and do not vary systematically with SiO_2 content. Their CaO contents range from 8.8 to 5.9 percent and generally decline as SiO_2 increases. They contain more total iron (5.9–9.6 percent as FeO) than MgO (3.5–6.7 percent) and much more K_2O (4.1–5.5 percent) than Na_2O (2.4–3.4 percent).

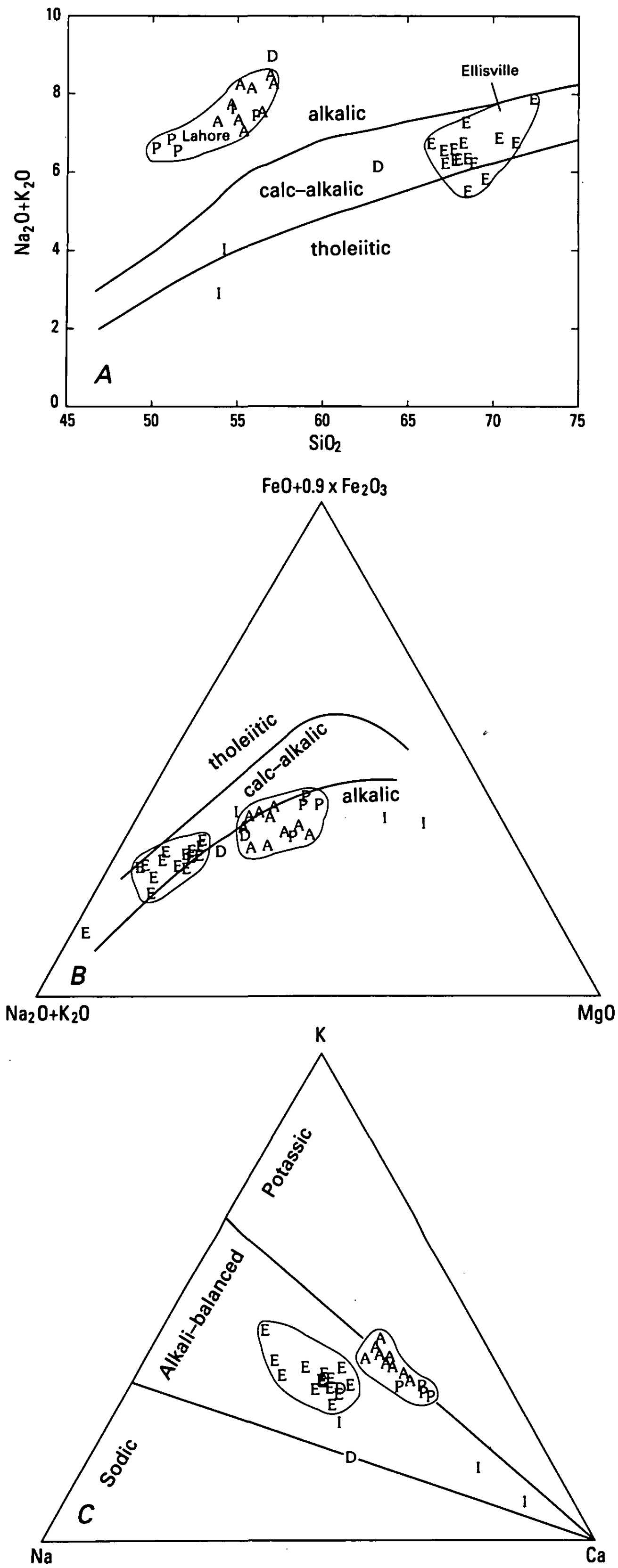
On a diagram comparing total alkalies (Na_2O+K_2O) and SiO_2 content (fig. 33*A*), the Lahore pyroxene and amphibole monzonites (symbols P and A, respectively) plot clearly in the alkalic field. On a triangular "Alk-F-M" diagram (fig. 33*B*), the Lahore monzonites again plot largely in the alkalic field. On a triangular molar plot of Na-K-Ca (fig. 33*C*), the Lahore rocks fall largely on the potassic side. The three diagrams thus characterize the Lahore monzonites as a potassic alkalic suite. The alkalic monzonites of the Lahore pluton are also subsilicic and contain less than 65 percent SiO_2 (table 3). The pyroxene monzonites contain only trace amounts of modal quartz in the range of 0.1–0.7 percent whereas the amphibole monzonites with their somewhat higher SiO_2 content (table 3) have a slightly higher modal quartz range of 0.2–3.7 percent (table 1, recast modal analyses). The Lahore monzonites also are characteristically metaluminous (Shand, 1943) with molecular proportions of $Al_2O_3>Na_2O+K_2O$ and $Al_2O_3<Na_2O+K_2O+CaO$. The metaluminous character of the Lahore is also clearly shown on the $Al_2O_3/CaO+Na_2O+K_2O$-Al_2O_3/Na_2O+K_2O alumina saturation diagram of figure 34.

MINOR ELEMENTS

Lahore monzonites have high concentrations of some trace elements for rocks of their SiO_2 contents. The large monovalent cations Rb and Cs show high concentrations (125–200 ppm and 1–4 ppm, respectively) and are probably contained in potassic feldspar and in mica.

The radioelements U and particularly Th are enriched in the monzonites of the Lahore pluton, especially in the amphibole monzonites. Crustal abundances estimated for U and Th are 2.7 ppm and 9.6 ppm, respectively (Taylor, 1964, table 3) giving a Th/U of 3.6. Uranium in the pyroxene monzonites ranges between 1.5 and 4.5 ppm and averages 2.9 ppm. Uranium has a somewhat comparable compositional range of 0.9–4.5 ppm with an average of 3.8 ppm in the amphibole monzonites (table 3). Thorium has a range of 5.3–12.1 ppm in the pyroxene monzonites and averages 8 ppm: it is markedly more abundant in the amphibole monzonites with a range of 4.3–53.8 ppm and an average of 20.8 ppm. Although the amphibole monzonites are richer in K_2O than the pyroxene monzonites (table 3), there is no systematic variation of either Th or of U with K_2O in either of these monzonites. There is also no apparent variation of U and Th with the SiO_2 content.

The higher concentration of Th in the amphibole monzonites is most likely related to the more petrologically evolved state of these rocks. Th and U generally increase with degree of fractionation in plutonic igneous



rocks and are particularly enriched in alkalic rocks. Examples of this are found in plutons of the White Mountain Plutonic-Volcanic Suite of New Hampshire. Chemical data from these rocks compiled by Butler (1961), Rogers and Ragland (1961), and Adams and others (1962) show U in the range 0.7–25.5 ppm and Th in the range 3.4–94 ppm. Somewhat similar U and Th concentrations occur in the alkalic Monteregian Hills intrusions of Quebec (Eby, 1985). Pyroxene monzonites of the Lahore pluton have a Th/U range of 1.2–4.7 (table 3) and average 3.2 whereas in the amphibole monzonites this ratio has a higher range of 2.6–11.7 (table 3) and an average of 5.9. The Th/U of the Lahore monzonites suggests initial crystallization of pyroxene monzonite with an average Th/U of 3.8 and a Th/U concentration of 5.9 in the magma of the more evolved amphibole monzonites.

The sites where the Th and U occur within the monzonites of the Lahore plutons is not certain. Undoubtedly a certain amount of the radioelement content of the monzonites occurs in zircon, allanite, apatite, and epidote, but these minerals are very sparse and, judging by the epidote content (table 1), they lack systematic distribution as compared to the Th and U content of these rocks (table 3). An unknown but significant amount of Th and U may be loosely bound along grain boundaries or cracks, one of the emplacement sites suggested by Neuerburg (1956) and also supported by the leaching studies of Tilton and others (1955) and Larsen (1957).

The divalent cations Sr and Ba are also very abundant (1027–1540 ppm and 1644–2060 ppm, respectively). These elements are probably contained mostly within feldspars of the monzonites, and some also may be contained in biotite, as discussed earlier in the report. That the Ba is highly concentrated in the potassic feldspars is summarized in table 5. The celsian content (Ba feldspar molecular proportion) of the potassic feldspar in the amphibole monzonites also is generally higher than in the plagioclase. Sr although less abundant than Ba also is generally more abundant in those monzonites with the higher Ba content (table 5). Potassic feldspar as a sink for Ba and Sr have, of course, been noted

◀ FIGURE 33.—Major-element classification diagrams for granitoid samples of the Lahore and Ellisville plutons. *A.* Na_2O+K_2O versus SiO_2 diagram showing the analyzed samples for Lahore pluton pyroxene monzonites (symbol P), amphibole monzonites (A), and dikes (D); and Ellisville pluton granodiorites (E), and inclusions (I); and the fields for tholeiitic, calc-alkalic, and alkalic suites as demonstrated by Kuno (1969). *B.* Ternary plot of total alkalies as Na_2O+K_2O, total iron as FeO, and MgO for the Lahore and Ellisville suites, and the fields demonstrated by Kuno (1969). Letter designations as in figure 33*A*. *C.* Ternary Ca-Na-K plot for Lahore and Ellisville suites. Letter designations as in figure 33*A*.

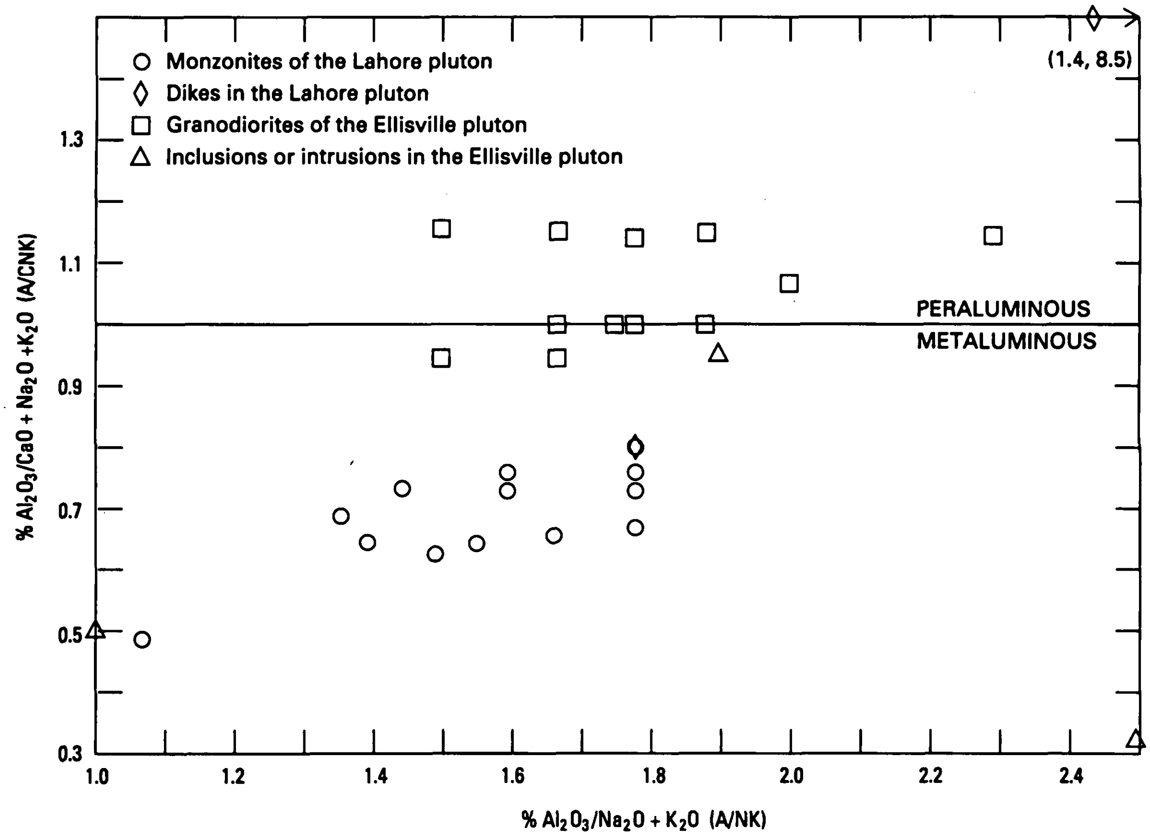


FIGURE 34.—A/CNK-A/NK aluminum saturation diagram for the monzonites and dikes of the Lahore pluton and the granodiorites of the Ellisville pluton and its inclusions/intrusions.

elsewhere (Mason and others, 1985; O'Halloran, 1985; Heier, 1966). The Sr content of the monzonite therefore is also believed to be abundant in the potassic feldspar.

As is characteristic of alkalic plutonic rocks in general, REE show strongly fractionated patterns (fig. 35) having La of about 200 times chondritic abundance, Lu of about 9 times chondritic values, and small or no Eu anomalies.

The initial $^{87}Sr/^{86}Sr$ ratio for five Lahore monzonites is reported in table 8. Values range from .7045 to .7048 and are indistinguishable within the propagated analytical and age uncertainties. These low initial values suggest deep crustal or mantle origin for the Lahore monzonites (discussed later).

LAHORE MAFIC PLUTON

The mafic body at the north side of the Lahore pluton and presumably intruded by it consists of serpentinized diopside-metapyroxenite and actinolitic diopside-metapyroxenite as described earlier. The chemistries of these two lithologies as well as of a highly silicified type are listed in table 6. On the basis of rock chemistry, Pavlides (1989) considered the nonsilicified metapyroxenites as ultramafic protoliths modified by metamorphism and serpentinization. Support for this interpretation stems from the Cr contents of 2950 and 2320 ppm in two samples as well as from an MgO and CaO range of 23.3 to 21.6 percent and 15.3 to 13.6 percent respectively (table 6). The extremely low Al_2O_3 content of 0.36 and 0.34 in these two samples is enigmatic; it may in part stem from their ultramafic ancestry as well as Al_2O_3 loss during metamorphic alteration. Sample 3 of table 6 indicates that, compared with samples 1 and 2, this sample underwent local silicification and depletion of MgO, CaO, Na_2O, and TiO_2 and enrichment of Fe_2O_3, Ni, and H_2O. The chondrite-normalized highly fractionated REE patterns for these three samples are given in figure 36. The silicified sample (no. 3 of fig. 36) apparently underwent systematic REE depletion with respect to the nonsilicified metapyroxenites (nos. 1 and 2, fig. 36) except for La, which may represent residual enrichment. Curiously, the REE patterns of the Lahore mafic mass are somewhat similar to the high-K spinel peridotites of St. Pauls Rocks in the equatorial Atlantic Ocean (Frey, 1984, p. 171). The Lahore mafic mass, however, is not spinel-bearing. The metapyroxenite of the Lahore Complex may represent an early fractionate from a mantle source, later intruded by the younger Lahore monzonite discussed earlier, rather than a fragment of ancient volcanic edifice (Pavlides, 1989).

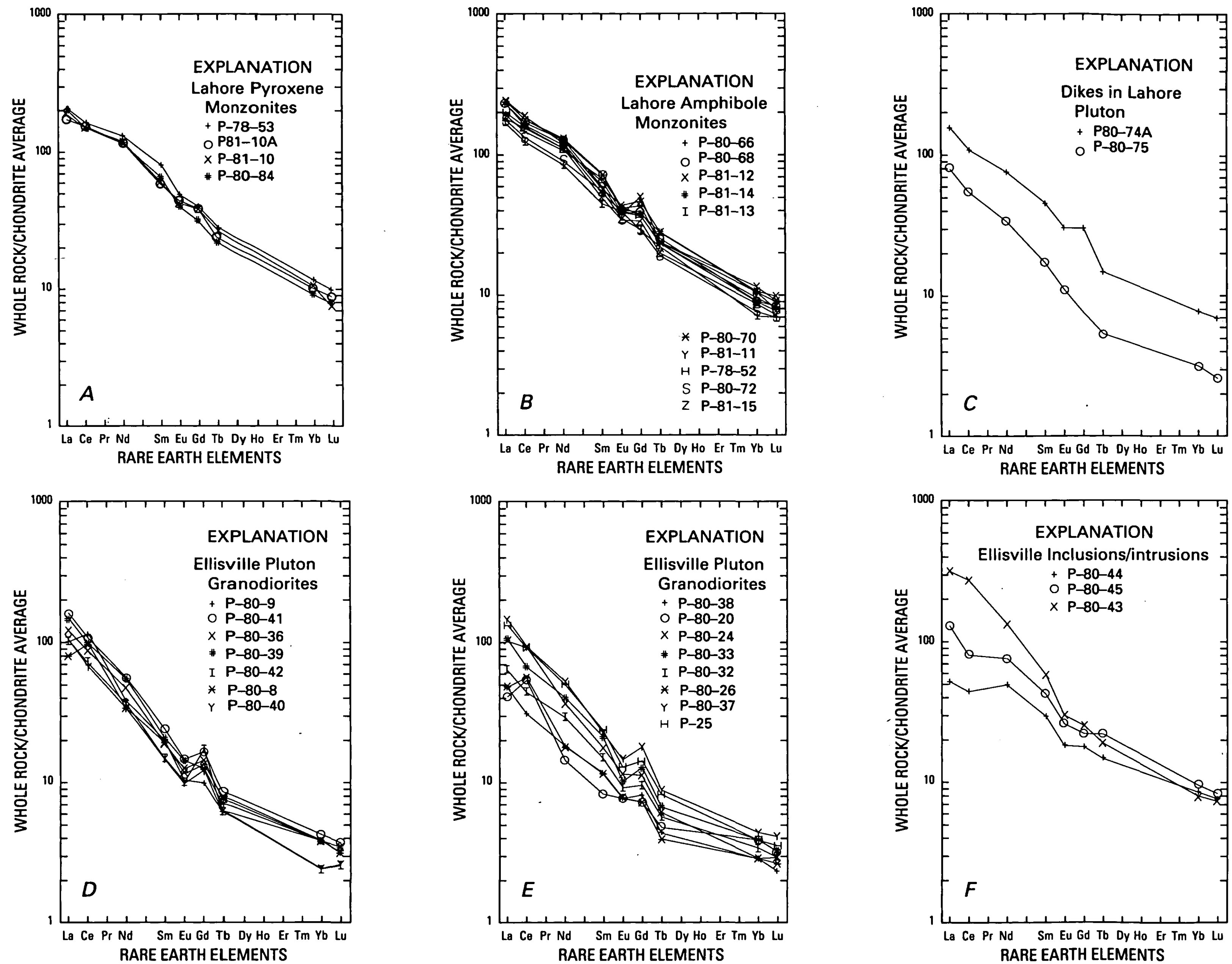


FIGURE 35.—Chondrite-normalized rare earth plots for granitoids of the Lahore and Ellisville plutons. *A*. Lahore pyroxene monzonites; *B*. Lahore amphibole monzonites and quartz monzonites; *C*. Dikes in Lahore pluton; *D*. Ellisville pluton granodiorites, samples containing 66.4 to 68.2 percent SiO_2; *E*. Ellisville pluton granodiorites, samples having 68.4 to 72.3 percent SiO_2; *F*. Inclusions/intrusions in Ellisville pluton. Normalizing chondrite values used are La 0.325, Ce 0.798, Pr 0.104, Nd 0.567, Sm 0.186, Eu 0.0692, Gd 0.255, Dy 0.305, Er 0.20, Yb 0.209, Lu 0.0349 (Hubbard and Gast, 1971); Tb 0.047, Ho 0.070, Tm 0.030 (Haskin and others, 1968).

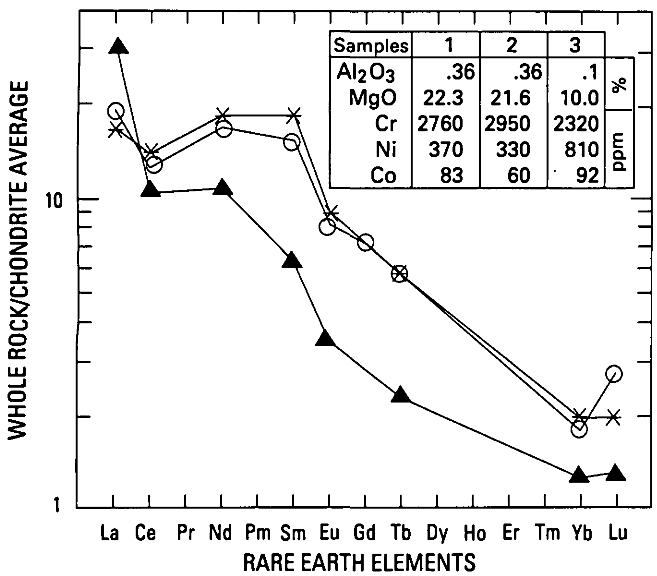


FIGURE 36.—Chondrite-normalized rare earth plots of three samples from the mafic pluton of the Lahore Complex. Chondrite values used in normalizing REE are those of Nakamura (1974). Partial chemical analyses are taken from table 6.

DIKES OF THE LAHORE PLUTON

The two dikes from within the Lahore pluton were probably late residual fractionates of the amphibole monzonite magma as suggested by their SiO_2 content of 57 and 63.1 percent as compared to the lower SiO_2 range of the amphibole monzonites in general (table 3). The dikes are somewhat more depleted in total iron in general than the monzonites (fig. 33*B*). The dike listed as number 15 in table 3 is a quartz monzonite, probably an early residual fractionate, and still has many chemical similarities to the amphibole monzonite suite, such as its high Ba and Sr content and similar compositional range in U, Th, Zr, and Hf (table 3). The dike listed under 16 of table 3 is a tonalite and was probably a late residual fractionate as is suggested by its lower or depleted content of Na, Ba, Sr, U, Th, Zr, and Hf (table 3). Like the amphibole monzonites, both dikes have strongly fractionated REE patterns (compare figs. 35*B* and *C*), but the tonalite dike (P-80-75) is more depleted in total REE's than P-80-74A, the quartz monzonite dike (fig. 35*C*). It may be a dike derived from the Ellisville pluton.

ELLISVILLE PLUTON

MAJOR ELEMENTS

Samples analyzed from the Ellisville pluton (table 4) include 13 biotite granodiorites, one monzogranite (P-80-38), and one biotite quartz monzonite, P-80-8 (table 2). The quartzose, oversaturated Ellisville samples have a range of SiO_2 content of 66.4 to 72.3 weight percent. Their Al_2O_3 contents of 14.6 to 16.8 percent do not vary with the SiO_2 content. They have low CaO contents of 1.9 to 4.3 percent that generally decline as SiO_2 increases. Total iron and MgO are low in these rocks and decrease with increasing SiO_2 content. Na_2O contents of 2.7 to 3.8 percent are similar to the K_2O contents of 2.7 to 4.0 percent.

The Ellisville granitoids constitute a weakly peraluminous calc-alkaline suite. Only eight Ellisville samples meet Shand's (1943) criteron for the peraluminous nature of granitoid rocks. Of the remaining five, the Al_2O_3 and the sum of alkali and CaO are equal, and two samples have $Al_2O_3 < Na_2O + K_2O + CaO$. A somewhat different distribution of these samples is shown in figure 34. On this diagram six samples fall in the peraluminous field, four on the metaluminous-peraluminous boundary and two in the metaluminous field. However, 13 of the granodiorites contain normative corundum (3.0–0.5 percent) and two are corundum-free (table 2). Biotite is an abundant and characterizing accessory of the Ellisville granodiorite and along with the minor amounts of muscovite in some granodiorites supports a peraluminous character for these rocks. In general, therefore, the Ellisville samples are considered weakly peraluminous.

On a diagram comparing total alkali-oxide content to SiO_2 content (fig. 33*A*), the Ellisville samples (symbol E) fall in the calc-alkalic field. On a triangular "Alk-F-M" diagram (fig. 33*B*), the Ellisville samples also fall in the calc-alkalic field. On the Na-K-Ca diagram (fig. 33*C*), the Ellisville samples are alkali-balanced. The three diagrams thus characterize the Ellisville granodiorites as an alkali-balanced calc-alkaline suite.

MINOR ELEMENTS

The Ellisville granodiorites have moderate concentrations of most minor elements. Rb (78–165 ppm) and Cs (1.4–4.6 ppm) (table 4) probably are mostly contained in biotite and potassic feldspar (0.7–12.3 and 0–21.8 percent, respectively; table 2, see recast modal analyses), and are neither high nor low for rocks in their SiO_2 range. Sr contents of 209–565 ppm and Ba contents of 366 to 1004 ppm (table 4) are probably mostly contained in potassic feldspar. As was described earlier for the Lahore monzonites and as seen in table 5, Ba also is highly concentrated as celsian in potassic feldspar and occurs in negligible amounts in the plagioclase of the granodiorites. Sr is less abundant than Ba in the granodiorites (table 5) but has not been analyzed for in the feldspars of these rocks. Nonetheless it is also believed to be more highly concentrated in the potassic feldspar as discussed earlier in the geochemistry of the Lahore monzonites.

TABLE 6.—*Chemical and normative compositions of the mafic pluton of the Lahore Complex. Modified from Pavlides (1989, table 3)*

Spec. No.	1	2	3
Field No.	P-80-86	P-80-87	P-80-92
Major-Element Composition: (Weight Percent)[1/]			
SiO_2	50.9	56.2	76.8
Al_2O_3	.36	.34	.1
Fe_2O_3	3.4	1.8	5.5
FeO	2.2	2.6	.8
MgO	22.3	21.6	10.0
CaO	15.3	13.6	.3
Na_2O	.11	.16	<.01
K_2O	.13	<.01	.02
H_2O+	3.3	.69	4.0
H_2O-	.54	.30	1.3
TiO_2	.21	.23	.07
P_2O_5	.03	.04	.03
MnO	.12	.10	.10
CO_2	.03	.09	.01
Total	98.93	97.75	99.0
Minor-Element Composition (Parts per Million)[2/]			
Rb	<19.	<17.	<15.
Ba	<210.	<190.	<100.
Sr	<500.	<400.	<190.
Th	.29	.67	.47
U	<2.	<1.0	.44
Zr	<400.	<400.	240.
Hf	.38	.55	.19
Nb	<.1	<.1	<1.1
Ta	<.3	<.3	.2
Co	83.	60.	92.
Ni	370.	330.	810.
Cr	2760.	2950.	2320.
Sc	48.5	51.3	6.23
V	51.	51.	15.
La	6.27	5.58	9.99
Ce	10.9	12.0	9.1
Nd	10.8	11.6	6.8
Sm	3.16	3.73	1.28
Eu	.642	.71	.270
Gd	2.0	<5.	<3.
Tb	.268	.27	.108
Yb	.40	.44	.28
Lu	.095	.068	.045
RATIOS			
Ni/Co	4.5	5.5	87.0
La/Lu_{cn}	6.8	8.4	22.9
Eu/Sm	.2	.19	.21
Normative Mineral Composition (Weight Percent). Based on analyses recalculated to 100 water-free oxides			
Q	—	7.5	65.6
or	.8	—	.1
ab	1.0	1.4	—
an	.1	.2	.2
wo	33.1	28.7	.5
en	57.3	55.6	26.6
fs	1.1	3.2	—
fo	.8	—	—
mt	5.2	2.7	2.9

TABLE 6.—*Chemical and normative compositions of the mafic pluton of the Lahore Complex. Modified from Pavlides (1989, table 3)—Contined*

Spec. No.	1	2	3
Field No.	P-80-86	P-80-87	P-80-92
Normative Mineral Composition (Weight Percent). Based on analyses recalculated to 100 water-free oxides—Continued			
hm	—	—	3.9
il	.4	.5	.1
ap	.1	.1	.1
cc	.1	.2	—
Total	100.	100.	100.
di	61.9	53.8	.8
di-wo	33.1	28.7	.5
di-en	28.2	23.7	.4
di-fs	.6	1.4	—
hy	29.7	33.7	26.2
hy-en	29.1	31.9	26.2
hy-fs	.6	1.8	—
ol	.8	—	—
ol-fs	.8	—	—
D.I.	1.8	8.9	65.8

Petrography

1. P-80-86: Green, massive, medium-grained serpentiniferous metapyroxenite. Anhedral to subhedral diopside with intersertal mesh textured serpentine. Lahore quadrangle at lat 38°13′37″ N. and long 77°56′55″ W.
2. P-80-87: Green, massive, medium-grained actinolite-diopside "metapyroxenite." Diopside with irregular embayed shapes is mantled by colorless tremolite-actinolite that pseudomorphously has partly replaced the diopside. Tremolite-actinolite also occurs as large laths probably formed through replacement of diopside. Chlorite is rare. Lahore quadrangle at lat 38°13′32″ N. and long 77°56′54″ W.
3. P-80-92: Green, massive, medium-grained metapyroxenite. Rock is highly silicified; round to subround outlines of replaced minerals, some clearly are amphibole pseudomorphs. Serpentine is local intergranular groundmass. Lahore quadrangle at lat 38°13′44″ N. and long 77°56′46″ W.

1/ Determined by rapid rock analyses, Z.A. Hamlin, Debby Kay, J. Gillison, and H. Smith, analysts.

2/ Rb, Ba, and Sr determined by X-ray spectroscopy, R. Johnson, and S. Fleming, analysts. Th, U, Hf, Ta, Co, Cr, Sc, La, Ce, Nd, Sm, Eu, Gd, Tb, Yb, and Lu determined by instrumental neutron activation analysis, Louis Schwarz, Jeffrey Grossman, and J.S. Mee, analysts. Zr determined by emission spectroscopy (samples 1 and 2), E. Silk, analyst, and by X-ray spectroscopy (sample 3); R. Johnson and S. Fleming, analysts. Nb determined by spectrophotometry, E.Y. Cambell, analyst; V determined by flameless atomic absorption, E.Y. Campbell, analyst.

The radioelement content of the Ellisville granodiorites is similar to those estimated for crustal abundances as well as for granodiorites elsewhere. As stated earlier, the estimated crustal abundance for U and Th are 2.7 and 9.6 ppm, respectively (Taylor, 1964, table 3) that yield Th/U of 3.6. The U of the Ellisville granodiorites ranges between 1.5 and 7.0 ppm and averages 3 ppm whereas Th ranges between 8.4 and 12 ppm. The Th/U range is 1.2–10.3 and averages 5. The radioelement content of the Ellisville granodiorites therefore is lower than that of the alkalic monzonite of the Lahore pluton described earlier.

Granodiorites analyzed from the batholiths of southern California, the Sierra Nevada, and Idaho (Larsen and Gottfried, 1960, table 1) have U and Th ranges and averages respectively of U: 1.1–4.2, 2.0; 5.2–5.2, 5.2; 1.1–5.1, 2.4; and Th: 3.1–15.1, 7.8; 14.3–24.0, 19.2, and 5.4–23.2, 10.3. The Th/U of the granodiorites from these batholiths respectively is 4.2, 3.8, and 4.8. Dodge and others (1982, table 2) analyzed 12 samples of granodiorite from the Central Sierra Nevada batholith of California and report a range of .922–13.2 for U and 3.83–28.2 for Th. The granodiorites of the Ellisville pluton therefore have generally similar U and Th ranges and Th/U as those of granodiorites in California and Idaho.

The sites of U and Th occurrence within the granodiorites of the Ellisville is uncertain. As in the case of the Lahore monzonites discussed earlier, it is believed that these radioelements occur in zircon, apatite, allanite, and epidote. The ubiquitous magmatic epidote (fig. 19) whose modal content ranges between .7 and 3.3 percent (table 2, recast modal analyses) and the sparser but generally closely associated allanite (fig. 19) may be important sites for the U and Th of these granodiorites. Also as discussed under the Lahore monzonites some of these radioelements may be loosely bound along grain boundaries or cracks.

Rare earth elements have strongly fractionated patterns (fig. 35) having La 50 to 150 times chondritic abundances, Lu of 2 to 4 times chondritic abundances and small negative anomalies. The initial $^{87}Sr/^{86}Sr$ of the Ellisville granodiorites is about 0.7062 and suggests a crustal origin for these rocks.

INCLUSIONS OR INTRUSIONS

Three rocks analyzed from bedrock exposures within the Ellisville pluton (S€i of plate 2*A*, analyses 16, 17, and 18 of plate 2*B*, and tables 2 and 4) are petrographically and chemically distinct from the granodiorites that constitute the pluton. These three outcrop areas are poorly exposed, and it is not clear if they represent inclusions (xenoliths) or intrusions, such as large dikes or plugs. Samples P-80–44 and P-80–45 (analyses 16 and 17 respectively, tables 2 and 4) respectively contain 41 and 37 percent amphibole, 2 to 5 percent magmatic epidote and 2.4 to 2.9 quartz. These are mineralogic compositions not too dissimilar from the amphibole monzonites of the Lahore pluton (compare tables 1 and 3, recast modal analyses). Chemically, however, they have marked differences in major element ranges such as lower Al_2O_3, Na_2O, K_2O, P_2O_5, and higher MgO, CaO, and TiO_2, as well as markedly different minor element contents (compare tables 3 and 4). Therefore, these two samples (nos. 16 and 17 of tables 2 and 4) cannot be unequivocally identified as either inclusions possibly derived from the Lahore pluton or small intrusions. Sample P-80–43 (no. 18, tables 2 and 4) is a diorite and is chemically distinct from the other two samples (nos. 16 and 17, table 2) and from the host granodiorite. However, this rock contains coarse-grained epidote cored by allanite, a feature found in some of the granodiorites of the Ellisville pluton (see Petrographic descriptions, table 2) and possibly could be a late fractionate dike derived from the residium of the magma chamber that supplied the Ellisville granoidiorite.

GEOCHRONOLOGY

An integrated geochronologic study of the monzonites of the Lahore pluton, the Ellisville pluton, and mafic olistoliths from the enclosing country rocks was completed to measure the crystallization ages of the plutonic rocks and possibly the olistoliths of the Mine Run Complex. The crystallization ages for the monzonite of the Lahore pluton and the granodiorite of the Ellisville pluton were measured by using the U-Th-Pb method on zircon separates and the Rb-Sr whole-rock isochron method. In some cases $^{40}Ar/^{39}Ar$ methods on amphibole provided younger limits on crystallization ages. Analytical methods for the three techniques are outlined in Appendix F.

LAHORE PLUTON

A U-Pb concordia plot for two bulk samples of zircon from monzonites of the Lahore pluton is shown in figure 37*A*. The samples plot concordantly (P-81–12) or nearly concordant (P-81–11) in the range 450 to 442 Ma. The $^{207}Pb/^{206}Pb$ ages for these samples are 448 and 455 Ma, respectively (table 7*A*).

A further constraint on the age of the Lahore monzonites is provided by an Ar-Ar isochron age of 445.1±2.0 Ma (fig. 38*B* and table 10) for an amphibole from a sample (P-81–15) that is distant from the Ellisville contact (pl. 2*B*). Amphiboles do not quantitatively retain argon at temperatures above 500°-530°C. Therefore, they cannot record crystallization ages of a pluton unless the rate of cooling from crystallization temperature to argon closure temperature is very rapid. Thus, $^{40}Ar/^{39}Ar$ plateau and Ar-Ar isochron ages of amphibole are best interpreted as times of cooling to about 530°–500°C if not subjected to

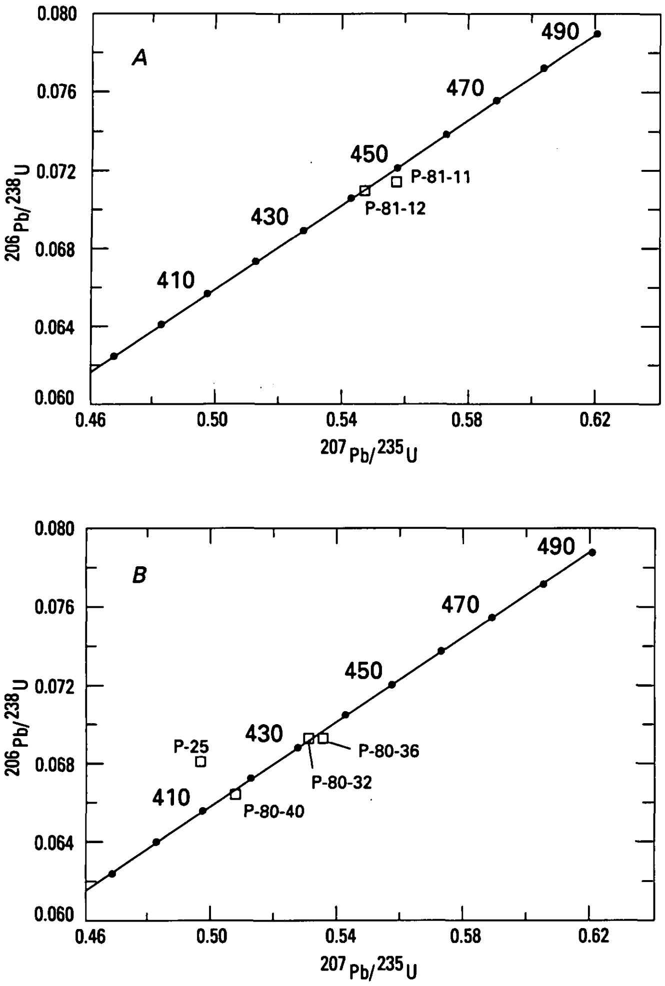


FIGURE 37.—Concordia diagrams of U-Pb analyses of zircon separates from the Lahore (*A*) and Ellisville (*B*) plutons. Sample rectangles represent analytical uncertainties of 1 percent. Numbers on graphs represent million years.

any later thermal events above 500°C. The time of crystallization of the Lahore monzonites is therefore probably older than about 445 Ma. Rb/Sr geochronology was not attempted on the Lahore pluton because Lahore samples have very high Sr contents (table 8) and very low Rb/Sr values that display very little variation. Hence, in the absence of additional criteria, we suggest that the crystallization age for the Lahore monzonites is between 455 and 445 Ma and in subsequent discussion an average age of about 450 Ma will be used.

ELLISVILLE PLUTON

A U-Pb concordia plot for four bulk samples of zircon from Ellisville granodiorite is shown in figure 37*B*, and the analytical data are listed in table 7. Three of the samples plot concordantly within analytical uncertainty in the range 415 to 436 Ma (fig. 37*B*). A fourth sample (P-25) shows reverse discordance, and may have experienced preferential loss of U. The $^{207}Pb/^{206}Pb$ ages for the three concordant samples range from 450 to 432 Ma and have an average value of 438±10 Ma.

A whole-rock Rb-Sr isochron age of 441±8 Ma was reported by Pavlides and others (1982a) for the Ellisville pluton. Figure 39 shows the isochron plot generated from the isotopic data (table 8). All the data points fit a single line within analytical uncertainty. Most of the data form a cluster of points in the $^{87}Rb/^{86}Sr$ range of 0.4 to 0.8. Sample P-80-38 plots higher than the cluster and strongly influences the precision of the isochron. This sample is a monzodiorite and plots just outside of the granodiorite field in figure 5. However, it contains magmatic epidote and well-formed titanite (table 2, recast modal analyses), both of which are characterizing minerals of the Ellisville granodiorite suite. Thus, it is appropriately included in the isochron, which indicates an age of 441±8 Ma for the Ellisville. The ±8 m.y. uncertainty of this age for the Ellisville overlaps the Ordovician-Silurian boundary of 438±12 Ma as shown on the Decade of North American Geology 1983 geologic time scale (Palmer, 1983). For purposes of systematic designation, the Ellisville pluton is herein considered Late Ordovician or Early Silurian in age and so desig-

TABLE 7.—*U-Th-Pb analytical data on zircons from monzonites of the Lahore pluton and granodiorites of the Ellisville pluton*

Sample No.	Concentration in parts per million			Atomic ratios			Millions of years			
	Pb	U	Th	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{204}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{232}Th$
					A. Lahore pluton					
P-81-11	45.3	601.3	315.9	0.15717	0.06137	0.00033	445.1	449.9	455.2	383.0
P-81-12	47.2	610.1	237.8	.18246	.06611	.00070	442.1	443.1	448.1	ND
					B. Ellisville pluton					
P-25	101.6	1529.9	347.7	0.07248	0.05675	0.00025	424.5	410.5	333.0	366.3
P-80-32	119.0	1700.7	522.4	.10648	.05842	.00020	432.6	432.6	432.6	433.4
P-80-36	68.3	959.1	374.0	.13089	.05841	.00017	432.8	435.5	449.8	429.7
P-80-40	36.3	517.9	201.0	.12828	.07153	.00110	414.9	417.5	431.9	294.4

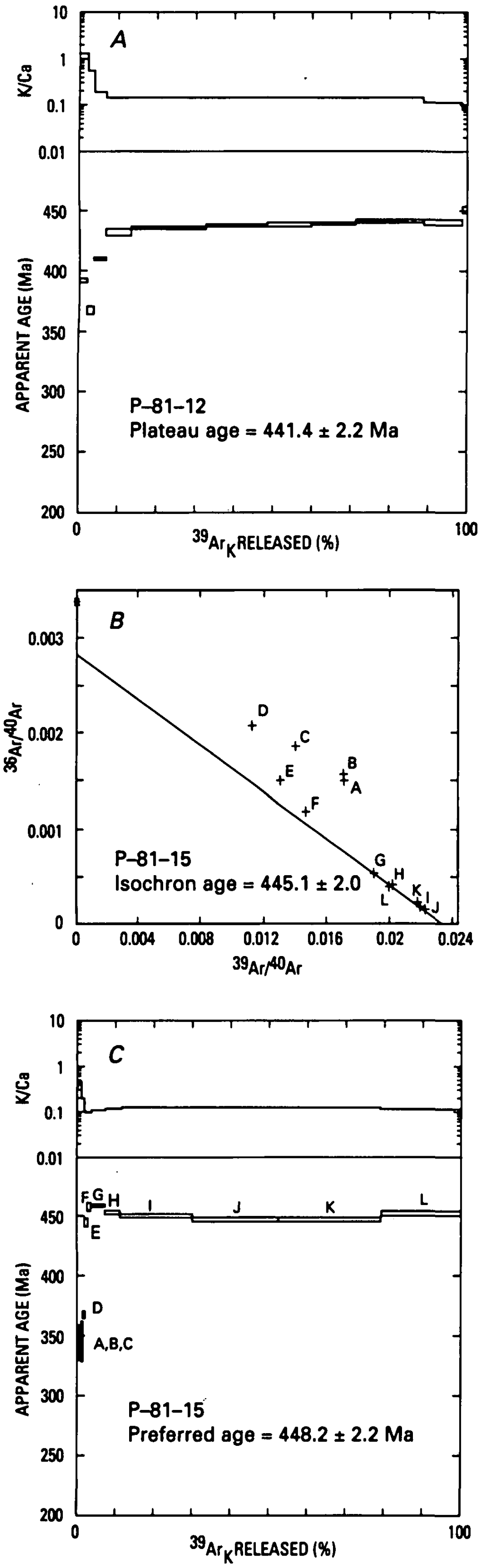


FIGURE 38.—$^{40}Ar/^{39}Ar$ age spectra and an isochron plot for (*A*) amphibole samples from the Lahore pluton. Letters on the age spectrum (*C*) and isochron plot (*B*) refer to temperature steps listed in table 9. Asterisk (*) in *B* represents the isotopic composition of present-day atmospheric argon.

TABLE 8.—*Rb/Sr data for whole-rock samples from monzonites of the Lahore pluton and granodiorites of the Ellisville pluton*

Sample No.	Concentration in parts per million[1]				
	Rb	Sr	Rb/Sr	Measured $^{87}Sr/^{86}Sr$	Initial[2] $^{87}Sr/^{86}Sr$
A. Lahore pluton					
P-81-10	141	1194	0.118	0.70668	0.7045
P-81-11	200	1126	.178	.70789	.7046
P-81-12	175	1252	.140	.70723	.7046
P-81-14	169	1027	.165	.70789	.7048
P-81-15	165	1260	.131	.70711	.7047
Sample No.	**Concentration in parts per million[3] Rb**	**Sr**	**Rb/Sr**	**$^{87}Rb/^{86}Sr$**	**Measured $^{87}Sr/^{86}Sr$**
B. Ellisville pluton					
P-80-33	107.9	426.3	0.2531	0.7325	0.71076
P-80-36	103.3	515.4	.2004	.5799	.70994
P-80-37	97.5	521.3	.1870	.5411	.70935
P-80-38	165.2	209.1	.7901	2.289	.72056
P-80-39	97.0	551.5	.1759	.5089	.70938
P-80-40	99.8	519.1	.1923	.5562	.70962
P-80-42	77.8	565.0	.1377	.3983	.70878

[1] Rb and Sr measured by x-ray fluorescene.
[2] Initial ratios calculated using an age of 452±5 Ma.
[3] Rb and Sr measured by isotope-dilution mass-spectrometry.

nated in plates 1 and 2. The average zircon Pb-Pb age of 438 Ma is in close agreement with the whole-rock Rb-Sr isochron age of 441 Ma.

Ar/Ar age spectrum date (table 9) and isochron data (table 10) from amphiboles in the interior of the Ellisville

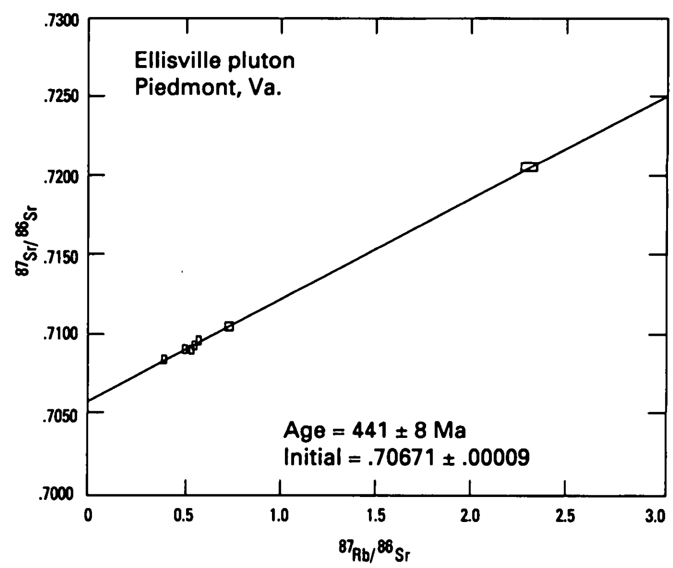


FIGURE 39.—Rb/Sr isochron plot for whole-rock samples from the Ellisville pluton.

pluton yield an $^{40}Ar/^{39}Ar$ plateau age (P-80–41; 429.5±2.1 Ma; fig. 40*A*) and an isochron age (P-80–42; 427.1±2.0 Ma; fig. 40*B*) that suggest that the pluton had cooled to about 530° to 500°C by this time and thus provide a minimum age estimate for the Ellisville pluton.

As discussed earlier in the section on contact metamorphism, sample P-81–12 from the southern part of the Lahore pluton (pl. 2*C*) is within the projected contact aureole of the Ellisville pluton. Amphibole from P-81–12 yields an Ar/Ar plateau age of 441.4±2.2 Ma (fig. 38), indistinguishable from the probable crystallization age of the Ellisville pluton. In addition, amphiboles from two metamafic olistoliths of the Mine Run Complex (P-80–48B and P-80–46C) in the contact aureole of the Ellisville pluton (pl. 2*C*) appear to have had their K-Ar isotopic systems reset by heating from the intrusions, yielding a plateau age of 434.8±2.2 Ma and 437.5±2.2 Ma (fig. 41), respectively. Amphibole from P-80–46C also yields an Ar/Ar isochron age of 436.9±2.0 Ma (fig. 41*C*). These amphibole ages in the contact aureole are indistinguishable (considering the analytical uncertainties) from the suggested crystallization age of the Ellisville pluton of about 440 Ma discussed above.

Using all pertinent geochronologic data, we suggest that the Ellisville pluton probably crystallized between 445 and 435 Ma, and in this paper will use an average of about 440 Ma as the crystallization age.

OLISTOLITHS OF THE MINE RUN COMPLEX

Two other metamafic olistoliths (P-78–22 and P-78–6) within melange zone rocks of the Mine Run Complex were sampled well outside the thermal contact aureoles of the Lahore and Ellisville plutons (pl. 2*B*). They each contain amphiboles that range in composition from magnesio-hornblende to edenite. Their $^{40}Ar/^{39}Ar$ age spectra (figs. 41*D* and 41*E*) are very discordant and U-shaped, typical of spectra interpreted to be the result of incorporation of relatively large amounts of extraneous or "excess" ^{40}Ar (Lanphere and Dalrymple, 1976). If this is the situation, none of the apparent ages on the spectrum necessarily have any geologic meaning. It is possible, however, that the age minimum in the U-shaped spectrum is a maximum age constraint for the timing of metamorphism exhibited by the olistoliths and acquired prior to their incorporation in the melange. In these two samples, the age minima are between 700 Ma and 670 Ma (table 7). It should be noted that isotopic data from neither of these samples form a linear array on an Ar/Ar isochron diagram and that the chances of any of the step ages having any specific geologic meaning is very remote. Another possible interpretation of the U-shaped age spectra is that they represent a composite of extraneous ^{40}Ar superimposed on a spectrum of severe ^{40}Ar loss (DeWitt and others, 1984; Miller and Sutter, 1982). In this scenario, the low-temperature steps are influenced by extraneous ^{40}Ar and the higher temperature steps reflect a diffusional loss profile for ^{40}Ar. The middle temperature steps may or may not be influenced by extraneous ^{40}Ar. Therefore, the apparent ages in the "saddle" of the U-shaped spectrum would be a maximum estimate of the timing of the ^{40}Ar loss event. Also, in this interpretation, the apparent ages of the highest temperature steps would be minimum estimates of the timing of initial closure of the amphibole K-Ar isotopic system. Using this interpretation, the initial closure of amphibole from P-78–22 was >940 Ma and from P-78–6 was >830 Ma and the ^{40}Ar loss event was <690 Ma and <670 Ma, respectively. Although this interpretation is very speculative, the olistoliths could be, at least in part, of Proterozoic age. Such an age is compatable with the interpretation by Pavlides (1989) that such olistoliths may represent Proterozoic marginal basin sea floor blocks.

PLUTONISM

The mode and place of origin within the earth's interior of the Lahore and Ellisville magmas is equivocal under our present data base. The geographic proximity of the Lahore and Ellisville bodies and their intrusive relationships cannot be taken to indicate any genetic relationship between the two bodies in view of the geochemical discussion above. They are distinct in mineralogy, distinct in major and trace-element chemistry, distinct in age, and distinct in initial compositon of Sr as discussed earlier. Either subduction-related or continental margin settings can be inferred for these plutons, and the following discussion outlines some of the interpretations for these two contrasting possibilities.

LAHORE PLUTON MONZONITES

The Lahore monzonites have many chemical and mineralogical features characteristic of the shoshonite association of Joplin (1968) and the shoshonite rock association of Morrison (1980). Morrison's classification excluded two groups from Joplin's 1968 classification, namely an undersaturated K-rich group as well as a group with low total alkalies and low K_2O/Na_2O. This exclusion was necessary because these groups could not be accommodated within the classification scheme of Irvine and Baragar (1971) for volcanic rocks. Morrison (1980) limited the discussion almost entirely to volcanic shoshositic rocks whereas the Joplin scheme (1968) included monzonitic intrusions that Joplin considered as plutonic equivalents of the volcanic rocks of the shoshonitic association. In this report, the Lahore monzonites

TABLE 9.—$^{40}Ar/^{39}Ar$ *data for minerals from the Lahore and Ellisville plutons and olistoliths from the enclosing rocks of the Mine Run Complex*

A. Lahore pluton

Temp (°C)	^{39}Ar (% of total)	$^{40}Ar \times 10^{-12}$ (initial and radiogenic)	$^{39}Ar \times 10^{-13}$ (K-derived)	$^{38}Ar \times 10^{-14}$ (Cl-derived)	$^{37}Ar \times 10^{-13}$ (Ca-derived)	$^{36}Ar \times 10^{-15}$ (initial)	Age[1,2] (Ma)
			1. Amphiboles				
			P-81-12				
			(J=0.006359; wt.=1.013g)				
450	2.0	22.44	5.25	5.78	2.11	8.10	392.2±2.0
550	1.8	19.20	4.67	6.88	4.46	8.81	367.6±2.4
650	3.2	36.75	8.30	32.39	23.04	11.57	410.1±2.0
750	6.4	74.25	16.71	91.92	61.79	10.29	432.6±2.4
800	19.2	221.9	50.39	290.5	187.7	16.42	436.7±2.0
850	15.8	184.4	41.41	243.0	156.2	16.50	439.4±2.1
900	11.4	135.8	29.74	175.5	112.2	22.18	440.2±2.2
950	11.3	136.3	29.68	176.2	112.8	23.99	441.0±2.1
1000	17.8	212.5	46.57	278.6	179.5	29.40	442.9±2.2
1050	9.7	124.2	25.49	153.5	109.6	43.43	442.2±2.3
1450	1.4	31.72	3.73	25.05	22.25	50.62	452.9±3.4
Total	100.0	1,199.	261.9	1,479.	971.7	241.3	
							Total gas age = 436.7
							Plateau age = 441.4±2.2
			P-81-15				
			(J=0.006506; wt.=1.1024g)				
A 450	0.3	4.53	0.77	4.44	1.14	6.70	350.2±5.6
B 550	.5	6.92	1.18	2.296	1.27	10.78	339.8±5.0
C 650	.3	5.91	.83	1.76	.93	10.89	346.4±5.0
D 750	.5	12.17	1.36	5.27	3.45	25.05	369.5±3.8
E 800	.6	12.13	1.58	12.02	7.63	17.98	445.9±3.4
F 850	.9	15.39	2.26	16.88	11.72	18.05	459.6±3.0
G 900	3.9	51.38	9.73	67.41	45.14	26.91	460.0±2.2
H 950	3.9	48.46	9.76	62.26	41.23	18.63	454.4±2.2
I 1000	19.2	222.3	48.41	287.6	192.5	36.42	451.4±2.2
J 1050	22.9	260.3	57.55	338.6	224.0	36.41	448.3±2.2
K 1150	26.5	307.2	66.74	395.9	259.4	60.53	448.2±2.2
L 1450	20.5	257.0	51.59	310.6	210.1	102.7	453.5±2.2
Total	100.0	1204.	251.8	1505.	998.6	371.0	
							Total gas age = 449.2
							49.4% of gas released in steps 1050–1150°C; preferred age = 448.2±2.2
			2. Biotites				
			P-81-12				
			(J=0.006532; wt.=0.1296g)				
400	5.6	37.33	9.98	7.77	0.05	11.28	362.2±1.8
450	16.9	118.7	30.26	22.63	.11	6.00	405.8±2.0
500	27.2	192.0	48.83	35.98	[3]	6.04	408.9±1.9
1250	50.3	355.2	90.30	68.14	2.42	9.48	409.7±2.0
Total	100.0	703.2	179.4	134.5	2.58	32.80	
							Total gas age = 406.2
							Plateau age = 409.2±2.0
			P-81-14				
			(J=0.006622; wt.=0.1215g)				
400	4.1	27.33	7.93	6.98	0.10	8.20	340.7±1.7
450	16.7	142.2	32.80	29.32	.06	7.93	448.7±2.1
500	20.2	172.4	39.52	35.59	.21	6.78	453.0±2.6
800	36.9	317.8	72.32	64.76	.93	18.11	454.0±2.3
1250	22.1	200.8	43.32	39.81	1.55	42.41	456.4±2.3
Total	100.0	860.5	195.9	176.5	2.85	83.43	
							Total gas age = 449.0
							Plateau age = 454.9±2.2

TABLE 9.—$^{40}Ar/^{39}Ar$ *data for minerals from the Lahore and Ellisville plutons and olistoliths from the enclosing rocks of the Mine Run Complex*—Continued

B. Ellisville pluton

Temp (°C)	^{39}Ar (%of total)	$^{40}Ar \times 10^{-12}$ (initial and radiogenic)	$^{39}Ar \times 10^{-13}$ (K-derived)	$^{38}Ar \times 10^{-14}$ (Cl-derived)	$^{37}Ar \times 10^{-13}$ (Ca-derived)	$^{36}Ar \times 10^{-15}$ (initial)	Age[1,2] (Ma)
			1. Amphiboles				
			P-80-41				
			(J=0.007420; wt.=0.5214g)				
850	3.6	24.71	6.11	1.54	6.91	15.33	395.3±2.0
950	6.1	39.57	10.43	3.67	32.23	10.53	416.2±2.5
1000	6.4	41.40	10.93	4.08	38.40	8.15	423.7±2.3
1050	11.6	74.53	19.86	7.37	74.37	8.71	429.5±2.0
1100	15.0	95.13	25.62	9.39	97.24	7.53	429.9±2.0
1150	13.4	84.96	22.90	8.37	88.64	7.15	428.9±2.0
1200	23.2	146.9	39.77	14.56	157.3	9.93	429.2±2.0
1250	13.4	85.28	22.98	8.64	91.53	6.80	429.6±2.0
1350	5.9	38.16	10.15	3.97	43.20	4.44	430.4±2.2
1450	1.4	12.07	2.44	1.31	10.58	10.52	434.4±2.4
Total	100.0	642.7	171.2	62.90	640.4	89.09	
							Total gas age = 427.2
							Plateau age = 429.5±2.1
A 850	0.9	12.07	2.13	1.54	2.01	10.07	519.1±5.0
B 950	5.6	51.88	13.39	4.44	46.88	14.56	442.3±2.2
C 1050	34.6	296.0	83.29	25.29	320.0	27.27	431.6±2.0
D 1100	36.3	306.0	87.36	27.69	350.7	27.64	426.3±2.0
E 1150	10.3	86.75	24.59	7.62	95.19	8.22	428.5±2.2
F 1200	8.2	69.61	19.75	5.90	78.57	4.01	432.5±2.0
G 1250	3.1	26.90	7.52	2.33	30.60	2.41	434.5±2.3
H 1300	1.0	8.91	2.40	0.86	9.88	2.49	425.9±4.4
Total	100.0	858.12	240.4	75.68	933.83	96.67	
							Total gas age = 430.9
				46.6% of gas released in steps 1100–1150°C; average age = 427+2			
			2. Microcline				
			P-80-37				
			(J=0.005910; wt.=0.0968g)				
550	8.6	50.64	18.99	0.28	0.14	4.72	257.2±1.3
650	1.7	10.07	3.69	.08	.05	1.70	257.0±1.3
750	2.4	14.13	5.22	[3]	.12	1.52	260.0±1.8
850	3.2	20.07	7.16	.10	.16	3.49	263.5±2.2
950	5.9	36.92	12.94	.15	.29	4.06	272.7±1.4
1050	8.4	56.25	18.57	.23	.24	5.29	289.5±1.5
1125	11.5	79.33	25.51	.19	.05	5.90	298.2±1.4
1200	14.8	102.3	32.79	.35	.34	7.04	299.6±1.8
1275	14.6	100.5	32.35	[3]	.33	5.33	299.8±1.8
1350	12.4	92.43	27.35	1.09	.24	27.76	301.6±1.7
1425	8.6	65.94	18.91	.87	[3]	24.14	304.3±1.5
1500	5.4	48.56	12.04	1.33	[3]	36.27	307.4±1.8
1575	1.8	20.29	3.99	.96	[3]	25.56	311.9±2.1
1650	2.7	11.13	1.52	.82	.01	21.54	307.2±4.8
Total	100.0	708.6	221.0	6.66	1.97	174.3	
							Total gas age = 292.0
			P-80-41				
			(J=0.007420; wt.=0.2580g)				
450	2.0	42.15	17.10	0.30	0.35	11.24	280.9±1.8
650	9.4	164.6	80.94	.08	.97	10.75	249.0±1.3
750	4.9	84.98	41.74	.07	.38	5.56	249.2±1.2
850	4.7	82.74	40.60	[3]	.55	2.42	252.0±1.3
950	14.1	253.1	121.1	[3]	.82	9.15	247.6±1.2
1050	13.5	257.1	115.8	[3]	.66	10.55	272.0±1.3

TABLE 9.—$^{40}Ar/^{39}Ar$ *data for minerals from the Lahore and Ellisville plutons and olistoliths from the enclosing rocks of the Mine Run Complex*—Continued

Temp (°C)	^{39}Ar (% of total)	$^{40}Ar \times 10^{-12}$ (initial and radiogenic)	$^{39}Ar \times 10^{-13}$ (K-derived)	$^{38}Ar \times 10^{-14}$ (Cl-derived)	$^{37}Ar \times 10^{-13}$ (Ca-derived)	$^{36}Ar \times 10^{-15}$ (initial)	Age[1,2/] (Ma)
			B. Ellisville pluton—Continued				
1150	14.7	292.0	126.4	[3/]	1.14	13.29	281.9±1.4
1250	15.6	314.7	134.1	[3/]	.38	12.38	286.4±1.4
1350	12.4	254.1	107.0	[3/]	.17	11.98	289.1±1.4
1450	7.8	165.2	67.24	[3/]	.51	10.91	296.7±1.5
1550	.8	22.40	6.78	.66	.08	18.06	309.0±1.7
1650	.2	8.07	1.54	.51	.09	13.94	314.5±2.5
Total	100.0	1,941.	860.34	1.62	6.10	130.2	
							Total gas age = 274.1
			P-80-42 (J=0.007012; wt.=0.2719g)				
450	2.8	57.09	23.53	0.41	0.33	13.24	265.3±1.4
650	10.3	191.3	86.99	.46	1.10	20.80	251.0±1.2
750	6.1	111.6	51.01	.08	.11	10.74	250.6±1.4
850	7.4	134.0	61.87	[3/]	.62	3.87	253.1±1.3
950	12.5	236.0	105.5	[3/]	.96	14.09	258.6±1.3
1050	8.1	160.5	68.14	[3/]	1.53	14.62	268.8±1.4
1150	15.1	318.6	126.8	[3/]	.96	14.28	289.1±1.4
1250	19.6	423.8	164.6	[3/]	[3/]	9.78	297.5±1.7
1350	9.3	207.3	78.08	[3/]	[3/]	11.55	303.3±1.5
1450	4.6	105.9	38.40	.36	.26	13.94	307.6±1.7
1550	2.9	70.24	24.08	.60	[3/]	19.36	310.6±1.6
1650	1.5	40.40	12.27	.81	.16	22.07	319.2±2.1
Total gas	100.0	2,057.	841.3	2.72	6.03	168.3	
							Total gas age = 279.(
			P-80-8 (J=0.005810; wt.=0.1134g)				
550	10.9	81.68	28.33	1.04	[3/]	27.66	253.3±1.3
650	4.0	35.60	10.27	1.06	0.06	28.36	258.2±1.6
750	3.6	33.31	9.29	.97	.07	27.18	264.8±1.8
850	1.0	23.86	2.63	2.12	[3/]	56.82	261.9±4.0
950	4.6	47.25	12.03	1.57	.10	43.15	278.1±1.6
1050	8.9	78.27	22.96	1.05	.04	30.28	291.6±1.5
1125	13.4	117.6	34.64	1.58	.28	39.15	295.4±1.6
1200	17.3	148.5	44.79	1.30	.30	36.29	296.6±1.5
1275	15.0	142.2	38.76	2.67	.28	73.91	299.2±1.6
1350	10.9	119.1	28.31	3.95	.17	103.4	301.2±1.8
1425	5.8	120.8	14.9	9.31	.17	248.2	306.1±3.5
1500	2.5	50.83	6.47	3.73	[3/]	99.80	316.2±3.0
1575	1.4	34.31	3.66	2.85	[3/]	74.69	320.2±4.0
1650	.7	56.58	1.93	6.34	[3/]	169.7	318.7±13.2
Total	100.0	1090.	259.0	39.54	1.47	1059.	
							Total gas age = 289.9
			3. Biotite P-80-37 (J=0.005730; wt.=0.1004g)				
550	4.9	37.22	8.07	0.99	[3/]	6.02	405.0±2.0
750	33.8	260.5	55.42	4.39	0.28	9.94	426.0±2.1
850	9.6	76.00	15.79	1.35	[3/]	3.93	433.4±2.1
950	8.9	70.87	14.68	1.29	[3/]	5.74	431.2±2.2
1050	15.9	124.0	26.10	2.22	.30	6.80	428.2±2.2
1250	22.0	173.1	36.13	3.09	.25	10.19	430.8±2.2
1450	4.3	37.08	7.04	1.02	.10	12.80	432.5±2.1
1650	.5	6.86	.78	.44	.02	10.57	435.5±3.9
Total	100.0	785.7	164.0	14.80	0.96	65.99	
							Total gas age = 427.9

TABLE 9.—$^{40}Ar/^{39}Ar$ *data for minerals from the Lahore and Ellisville plutons and olistoliths from the enclosing rocks of the Mine Run Complex*—Continued

Temp (°C)	^{39}Ar (% of total)	$^{40}Ar \times 10^{-12}$ (initial and radiogenic)	$^{39}Ar \times 10^{-13}$ (K-derived)	$^{38}Ar \times 10^{-14}$ (Cl-derived)	$^{37}Ar \times 10^{-13}$ (Ca-derived)	$^{36}Ar \times 10^{-15}$ (initial)	Age[1,2] (Ma)
B. Ellisville pluton—Continued							
P-80-41 (J=0.007420; wt.=0.1142g)							
650	25.5	191.0	66.29	3.15	0.59	15.94	341.7±1.6
800	19.4	147.4	50.56	2.35	.25	12.29	345.5±1.7
950	19.0	143.7	49.53	2.10	1.02	7.18	347.1±1.7
1050	25.0	186.9	65.02	2.64	.75	8.01	344.7±1.7
1150	9.7	73.09	25.22	1.06	.35	3.42	346.9±1.7
1250	1.4	11.55	3.53	.29	.57	4.42	351.6±1.9
Total	100.0	753.7	260.2	11.59	3.52	51.25	
							Total gas age = 344.8
P-80-42 (J=0.007083; wt.=0.1092g)							
650	31.8	253.5	74.51	2.84	0.56	14.99	383.3±1.8
800	21.9	178.1	51.46	2.25	.08	15.90	386.2±1.8
950	23.0	185.1	54.06	1.90	.32	6.74	387.9±1.9
1050	17.3	139.3	40.71	1.36	.87	5.66	387.2±1.9
1150	5.2	42.98	12.27	.60	.10	5.65	385.9±2.0
1250	.7	6.85	1.63	.22	.19	4.30	390.4±2.0
Total	100.0	805.8	234.6	9.17	2.12	53.24	
							Total gas age = 385.9
C. Olistoliths							
1. Amphiboles							
P-80-48B (J=0.007973; wt.=0.8985g)							
1050	0.5	1.70	0.24	0.18	8.61	2.64	474.0±11.1
1100	1.3	3.65	.70	.35	22.00	3.93	448.8±4.0
1150	7.1	14.38	3.72	.93	96.10	5.02	439.7±2.3
1200	42.9	80.97	22.59	4.35	504.2	12.87	434.5±2.2
1250	40.8	77.17	21.52	4.02	436.7	12.14	434.9±2.1
1300	4.8	9.37	2.52	.50	48.75	2.34	437.5±1.1
1350	2.6	5.07	1.39	.27	25.31	.94	439.0±2.7
Total	100.0	192.31	52.68	10.60	1,142.	39.88	
							Total gas age = 435.7
							Plateau age = 434.8±2.2
P-80-46C (J=0.008000; wt.=0.4521g)							
A 850	0.6	3.60	0.32	0.39	4.36	7.88	493.3±10.2
B 950	3.0	8.12	1.68	.39	22.41	7.63	444.3±3.5
C 1000	3.4	8.10	1.90	.29	26.52	5.24	439.2±2.8
D 1050	5.5	12.04	3.08	.31	42.06	5.02	436.7±2.3
E 1100	8.0	16.77	4.44	.41	54.77	5.53	434.8±2.2
F 1150	21.1	42.40	11.78	.81	122.7	7.18	436.1±2.2
G 1200	35.8	71.12	19.98	1.03	178.1	7.93	438.7±2.1
H 1250	17.3	34.84	9.66	.55	107.9	4.11	443.2±2.2
I 1450	4.5	11.79	2.49	.49	28.17	10.42	444.6±2.6
J 1650	.8	4.12	.45	.33	5.49	8.45	459.3±7.3
Total	100.0	212.9	55.80	5.00	592.5	69.39	
							Total gas age = 439.5
							Plateau age = 437.5±2.2
P-78-22 (J=0.008215; wt.=0.8930g)							
850	1.8	44.60	0.75	11.31	5.51	32.99	283.9 ±11
950	1.6	8.88	.68	2.90	11.99	17.86	652.9±7.5
1050	3.5	12.48	1.46	6.17	47.05	13.94	694.2±4.2

TABLE 9.—$^{40}Ar/^{39}Ar$ *data for minerals from the Lahore and Ellisville plutons and olistoliths from the enclosing rocks of the Mine Run Complex*—Continued

C. Olistoliths—Continued

Temp (°C)	^{39}Ar (% of total)	$^{40}Ar \times 10^{-12}$ (initial and radiogenic)	$^{39}Ar \times 10^{-13}$ (K-derived)	$^{38}Ar \times 10^{-14}$ (Cl-derived)	$^{37}Ar \times 10^{-13}$ (Ca-derived)	$^{36}Ar \times 10^{-15}$ (initial)	Age[1,2] (Ma)
			P-78–22 (J=0.008215; wt.=0.8930g)—Continued				
1100	3.8	12.58	1.56	6.38	51.55	10.44	731.0±3.8
1150	6.1	22.00	2.52	10.12	77.64	21.93	737.4±3.8
1200	15.7	42.16	6.51	22.08	184.0	14.44	704.8±3.4
1250	18.2	48.69	7.52	24.47	211.4	19.26	694.5±3.4
1300	20.5	54.41	8.48	25.71	229.7	15.89	708.9±3.2
1350	16.2	52.42	6.71	21.83	186.8	13.84	838.4±3.8
1450	8.1	30.42	3.36	11.57	82.65	11.35	916.8±4.1
1650	4.5	17.22	1.85	6.55	51.47	6.06	943.2±4.2
Total	100.0	345.9	41.41	149.1	1,140.	178.0	
							Total gas age = 827.2
			P-78–6 (J=0.008346; wt.=0.3187g)				
850	1.5	20.87	0.20	2.94	8.17	12.05	3771. ±12
950	5.4	9.10	.73	2.00	33.31	8.81	996.8±6.0
1000	4.3	5.75	.58	1.44	24.93	4.48	894.5±6.2
1050	10.5	11.29	1.42	3.40	47.07	7.16	778.4±4.2
1100	21.2	18.04	2.85	6.52	78.97	7.55	686.0±3.2
1150	23.0	19.18	3.11	7.03	84.07	8.25	670.1±3.2
1200	16.6	15.47	2.24	5.11	64.51	5.87	747.0±3.3
1250	6.3	6.53	.85	2.02	24.30	2.82	801.2±4.2
1450	8.5	8.83	1.14	2.77	32.10	2.74	832.0±4.2
1650	2.7	4.63	.36	1.10	9.96	6.95	837.5±8.9
Total	100.0	119.7	13.48	34.33	407.4	66.67	
							Total gas age = 869.1

Note: All gas quantities are in moles. No blank corrections have been made. Letters on some amphibole temperature steps are those shown on the isochron plots of figures 41C.

[1]/Ages have been calculated assuming that the initial $^{40}Ar/^{36}Ar$=295.5 (present-day atmospheric argon).

[2]/1-sigma precision estimates are for intra-irradiation package reproducibility. This includes an estimated uncertainty in the J-value of 0.5%.

[3]/Signal was below the detection limit of the mass spectrometer.

TABLE 10.—$^{40}Ar/^{39}Ar$ *isochron data for amphiboles from a monzonite of the Lahore pluton, granodiorite of the Ellisville pluton, and an olistolith of the Mine Run Complex from within the contact-metamorphic aureole of the Ellisville pluton*

Sample No.	Temperature Steps Regressed	F[1]	$^{40}Ar/^{36}Ar$ Initial	Isochron[2] "Age" (Ma)
Lahore pluton:				
P-81-15	900–1450°C(G–L)[3]	43.01	352±36	445.1±2.0
Ellisville pluton:				
P-80-42	950–1250°C(B–G)[4]	34.16	423±15	427.1±2.0
Olistolith: P-80-46C	ALL (A–J)[5]	34.26	308±4	436.9±2.0

[1] $F={}^{40}Ar_R/{}^{39}Ar_K$=reciprocal of intercept on $^{39}Ar/^{40}Ar$ axis of isotope correlation plot.

[2] Age=1/λln [1+J (F)]; where 1/λ=1804 Ma and the J-value is that listed for the sample in table 9.

[3] Letters refer to temperature steps of figure 38*C* and table 9.

[4] Letters refer to temperature steps of figure 41*C* and table 9.

[5] Letters refer to temperature steps of figure 40*C* and table 9.

are considered as silica- or near silica-saturated K-rich plutonic rocks of the shoshonite association.

Among the characterizing chemical features of such shoshonitic rocks as summarized by Morrison (1980, table 1), Meen (1987), and Hyndman (1985, table 8-6) are

1. High content of large ion lithophile elements (LILE) such as K, Ba, Sr, U, Th, and light rare earth elements (LREE);
2. Total Na_2O+K_2O greater than 5 percent;
3. Al_2O_3 in the range of 14 to 19 percent;
4. Low TiO_2: less than 1.3 percent;
5. High K_2O/Na_2O: greater than 0.6 at 50 percent SiO_2 and greater than 1 at 55 percent SiO_2;
6. Presence of normative hypersthene.

Earlier discussions on the general geochemistry of the Lahore monzonites and the analyses listed in tables 1 and 3 indicate that the Lahore monzonites have the above listed chemical characteristics.

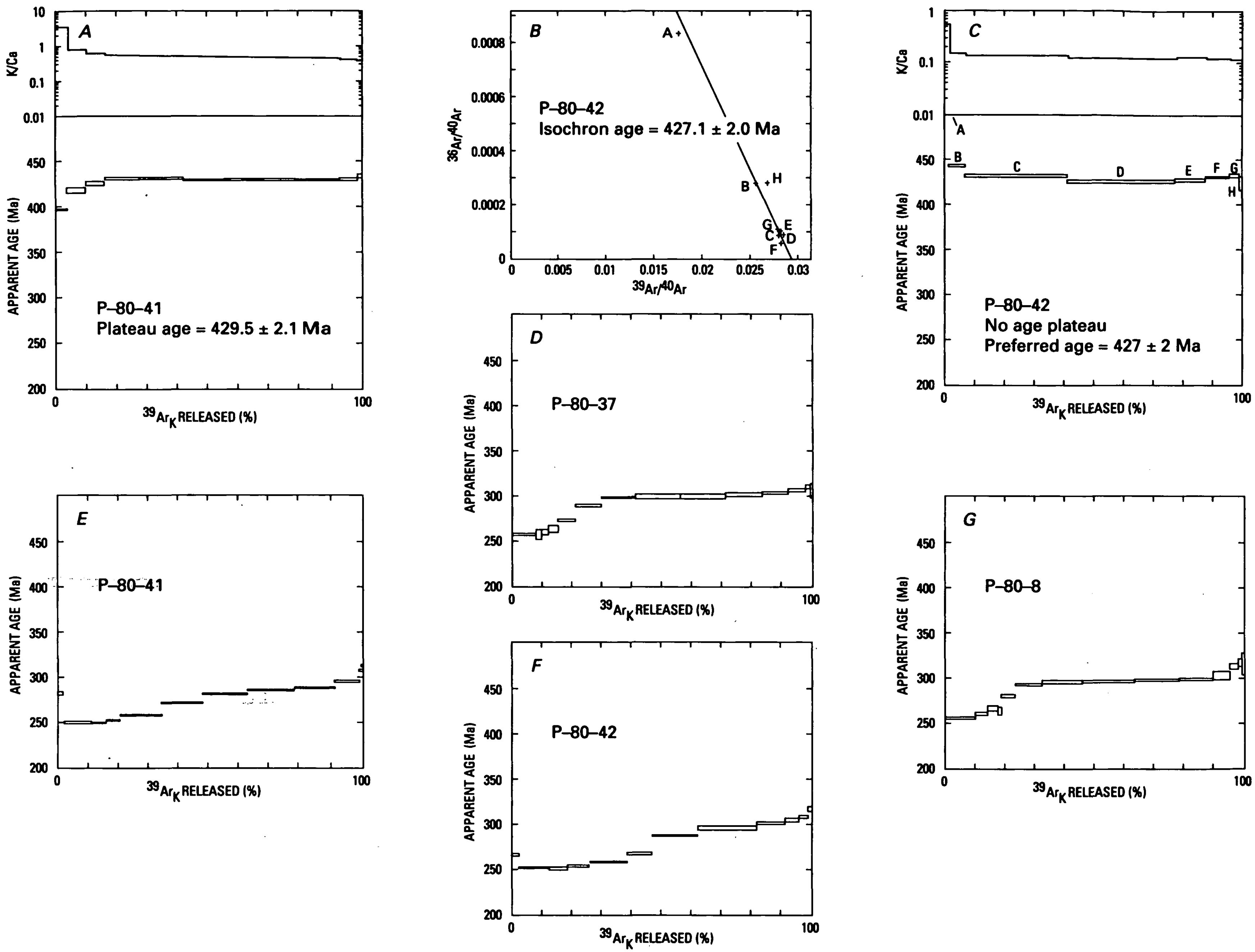


FIGURE 40.—$^{40}Ar/^{39}Ar$ age spectra (*A* and *C*) and an isochron plot (*B*) of amphibole samples and microcline samples (*D*, *E*, *F*, and *G*) from the interior of the Ellisville pluton. Letters on the isochron plot (*B*) and on the age spectrum (*C*) refer to temperature steps listed in table 9.

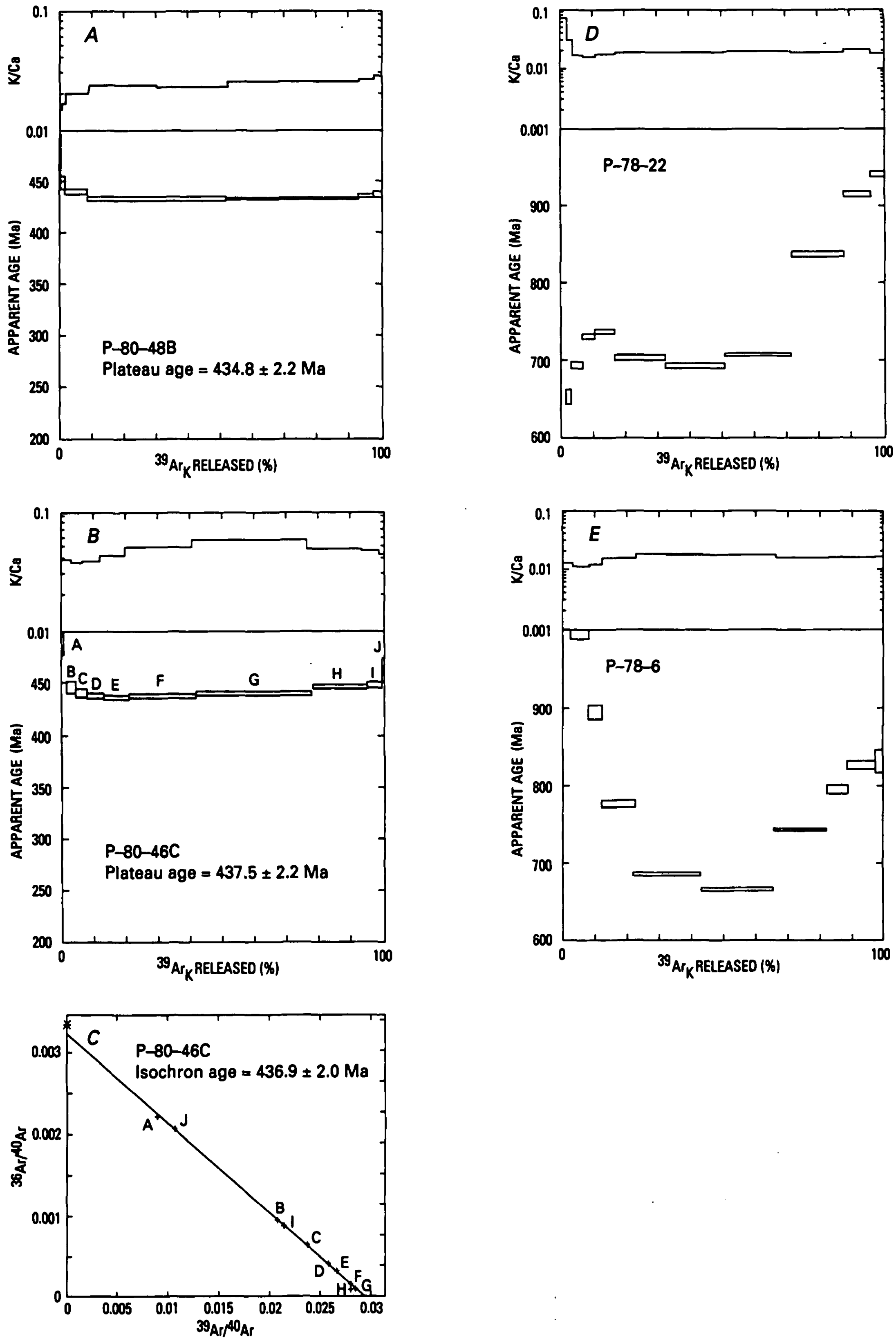


FIGURE 41.—$^{40}Ar/^{39}Ar$ age spectra and an isochron plot of amphibole samples from olistoliths within the contact-metamorphic aureole of the Ellisville pluton (*A*, *B*, and *C*) and from outside the aureole (*D* and *E*). Letters on the age spectrum (*B*) and isochron plot (*C*) refer to temperature stops listed and table 9. Asterisk (*) in *C* represents the isotopic composition of present-day atmospheric argon.

The mineralogic features of the shoshonitic monzonites of the Lahore plutons show different magmatic textures between the pyroxene-and-amphibole bearing suites. The pyroxene monzonites (recast modal analyses, table 1) are characterized by unaltered augite (fig. 6), plagioclase in excess of potassic feldspar, and abundant brown biotite that decreases as SiO_2 increases. In grading westward into amphibole monzonites (pl. 1*A*) augite gradually becomes altered in various degrees to edenitic amphibole; this commonly results in a core of pyroxene enclosed by amphibole (fig. 11), a feature common in many alkalic rocks. Also, in some of the altered pyroxene monzonites, some of the plagioclase is marginally altered by potassium feldspar (fig. 8*B*). In the amphibole monzonites, pyroxene and biotite are minor or absent as compared to the pyroxene monzonites whereas amphibole is very abundant, and potassium feldspar is more abundant than plagioclase (recast modal analyses, table 1).

The above mineralogic features of the pyroxene monzonite reflect the general magmatic history of the Lahore pluton. Pyroxene monzonite was the first phase to crystallize. As crystallization progressed, the magma became enriched in H_2O, possibly absorbing it from the enclosing country rocks through which it was emplaced. It also became residually enriched in K_2O as the pyroxene and plagioclase crystallized. This gradual enrichment in H_2O and K_2O led to the alteration of pyroxene to amphibole and the local potassic alteration of plagioclase by potassium feldspar. Eventually at higher H_2O pressures magmatic amphibole crystallized.

Rocks of the shoshonitic rock association of Morrison (1980) can include both shoshonitic volcanic rocks as well as their plutonic equivalents, generally monzonites. Such shoshonitic rocks occur along continental margins as for example in Chile (Dostal and others, 1977), northern New Guinea (Morrison, 1980), in island arcs such as the Eolian Arc of the Tyrrhenian Sea, Puerto Rico, Viti Levu, and Fiji (Morrison, 1980), and parts of New Guinea (Smith, 1972; Milson and Smith, 1975) as well as in massifs (Pagel and Leterrier, 1980), and in continental interiors such as the monzonites in Wyoming and Montana (Joplin, 1968).

A variety of petrogenetic models have been proposed for the origin of shoshonitic rocks and have been summarized by Hyndman (1985, p. 405). The major proposals include partial melting of mantle enriched by (1) previous subduction or metasomatic events; (2) magma generated over deeper parts of subducted slabs at distal regions from a trench; (3) differentiation of mantle basaltic or peridotitic magma; or (4) assimilation of crustal rocks of various types. The origin of the Lahore magma is uncertain. Structurally, the Lahore pluton is a late or postkinematic intrusion into deformed melange deposits of a back-arc basin (Pavlides, 1989). The island arc Central Virginia volcanic-plutonic belt (CVVPB) on the east side of these back-arc melange deposits (the Mine Run Complex; Pavlides, 1989) contains island-arc tholeiites and calc-alkaline metavolcanic rocks (Pavlides, 1981). The absence of shoshonitic metavolcanics in the Chopawamsic Formation on the continentward side of the CVVPB may be an original genetic feature. If ever present as an inner belt in the CVVPB, it may have been overridden and concealed by the westward thrusting in Taconian times. However, it is possible that the westward-dipping oceanic subducted slab postulated as extending below the CVVPB (Pavlides, 1981 and 1989) may have had distal portions of the slab extending beneath the deformed melange zones, and this generated the high-potassic magma of the Lahore pluton. This model presents a diachroneity in magma generation between the *CVVPB* of Early to Late Cambrian age (Pavlides, 1989) and the Late Ordovician age of 450 Ma (this report) for the Lahore pluton. This temporal and chemical zonation may be generally analogous to that reported for subduction-related volcanism in the Central Andes. There, calc-alkaline volcanic rocks of Jurassic to Eocene age are close to the Peru-Chile trench. Shoshonitic metavolcanic rocks derived from the same subducting process are of Miocene to Quaternary age and are the most distal from the trench (Dostal and others, 1977). Under this model, magmas are formed through anatexis of an upper mantle peridotite source previously enriched in LILE and located above the subducted descending ocean slab. The spatial and chemical variation across the CVVPB (island-arc tholeiitic and calc-alkaline volcanism) to shoshonitic pluton (Lahore monzonites) emplacement in the deformed and accreted back-arc basin deposits may, in general, be similar to that suggested by Dostal and others (1977) for the Chilean Andes.

The Lahore Complex, however, was emplaced within the deformed melange deposits of the Mine Run Complex at about the time these rocks had been thrust westward and accreted onto the continental margin of the Blue Ridge massif of North America. Alternatively, therefore, the Lahore pluton may have been generated along the ancestral North American continental margin without a subduction related process. It could have been directly melted out from a mantle peridotite enriched in LILE by heat generated from the progressive accretion and stacking of the melange and island-arc deposits onto the continental margin.

In summary, the Lahore pluton samples have geochemical characteristics that are found elsewhere in potassium-rich suites and in particular plutonic rocks of the shoshonite association: high concentrations of LILE (K, Rb, Cs, Sr, Ba, U, Th) and LREE as well as strongly fractionated REE patterns. The K-rich continental suites generally have high initial $^{87}Sr/^{86}Sr$ but exhibit a range of values that encompass the Lahore initial ratio of about .7046 (table 8). On this basis, the mafic character of the Lahore and its chemical and isotopic features suggest a source for Lahore magmas in the deep continental lithosphere, either in mafic deep continental crust or in the subjacent continental mantle.

As described earlier, the metamorphosed Lahore mafic rock at the north end of the Lahore Complex, presumably intruded by the monzonitic pluton, may be an early mantle-derived mafic intrusion preceding Lahore plutonism.

ELLISVILLE PLUTON GRANODIORITES

The initial $^{87}Sr/^{86}Sr$ for the Ellisville pluton is $.7062\pm.0001$ (see Geochronology section). This value is higher than those of modern calc-alkalic suites in oceanic arcs (Hawkesworth, 1982) and similar to those found in some granodiorites in Cretaceous continental margin batholiths such as the Sierra Nevada, for example, Kistler and others (1986). During Paleozoic time the $^{87}Sr/^{86}Sr$ ratios of oceanic rocks were probably lower than they are in the Holocene so that an initial $^{87}Sr/^{86}Sr$ ratio of .7062 in the Ellisville strongly suggests the involvement of continental crust in the origin of Ellisville magma.

Granodiorites having the major and trace-element characteristics of the Ellisville pluton have been described in orogenic suites as old as Archean (Arth and Hanson, 1975) and as young as Cretaceous and Eocene (Kistler and others, 1986; Arth and others, 1988). Highly fractionated REE patterns in Archean granodiorite to granite plutons of northeastern Minnesota were thought by Arth and Hanson (1975, p. 346–354) to be the product of melting of a metagraywacke parent that itself had a mildly fractionated REE pattern. Arth and Hanson (1975) suggested that a melting process in which the solid residue included plagioclase, amphibole, and garnet would result in a melt having the observed high concentrations of light rare earths, low concentrations of heavy rare earths, and a negative Eu anomaly. In the Tuolumne Intrusive Suite of the Sierra Nevada, Kistler and others (1986) suggested that granitic melts derived from the crust and having high $^{87}Sr/^{86}Sr$ could mix with mafic melts having low $^{87}Sr/^{86}Sr$ to produce granodioritic mixtures of intermediate $^{87}Sr/^{86}Sr$. Some of these granodiorites fractionally crystallized to produce more evolved magmas.

The compositional similarity of Ellisville granodiorite to granodiorites that are thought to be largely of crustal origin suggests that Ellisville magma may have formed in large part from a silicic crustal source. The uniformity of composition and lack of more mafic variants may favor melting of a crustal source without mafic input.

The potassic-alkalic Lahore magma probably originated by melting of mafic-ultramafic rocks in the deeper part of the continental lithosphere, whereas the calc-alkalic Ellisville magma probably originated by melting in garnet- and amphibole-bearing intermediate rocks in the continental crust.

REGIONAL RELATIONSHIPS OF THE PLUTONS

The alkalic, metaluminous shoshonitic monzonites of Late Ordovician age of the Lahore pluton constitute an unusual plutonic lithology in the Piedmont of the Eastern United States. Indeed, in so far as is known to us, such rocks have not been described from anywhere in the Appalachian orogen. Their unique character is perhaps attributable to their origin within a subduction regime in an island-arc back-arc terrane of limited geographic extent in the Appalachians. The distinctive character of this island arc was first assigned a terrane status by Williams and Hatcher (1983) who named it the Chopawamsic terrane. The terrane map of Horton and others (1991) shows the Chopawamsic terrane in fault contact with the Potomac terrane (allochthonous melange terrane) that includes the Mine Run Complex melanges (this report and Pavlides, 1989) and that are in fault contact to the west with the Jefferson terrane of their usage. They show the Ellisville and Lahore plutons as a single pluton. The Chopawamsic terrane and the Mine Run Complex, however, are here considered a single island-arc back-arc assemblage and under this usage would be considered a single terrane accreted to the Blue Ridge terrane along the Mountain Run fault zone (Pavlides, 1989).

The Ellisville pluton has many similarities to the epidote-bearing Ellicott City Granodiorite of Hopson (1964) in the Piedmont of Maryland, which has a U/Pb zircon age of 453 Ma (Sinha and others, 1989, table 2). The Ellicott City Granodiorite is described (Hopson, 1964) as shaped like a steeply-plunging double phacolith that was forcefully emplaced and that is crudely zoned inward from granodiorite to quartz monzonite. The Ellicott City pluton was apparently emplaced along a thrust fault that separates the Baltimore Mafic Complex and the Wissahickon Group, both of Crowley (1976). Like the Ellisville, the Ellicott City also consists of plagioclase, potassic feldspar, biotite, allanite, and minor amphibole (Hopson, 1964; Mario, 1984) and also contains sphene (Sinha and others, 1989), in addition to magmatic epidote. Plutons of Ordovician age with magmatic epidote have not been reported from the Piedmont of the Southeastern United States. Monzogranitic plutons of Alleghanian age that contain magmatic epidote, however, occur in the southern Appalachian Piedmont (McSween and others, 1991, p. 102).

GEOTHERMOMETRY

Several attempts have been made by others to ascertain the temperatures and pressures that prevailed when the ore deposits within the Chopawamsic Formation in the Mineral district were metamorphosed. Cox (1979, p. 60–61) used the method of Ferry and Spear (1978) to analyze six coexisting biotite-garnet pairs and obtained thermal equilibration temperatures ranging between 428°C through 499°C. Cox considered 465°±35°C as a representative average temperature for these analyses. In addition, Cox also obtained an approximate sliding scale geothermometer with temperature in the range of 390° to 420°C by using the rim compositions of coexisting arsenopyrite and pyrite within the Arminuis deposit (pl. 2*B*), using the method described by Kretschman and Scott (1976). Sandhaus (1981) determined metamorphic temperatures through the use of distribution coefficients of coexisting garnet-biotite pairs as extrapolated from the data of Goldman and Albee (1977). Sandhaus obtained average metamorphic temperatures ranging between 444° and 488° for four deposits within the Mineral district and an average temperature for the district in general of 469°. This average temperature is close to the average temperature of 465°C for the Arminuis deposit estimated by Cox (1979).

The amphibole-plagioclase geothermometer of Blundy and Holland (1990) has been used in this report to evaluate the general limits of the temperature of emplacement of the Ellisville and Lahore plutons and, in part, the ambient temperature in the surrounding country rocks during contact metamorphism. This geothermometer is restricted to rocks that formed in the temperature range of 500°C–1100°C and that contain calcic amphiboles with less than 7.8 silicon (Si) atoms per formula unit and plagioclase with an anorthite content of less than 92 percent. For rocks meeting these requirements the geothermometer is reported to have an uncertainty of about ±75°C. The equation derived by Blundy and Holland (1990) is

$$T=\frac{0.677\ P-48.98+Y}{-0.0429-.008314\ \ln K} \text{ and } K=\frac{Si-4}{8-Si}\cdot X\frac{Plag}{Ab}$$

with T in Kelvin and P in kb (kilobar). For the plagioclase compositions used in this report, Y (plagioclase nonideality)=0 for $X_{Ab}>0.5$. Although it is preferable to use rim compositions of amphibole-plagioclase pairs that are in contact with each other, such data were unavailable for this study. Therefore only electron microprobe analyses of separate plagioclase and hornblende grains within the same probe section or specimen were used. Thus the calculated temperatures listed in table 11 are not closely constrained equilibrium temperatures. Also, a range in plagioclase and amphibole compositions exists in the rocks of interest. Therefore, the analyses of plagioclase used (table 11) were chosen to represent the upper and lower Ab contents of the analyzed plagioclases (tables A-2; B-6; and C-1). Similarly, the available amphiboles used were those with the widest available range of silicon per formula unit (tables A-3, B-10, and C-6). The results derived from these data are representative, therefore, of only approximate temperatures.

Calculations were made for pressure of 6 kb and 4.6 kb (table 11). The 6 kb calculation was made because it represents the average (arithmetic) pressure determined by the aluminum-in-hornblende geobarometers (table 12A) for the Ellisville pluton. The 4.6 kb calculations are based on the pressure estimates of Cox (1979), using the sphalerite geobarometer cited above for rocks within the thermal aureole of the Ellisville pluton.

As pointed out by Hammarstrom and Zen (1986, p. 1299), the data of Wyllie (1977) and Kenah and Hollister (1983) indicate that the melting interval of hydrous tonalite to granodiorite compositions is between 700°C and 900°C. The hydrous nature of Ellisville granodiorites is reflected in the content of biotite (0.7–12.9 percent; recast modal analyses, table 2) and less common amphibole (0–1.4 percent; recast modal analyses, table 2). The Lahore pluton monzonites with biotite and hornblende contents respectively of 0.2–25 percent and 2.8–38.1 percent (recast modal analyses, table 1) were derived from an even more hydrous melt. Based on the 700°C to 900°C melting interval for such hydrous melts and the temperatures listed in table 11A, an emplacement temperature of about 760°±20°C (table 11A) is adopted for the Ellisville and a temperature of about 760°±75°C for the Lahore pluton (table 11B).

Uncertainties also prevail in the temperature estimate made for sample P-80-46C (table 11C), an exotic block of the Mine Run Complex within the thermal aureole of the Ellisville pluton. This block is believed to have had its amphibole K/Ar isotopic system reset (described earlier) by the contact thermal effects of the Ellisville pluton at the time of its emplacement. P-80-46C must have cooled through the Ar closure temperature of amphibole at about 530°C from a somewhat higher temperature. Temperature estimates for various amphibole grains in sample P-80-46C are listed in table 11C. An average value of about 610°±30°C is probably a reasonable estimate of the peak temperature experienced by the olistolith (P-80-46C) and, by analogy, olistolith P-80-48B in the contact aureole of the Ellisville pluton. This temperature estimate is also supported by the mineral assemblage within the contact-metamorphic aureole described earlier. There, the mineral assemblage kyanite-staurolite± chloritoid is compatible with a temperature estimate of about 600°C.

TABLE 11.—*Geothermometry of the Ellisville and Lahore plutons and a contact-metamorphosed exotic block within the Mine Run Complex*
[Using the amphibole-plagioclase geothermometer of Blundy and Holland (1990)]

Sample No.	Pressure (kb)	Si (amph)	X Ab	ln K	Temperature (°C)	Average
			A. Ellisville pluton			
P-80-41	6	6.385[1]	0.8095[2]	0.179	739	
	6	6.385[1]	.7038[3]	.039	766	763±20
	4.6	6.385[1]	.8095[2]	.179	760	
	4.6	6.385[1]	.7038[3]	.039	788	
			B. Lahore pluton[4]			
P-81-15	6	6.999[5]	0.7695[6]	0.468	687	
P-81-15	6	6.999[5]	.5832[7]	.191	814	761±75
P-81-15	4.6	6.999[5]	.7695[6]	.468	707	
P-81-15	4.6	6.999[5]	.5832[7]	.191	837	
			C. Exotic block within the Mine Run Complex			
P-80-46C	6	7.175[8]	0.8342[9]	1.166	581	
P-80-46C	6	7.175[8]	.8699[10]	1.208	575	
P-80-46C	6	6.955[11]	.8342[9]	.858	625	
P-80-46C	6	6.955[11]	.8699[10]	.900	619	609±26
P-80-46C	4.6	7.175[8]	.8342[9]	1.166	599	
P-80-46C	4.6	7.175[8]	.8699[10]	1.208	593	
P-80-46C	4.6	6.955[11]	.8342[9]	.858	644	
P-80-46C	4.6	6.955[11]	.8699[10]	.900	637	

[1] Appendix table C-6, analysis 12[12].
[2] Appendix table C-1, analysis 20[12].
[3] Appendix table C-1, analysis 21[12].
[4] Sample P-81-15 is used to calculate temperature because within the Lahore pluton it is most distinctly removed from the exposed contact of the Ellisville pluton and presumably unaffected by the thermal effects of Ellisville contact metamorphism as discussed earlier in the text[12].
[5] Appendix table B-10, analysis 30[12].
[6] Appendix table B-6, analysis 42[12].
[7] Appendix table B-6, analysis 33[12].
[8] Appendix table A-3, analysis 19A[12].
[9] Appendix table A-2, analysis 2[12].
[10] Appendix table A-2, analysis 6[12].
[11] Appendix table A-3, analysis 25[12].
[12] Si for amphibole recomputed according to Blundy and Holland's (1990) cation normalization scheme.

GEOBAROMETRY

A pressure of 4.6 kb (±0.1) was obtained by Cox (1979, p. 69) for the Arminuis deposit by using the sphalerite geobarometer of Hutcheon (1978), Lusk and Ford (1978), and Scott (1976). Sandhaus (1981, p. 65) also used the sphalerite geobarometer for studies of the Cofer deposit and obtained a pressure range of 3.5 to 6.0 kb. An estimate of 4.6 kb (about 14 km) is accepted as a reasonable average for the Mineral district of Virginia by Spry and Scott (1986).

Various pressure estimates have been obtained for the Lahore and Ellisville plutons in this report by using four of the presently available aluminum-in-hornblende geobarometers as shown in table 12. An empirical aluminum-in-hornblende geobarometer was proposed by Hammarstrom and Zen (1986) for calc-alkaline intrusions characterized by the magmatic mineral assemblage of plagioclase and potassic feldspar, hornblende, biotite, quartz, sphene (titanite), magnetite, or ilmenite± epidote. Magmatic hornblende was characterized by the proposed limit of $Si<7.5$ (Leake, 1971). Hammarstrom and Zen (1986) further limited their data set to amphibole analyses with $Ca>1.6$. These mineral assemblages are present in the granodiorite of the Ellisville pluton (table 2, recast modal analyses; see also mineralogy of granodiorite discussed earlier) as are the pertinent Si-Ca parameters listed in table C-6 (analyses 12 and 23). Magmatic hornblende mineral-grain separates from two samples (not hornblende rims in contact with quartz) were used to estimate pressures within the Ellisville pluton, presumably at the time of crystallization of the amphibole. These pressures are listed in table 12 and were calculated from the four different linear regression equations developed by Hammarstrom and Zen (1986), Hollister and others (1987), Johnson and Rutherford

TABLE 12.—*Geobarometry of the Ellisville and Lahore plutons*

[Using the regression equations of Hammarstrom and Zen (1968), Hollister and others (1987), Johnson and Rutherford (1988), and Schmidt (1991)]

Sample No.	Al^{T}[1]	Average Pressure (kb)	Pressure	
A. Ellisville pluton				
1. Hammarstrom and Zen: $P=5.03\ Al^{T}-3.92\pm3$ kb				
P-80-41	1.99[2]	6.1	6.2	
P-80-42	2.006[3]	6.2		
2. Hollister and others: $P=5.64\ Al^{T}-4.76\pm1$ kb				
P-80-41	1.99[2]	6.5	6.6	~6
P-80-42	2.006[3]	6.6		
3. Johnson and Rutherford: $P=4.28\ Al^{T}-3.54\pm20$ bars				
P-80-41	1.99[2]	5.0	5.0	
P-80-42	2.006[3]	5.0		
4. Schmidt: $4.84\ Al^{T}-3.30\pm0.5$ kb				
P-80-41	1.99[2]	6.3	6.4	
P-80-42	2.006[3]	6.4		
B. Lahore pluton[4]				
1. Hammarstrom and Zen: $P=5.03\ Al^{T}-3.92\pm3$ kb				
P-81-15[4]	1.62[5]	4.2	4.2	
2. Hollister and others: $P=5.64\ Al^{T}-4.76$ kb				
P-81-15	1.62[5]	4.4	4.4	
3. Johnson and Rutherford: $P=4.28\ Al^{T}-3.54\pm20$ bars				~4
P-81-15	1.62[5]	3.4	3.4	
4. Schmidt: $4.84Al^{T}-3.30\pm0.5$ kb				
P-81-15	1.62[5]	4.6	4.6	

1/ $Al^{T}=Al^{iv}+Al^{vi}$.

2/ Analysis 12, table C-6.

3/ Analysis 23, table C-6.

4/ The sample P-81-15 is used to calculate pressure because it is most distantly removed from the exposed contact of the Ellisville pluton and presumably unaffected by the thermal affects of Ellisville contact metamorphism as discussed earlier in the text.

5/ Analysis 30, table B-10.

(1988), and Schmidt (1991) as shown in table 12. The equations of Hammarstrom and Zen (1986) and of Hollister and others (1987) were obtained empirically by using total aluminum (Al^{T}) in plutons with the appropriate compositions. The data for the Hammarstrom and Zen (1986) geobarometer are for plutons that crystallized at shallow (1.5–3 kb) and deep (7–10 kb) levels whereas that of Hollister and others (1987) are from plutons that crystallized at intermediate levels (4–6 kb). Both of these geobarometers estimate total pressure from field evidence such as metamorphic assemblages in metamorphic rocks near the plutons. The aluminum-in-hornblende geobarometer of Johnson and Rutherford (1988) and Schmidt (1991) were calculated experimentally. The pressure data tabulated in table 12A suggest a maximum pressure of about 6 kb although the sphalerite geobarometer used by Cox (1979) indicates 4.6 kb as about the prevailing minimum pressure in the country rocks at the time of Ellisville pluton emplacement. The contact-metamorphic mineral assemblage within the thermal aureole of the Ellisville of kyanite-staurolite and the apparent absence of andalusite indicates crystallization at temperatures and pressures higher than the Al_2SiO_5 triple point. Holdaway (1971) established this triple point at 501°C and 3.76 kb, and Robie and Hemingway (1984) calculated the triple point at 517°C and 4 kb, in close agreement with the values of Holdaway (1971).

The Ellisville contains magmatic epidote as described earlier and as shown in figure 20*A* and *B*. Also its pistacite (Ps) range of 25–28 (table B-9) is within the field of primary epidote rather than secondary epidote (McSween and others, 1991, p. 102). Zen and Hammarstrom (1984) concluded that plutonic rocks with magmatic epidote formed under moderately high pressures namely about 8 kb (about 25 km) or greater. Later, Zen (1988) accepted 6 kb (18 km) as the minimum pressure under which magmatic epidote could form in a tonalite-to-granodiorite magma with the appropriate mineral composition. McSween and others (1991), however, state that magmatic epidote may be stable at pressure as low as about 3 kb in oxidizing, water-saturated magmas, but higher pressures are required to crystallize epidote in water-undersaturated tonalitic melts.

Because of the uncertainties inherent in both geobarometeric methods as well as the uncertainties introduced by other factors, such as the non-rim amphibole analyses used in the calculations given in table 12, the differences in pressure may be more apparent than real. For purposes of this report, the Ellisville pluton is considered to have been emplaced in the range of 4 to 6 kb or at about 12 to 18 km in crustal depth. The Lahore alkalic metaluminous pluton contrasts with the calc-alkaline character of the Ellisville and most of the plutons studied by Hammarstrom and Zen (1986) and Hollister and others (1987), but it has the appropriate mineralogy, and the four hornblende geobarometer equations were used to estimate its crystallization pressure. The average pressure of 4 is listed in table 12B and is considered broadly comparable to those obtained for the Ellisville. In addition these pressures are mostly above the stability range for andalusite. The present juxtaposition of the Lahore and Ellisville plutons suggests that they were emplaced at a similar level in the earth's crust. The value of 3.4 kb obtained by the Johnston and Rutherford equation (table 12B) is possibly unrepresentative in so far as the kyanite in the thermal aureole formed at pressure above the Al_2SiO_5 triple point, 3.76–4.0 kb.

THERMOCHRONOLOGY

The post-crystallization cooling history of this part of the Central Virginia Piedmont has been measured using $^{40}Ar/^{39}Ar$ methods and the "closure temperature" concept for diffusion of argon in various minerals (Sutter and others, 1985b). In this study we have employed edenitic to pargasitic amphibole (fig. 3) as well as biotite and perthitic microcline. In our studies of the granodiorites of the Ellisville pluton, the general "closure temperatures" (see McDougall and Harrison, 1988, for discussion) of these minerals to argon diffusion are 480°C–530°C (amphibole), 240°C–320°C (biotite), and about 130°C–250°C (microcline). The specific "closure temperature" is dependent on the rate of cooling. In addition, for biotite the "closure temperature" is also dependent on its chemical composition; for potassic feldspar there is a dependence on structural state as well as size and shape of intragrain diffusion domains.

Using the crystallization age for monzonite of the Lahore pluton as 450 Ma (as described earlier), an average intrusion temperature of about 760°C, and a closure temperature of argon in its amphibole as about 530°C, we can use the $^{40}Ar/^{39}Ar$ isochron age of amphibole in sample P–81–15 of about 445 Ma (fig. 38*B*) to calculate an average cooling rate for the Lahore monzonites between emplacement temperature and ^{40}Ar closure temperature in amphibole of about 46°C/m.y. (a relatively rapid cooling rate).

A similar exercise can be done for the Ellisville pluton using the amphiboles from the interior of the pluton (average closure age of 428 Ma). Assuming an intrusion temperature of 760°C, a closure temperature of 530°C for the amphibole, and an intrusion age of about 440 Ma, an average cooling rate of about 19°C/m.y. is obtained for the interior of the Ellisville pluton.

An average cooling rate from the maximum temperature to amphibole closure temperature within the contact-metamorphic aureole of the Ellisville pluton can also be estimated. This estimate was made by using the age of the Ellisville (440 Ma), the average age of the two amphiboles from olistoliths in the contact aureole (P-80–48B, fig. 41A and P-80–46C, fig. 41B of 436 Ma; see Geochronology section), the temperature estimate of 600°C (see table 11C) imparted by the Ellisville intrusion onto these olistoliths, as well as accepting a closure temperature of their amphiboles of about 530°C. The olistoliths therefore appear to have cooled from 440 Ma to 436 Ma at an average rate of 18°C/m.y., which is similar to that of the Ellisville pluton. Uncertainties in the crystallization ages, crystallization temperatures, and contact aureole temperature preclude interpreting these averages as precise cooling rate estimates. However, it can be said that cooling from intrusion to amphibole closure was moderate. The cooling rate estimates are compatible with the suggested depth of intrusion of 12 to 18 km. These estimates, of course, do not consider the effects of the geothermal gradient that prevailed at that time.

Apparent ages of biotites from both the monzonites of the Lahore pluton and the granodiorite of the Ellisville pluton are quite variable (table 9) and therefore are not useful for helping to delineate cooling history. For example, two biotites from the monzonites of the Lahore pluton, P-81–12 and P-81–14, yielded $^{40}Ar/^{39}Ar$ total-gas ages of 409 and 455 Ma, respectively. It is unlikely that the apparent ages from both these samples can be correct since the closure temperatures of the biotites should be similar. In addition, the plateau age of biotite from P-81–14 is older than the isochron age of the P-81–15 amphibole. Even though the two samples are not from the same locality in the monzonitic pluton, reversals between amphibole and biotite cooling ages are unexpected. More likely this discrepancy results from the incorporation of "excess" ^{40}Ar in the biotites that is unresolvable using the $^{40}Ar/^{39}Ar$ age spectrum and isochron techniques now available.

Three biotites from the Ellisville pluton, P-80–37, P-80–41, and P-80–42, yield $^{40}Ar/^{39}Ar$ total-gas ages of 428, 345, and 386 Ma, respectively (table 9), with P-80–41 and P-80–42 having been collected within a km of one another. The lack of consistency of the biotite cooling ages precludes their use for determining the cooling history of the pluton. More than likely, these biotites also contain variable amounts of "excess" ^{40}Ar that is unresolvable.

The low-temperature (130°C–250°C) cooling history for the study area has been approximated using four samples of perthitic microcline from the Ellisville pluton. All four samples yield $^{40}Ar/^{39}Ar$ age spectra (figs. 40*D*–40*G*) that show a steady increase in apparent age with increasing percentage of ^{39}Ar released (increasing temperature of extraction), most easily interpreted as a gradient caused by slow cooling through the closure temperature range. All microline samples show a gradient that ranges from about 320 Ma to about 250 Ma (table 9) with total-gas ages averaging about 290–270 Ma. If we assume that the linear cooling gradients in the potassic feldspars represent cooling of about 120°C over about 70 million years, a cooling rate of <2°C/Ma is calculated, which is assumed to be due to simple denudation of the area (erosion) during the late Paleozoic and early Mesozoic, a model that appears to be common for much, if not all, of the Piedmont Province from Virginia to Alabama (Durrant and others, 1980; Sutter and others, 1985a; Horton and others, 1987; Atekwana and others, 1989; Steltenpohl and others, 1990).

All of the geochronologic data support the conclusion that monzonites of the Lahore pluton intruded and contact-metamorphosed greenschist facies regionally metamorphosed rocks of the Mine Run Complex in the Late Ordovician (about 450 Ma). Subsequently in latest Ordovician to earliest Silurian time (about 440 Ma), the Lahore pluton monzonites, the Mine Run Complex, and the Chopawamsic Formation were intruded by the Ellisville pluton at about 13–18 km depth in the earth's crust. Emplacement of the Ellisville produced a well developed contact aureole in the country rocks. Thermochronologic data from various minerals demonstrate that (1) initial cooling from crystallization temperature was of a moderate rate; (2) cooling to relatively low temperatures (130°C–250°C) occurred in the late Paleozoic to Mesozoic time at a time-averaged rate of <2°C/Ma, very similar to other parts of the Piedmont; and (3) no post-intrusion metamorphism above lower greenschist facies has affected the study area west of the Quantico Formation. About 45 km from Mineral (pl. 2*A*) and east of the Long Branch thrust, in the vicinity of Fredericksburg, Va., high-grade metamorphism and concomitant deformation of late Paleozoic age has been documented (Sutter and others, 1985a).

SUMMARY

The region discussed in this report lies within an allochthonous terrane composed primarily of Cambrian and Ordovician metasedimentary (includes melange) and meta-igneous rocks. Of particular relevance are the metavolcanic and metaplutonic rocks of the Central Virginia volcanic-plutonic belt, the melanges of the Mine Run Complex, and, of course, the igneous intrusions into these rocks, namely, the Lahore and Ellisville plutons.

The Central Virginia volcanic-plutonic belt has been interpreted (Pavlides, 1981; Pavlides, 1989) as a Cambrian island-arc formed above a westward-dipping (present geographic coordinates) subduction zone with an oceanward low-K, mafic facies (Ta River Metamorphic Suite) and a continentward facies of mostly island-arc tholeiitic and calc-alkaline volcanic composition (Chopawamsic Formation). These metavolcanic rocks may have formed, in part, on continental crust (Pavlides and others, 1982a, c) rifted from ancestral North America (Laurentia) during the late Precambrian (Pavlides, 1989).

Westward (continentward) from the island arc, a back arc basin has been interpreted as lying between the volcanic arc and the continental margin. Within the basin the melange deposits of the Mine Run Complex were formed through concurrent structural and sedimentilogical processes (Pavlides, 1989). Deformation affecting the island-arc metavolcanic and back-arc basin rocks probably began by Middle to Late Cambrian and involved folding and, later, westward-thrusting of the island-arc terrane. The Chopawamsic Formation of this terrane was intruded by minor late-kinematic gabbro, low-K plagiogranite tonalite, and oceanic trondhjemite (Pavlides, 1981). By Middle Ordovician time, the back-arc basin and its contained melange deposits had been greatly reduced in size due to folding and faulting by westward-directed thrusting.

The high-K, alkalic-metaluminous shoshonitic Lahore pyroxene and amphibole monzonites were intruded into the deformed and regionally metamorphosed Mine Run Complex at about 450 Ma. They locally contact metamorphosed the enclosing country rock. At about 440 Ma the calc-alkaline, weakly peraluminous biotite granodiorites of the Ellisville pluton were emplaced. Around its border the Ellisville has deformed the regional tectonic foliation of the Mine Run Complex. A fairly wide contact-metamorphic zone was developed along the eastern border and a much thinner one along the western side. The volcanogenic massive sulfide deposits of the Chopawamsic Formation in the Mineral district of Virginia were locally recrystallized by this contact metamorphism. Some of the sulfides may have been reworked and locally concentrated by the contact metamorphism into exploitable ores that were formerly mined. The thermal aureole is characterized by fibrolite, kyanite, staurolite, and chloritoid that occur either individually or in different assemblages. The Ellisville also locally intruded the Lahore and near that contact reset the K/Ar isotopic system of amphibole in that pluton. Amphibole also was reset in some amphibolitic exotic blocks in melange of the Mine Run Complex within the contact zone on the east side of the Ellisville pluton.

The shoshonitic Lahore pluton may have formed through processes affecting the mantle wedge above the subducting slab that formed the island-arc terrane to the east. In the island arc, low-K plagiogranite tonalite and trondhjemite plutons were emplaced into tholeiitic and calc-alkaline metavolcanic rocks. As tectonic shortening occurred, the high-K metaluminous Lahore monzonites may have been fractionated from metasomatized peridotite in the mantle wedge above the still-subducting slab and emplaced as the Lahore pluton. About 10 million years later, when the island-arc terrane and Mine Run Complex had further accreted onto the continental margin along the Mountain Run fault zone, the calc-alkaline, weakly peraluminous epidote-bearing granodiorites of the Ellisville pluton were generated in the lower crust of the continental margin and were intruded as the Ellisville pluton upward into the terrane consisting of the Chopawamsic Formation, the Mine Run Complex, and the Lahore Complex. Of interest is the similar observa-

tion of Zen (1988) that plutons with magmatic epidote in the western Cordillera of North America occur in Mesozoic-accreted terranes and are post-accretion.

The Lahore and Ellisville plutons record emplacement pressures of about 4–6 kb (12–18 km depth) and emplacement temperatures of about 760°±75°C and 760°±20°C, respectively. Cooling from emplacement temperatures to about 530°C (the estimated closure temperature to Ar diffusion in amphibole) proceeded at a moderate to fairly rapid rate (20 to 50°C/m.y.), probably due to the relatively high thermal contrast between the plutons and their country rocks. Biotite from these plutons appears to contain "excess" Ar and cannot be used to help define their cooling history. Microcline thermochronology suggests a cooling rate for this region during the late Paleozoic and early Mesozoic of <2°C/m.y., a rate that is probably related to denudation or erosion and which may be characteristic of the Piedmont province from Alabama to Virginia. The rocks west of the Long Branch thrust fault (Pavlides, 1990) reflect only a Cambrian to Ordovician metamorphism whereas the rocks east of this fault have undergone metamorphism that includes Alleghanian thermotectonic events.

REFERENCES CITED

Adams, J.A.S., Kline, M.C., Richardson, K.A., and Rogers, J.J.W., 1962, The Conway granite of New Hampshire as a major low-grade thorium resource: U.S. National Academy of Sciences Proceedings, v. 48, p. 1898–1905.

Albee, A.L., and Ray, L., 1970, Correction factors for electron probe microanalysis of silicates, oxides, carbonates, phosphates, and sulfates: Analytical Chemistry, v. 42, p. 1408–1414.

Alexander, E.C., Jr., Michelson, G.M., and Lanphere, M.A., 1978, MMhb-1: A new $^{40}Ar/^{39}Ar$ dating standard, *in* Zartman, R.E., ed., Fourth International Conference on Geochronology, Cosmochronology, and Isotope Geology: U.S. Geological Survey Open-File Report 78–701, p. 6–8.

Arth, J.G., Barker, F., and Stern, T.W., 1988, Coast batholith and Taku plutons near Ketchikan, Alaska: Petrography, geochronology, geochemistry, and isotopic character: American Journal of Science, v. 288A, p. 461–489.

Arth, J.G., and Hanson, G.N., 1975, Geochemistry and origin of the early Precambrian crust of northeastern Minnesota: Geochimica et Cosmochimica Acta, v. 39, p. 325–362.

Ashworth, J.R., 1975, Staurolite at anomalously high grade: Contribution to Mineralogy and Petrology, v. 53, p. 281–291.

Atekwana, E., Sutter, J.F., and Schwartzman, D., 1989, Thermochronology of the Pennsylvanian Liberty Hill, Pageland, and Lilesville plutons and the Wadesboro basin, North and South Carolina [abs.]: Geological Society of America Abstracts with Programs, v. 21, no. 3, p. 2.

Atherton, M.P., Naggar, M.H., and Pitcher, W.S., 1975, Kyanite in some thermal aureoles: American Journal of Science, v. 275, p. 432–443.

Aumento, F., 1970, Serpentine mineralogy of ultrabasic intrusions in Canada and on the Mid-Atlantic Ridge: Geological Survey of Canada Paper 69–53, 51 p.

Barnes, I.L., Murphy, T.J., Gramlich, J.W., and Shields, W.R., 1973, Lead separation by anodic deposition and isotope ratio mass spectrometry of microgram and smaller samples: Analytical Chemistry, v. 46, p. 1881–1884.

Bence, A.E., and Albee, A.L., 1968, Empirical correction factors for the electron microanalyses of silicates and oxides: Journal of Geology, v. 76, p. 382–403.

Blundy, J.D., and Holland, T.J.B., 1990, Calcic-amphibole equilibria and a new amphibole-plagioclase geothermometer: Contributions to Mineralogy and Petrology, v. 104, p. 208–224.

Bobyarchick, A.R., Pavlides, Louis, and Wier, Karen, 1981, Piedmont geology of the Ladysmith and Lake Anna East quadrangle, and vicinity, Virginia: U.S. Geological Survey Miscellaneous Investigation Series Map 1282, scale 1:24,000.

Buddington, A.F., 1959, Granite emplacement with special reference to North America: Geological Society of America Bulletin, v. 70, p. 671–748.

Butler, A.P., Jr., 1961, Ratio of thorium to uranium in some plutonic rocks of the White Mountain plutonic-volcanic series, New Hampshire: Article B-31 in U.S. Geological Survey Professional Paper 424–B, p. B67–B69.

Cameron, A.E., Smith, D.H., and Walker, R.L., 1969, Mass spectrometry of nanogram-size samples of lead: Analytical Chemistry, v. 41, p. 525–526.

Chidester, A.H., 1962, Petrology and geochemistry of selected talc-bearing ultramafic rocks and adjacent country rocks in north central Vermont: U.S. Geological Survey Professional Paper 345, 207 p.

Coleman, R.G., 1971, Petrologic and geophysical nature of serpentinites: Geological Society of America Bulletin 82, p. 897–918.

Cox, L.J., 1979, Mineralogy and petrogenesis of the Arminius deposit, Louisa County, Virginia: Unpub. M.Sc. thesis, Blacksburg, Virginia Polytechnic Inst. State Univ., 114 p.

Craig, J.R., 1980, Stratiform sulfide mineralization in the central U.S. Appalachians, *in* Vokes, F.M., and Reinsbakken, Arne, eds., Stratabound sulphides in the Caledonian-Appalachian orogen: Norges geologiske undersokelse, nr. 360, Bull. 57, p. 295–325.

Craig, J.R., Miller, J.W., Cox, L.J., and Kazda, R.S., 1978, Ores of the Mineral District, *in* Gair, J.E., ed., Massive sulfides of Virginia field trip; Guidebook, U.S. Geological Survey Open-file Report 78–1068, p. 26–31.

Dalrymple, G.B., Brent, G., Alexander, E.C., Jr., Lanphere, M.A., and Kraker, G.P., 1981, Irradiation of samples for $^{40}Ar/^{39}Ar$ dating using the Geological Survey TRIGA reactor: U.S. Geological Survey Professional Paper 1176, 56 p.

Daniels, D.L., and Leo, G.W., 1985, Geologic interpretation of basement rocks of the Atlantic Coastal Plain: U.S. Geological Survey Open-File Report 85–655, 45 p.

De La Roche, H., Leterrier, J., Grandclaude, P., and Marchal, M., 1980, A classification of volcanic and plutonic rocks using R_1R_2-diagram and major element analyses- -its relationships with current nomenclature: Chemical Geology, v. 29, p. 183–210.

Deer, W.A., Howie, R.A., and Zussman, J., 1962, Rock forming minerals, v. 1, New York, N.Y., John Wiley and Sons, Inc., 333 p.

———1966, An introduction to the rock-forming minerals: New York, N.Y., John Wiley and Sons, Inc., 528 p.

DeWitt, E., Armstrong, R.L., Sutter, J.F., and Zartman, R.E., 1984, U-Th-Pb, Rb-Sr, and Ar-Ar mineral and whole rock isotopic systematics in a metamorphosed granitic terrain, southeastern California: Geological Society of America Bulletin, v. 95, p. 723–739.

Dodge, F.C.W., Millard, H.T., Jr., and Elsheimer, H.N., 1982, Compositional variations and abundances of selected elements in granitoid rocks and constituent minerals, central Sierra Nevada Batholith, California: U.S. Geological Survey Professional Paper 1248, p. 1–14.

Dostal, J., Zentilli, M., Caelles, J.C., and Clark, A.H., 1977, Geochemistry and origin of volcanic rocks of the Andes (26°–28°S): Contributions to Mineralogy and Petrology, v. 63, p. 113–128.

Drake, A.A., Jr., 1985, Tectonic implications of the Indian Run Formation; A newly recognized sedimentary melange in the northern Virginia Piedmont: U.S. Geological Survey Professional Paper 1324, 12 p.

Drake, A.A., Jr., and Lyttle, P.T., 1981, The Accotink Schist, Lake Barcroft Metasandstone and Popes Head Formation—Keys to an understanding of the tectonic evolution of the northern Virginia Piedmont: U.S. Geological Survey Professional Paper 1205, 16 p.

Drake, A.A., Jr., and Morgan, B.A., 1981, The Piney Branch Complex—A metamorphosed fragment of the central Appalachian ophiolite in northern Virginia: American Journal of Science, v. 281, p. 484–508.

Durrant, J.M., Sutter, J.F., and Glover, L., III, 1980, Evidence for an Alleghenian (Hercynian?) metamorphic event in the Piedmont Province near Richmond, Virginia: Abstracts with Programs, Geological Society of America, v. 12, no. 4, p. 176.

Eby, G.N., 1985, Sr and Pb isotopes, U and Th chemistry of the alkaline Monteregian and White Mountain igneous provinces, eastern North America: Geochimica et Cosmochimica Acta, v. 49, p. 1143–1153.

Ferry, J.M., and Spear, F.S., 1978, Experimental calibration of partitioning of Fe and Mg between biotite and garnet: Contributions to Mineralogy and Petrology, v. 66, p. 113–117.

Flohr, M.J.K., 1983, BASIC programs for calculation of cation site occupancies and plotting of mineral data with applications for evaluation of metamorphic mineral assemblages: U.S. Geological Survey Open-File Report 83–905.

Flohr, M.J.K., and Pavlides, Louis, 1986, Thermobarometry of schists from the Quantico Formation and Ta River Metamorphic Suite, Virginia: Geological Society of America Abstracts with Programs, v. 18, no. 3, p. 221.

Foster, M.D., 1962, Interpretation of the composition and a classification of the Chlorites: U.S. Geological Survey Professional Paper 414A, p. A1–A33.

Freeborn, W.P., McGee, E.S., and Huebner, J.S., 1985, MINCALC, A FORTRAN program for recalculating mineral analyses: U.S. Geological Survey Open-file report 85–257, 45 leaves.

Frey, F.A., 1984, Rare earth element abundances in upper mantle rocks, *in* Henderson, P., ed., Rare earth element geochemistry: New York, Elsevier, p. 151–203.

Gair, J.E., 1988, Origin of unusual wallrocks at Ducktown, Tennessee, as indicated by rare-earth element geochemistry: Joint Annual Meeting GAC-MAC, Program with Abstracts, v. 13, p. A42.

Goldman, D.S., and Albee, A.L., 1977, Correlation of Fe/Mg partitioning between quartz and magnetite: American Journal of Science, v. 277, p. 1669–1680.

Grosh, W.A., 1949a, Investigation of the Allah Cooper lead-zinc mine in Louisa County, Virginia: U.S. Bureau of Mines Report Inv. 4604, 6 p.

———1949b, Investigation of Valzinco lead-zinc mine, Spotsylvania County, Va.: U.S. Bureau of Mines Report. Inv. 4403, 7 p.

Guidotti, C.V., 1984, Micas in Metamorphic Rocks, *in* Bailey, S.W., ed., Micas: Reviews in mineralogy, v. 13, Mineralogical Society of America, p. 357–467.

Hammarstrom, J.M., and Zen, E-an, 1986, Aluminum in hornblende: An empirical igneous geobarometer: American Mineralogist, v. 71, p. 1297–1313.

Haskin, L.A., Haskin, M.A., Frey, F.A., and Wildeman, T.R., 1968, Relative and absolute terrestrial abundance of the rare earths, *in* Alviens, L.H., ed., Origin and distribution of the elements: Oxford, N.Y., Pergamon, p. 889–912.

Hawkesworth, C.J., 1982, Isotope characteristics of magmas erupted along destructive plate margins: *in* Thorpe, R.S., ed., Andesites: New York, N.Y., John Wiley & Sons, p. 549–571.

Heier, K.S., 1966, Some crystallo-chemical relations of nephelines and feldspars on Stjernoy, North Norway: Journal of Petrology, v. 7, p. 95–113.

Henry, D.J., and Guidotti, C.V., 1985, Tourmaline as a petrogenetic indicator: an example from the staurolite-grade metapelites of NW Maine: American Mineralogist, v. 70, p. 1–15.

Hickman, R.C., 1947, Pyrites, Mineral, Louisa County, Virginia: U.S. Bureau of Mines Report of Investigations 4116, 6 p.

Holdaway, M.H., 1971, Stability of andalusite and the aluminum silicate phase diagram: American Journal of Science, v. 271, p. 97–131.

———1972, Thermal stability of Al-Fe epidote as a function of fo_2 and Fe content: Contributions to Mineralogy and Petrology, v. 37, p. 307–340.

Hollister, L.S., Grissom, G.C., Peters, E.K., Stowell, H.H., and Sisson, V.B., 1987, Confirmation of the empirical correlation of Al in hornblende with pressure of solidification of calc-alkaline plutons: American Mineralogist, v. 72, p. 231–239.

Hopkins, H.R., 1960, Geology of western Louisa County, Virginia: Ithaca, New York, Cornell University, Unpublished Ph.D. thesis, 98 p.

Hopson, C.A., 1964, The crystalline rocks of Howard and Montgomery Counties, *in* The geology of Howard and Montgomery Counties: Baltimore, Md. Geological Survey, p. 27–215.

Horton, J.W., Jr., Drake, A.A., Jr., Rankin, D.W., and Dallmeyer, R.D., 1991, Preliminary tectonostratigraphic terrane map of the central and southern Appalachians: U.S. Geological Survey Miscellaneous Investigation Series Map I–2163, scale 1:2,000,000.

Horton, J.W., Jr., Sutter, J.F., Stern, T.W., and Milton, D.J., 1987, Alleghanian deformation, metamorphism, and granite emplacement in the central Piedmont of the southern Appalachians: American Journal of Science, v. 287, p. 635–660.

Hubbard, N.J., and Gast, P.W., 1971, Chemical composition and origin of nonmare Lunar basalts: Proceedings of the Second Lunar Science Conference, Houston, Texas, June 11–14, 1971, Cambridge, Mass., MIT Press (Geochimica et Cosmochimica Acta Supplement 2, v.2, p. 999–1020).

Hutcheon, I., 1978, Calculations of metamorphic pressure using the sphalerite-pyrrhotite-pyrite equilibrium: American Mineralogist, v. 63, p. 87–95.

Hyndman, D.W., 1985, Petrology of igneous and metamorphic rocks: McGraw-Hill Book Company, New York, N.Y., 2nd Edition, 786 p.

Irvine, T.N., and Baragar, W.R.A., 1971, A guide to the chemical classification of the common volcanic rocks: Canadian Journal of Earth Sciences, v. 8, p. 523–548.

Johnson, M.C., and Rutherford, M.J., 1988, Experimental calibration of an Aluminum-in-Hornblende geobarometer applicable to calc-alkaline rocks: EOS, v. 69, p. 1511.

Joplin, G.A., 1968, The shoshonite association: a review, Journal Geological Association of Australia, v. 15, p. 275–294.

Katz, A.S., 1961, The mineralogy of the Sulphur mine, Mineral, Virginia, including a history of the property: Unpub. M.S. thesis, Univ. of Virginia, 104 p.

Kenah, C., and Hollister, L.S., 1983, Anatexis in the Central Gneiss Complex, British Columbia, *in* Atherton, M.P., and Gribble, C.D., eds., Migmatites, melting, and metamorphism, Shiva Publishing Company, Nantwich, U.K., p. 142–162.

Kerrick, D.M., 1987, Fibrolite in contact aureoles of Donegal, Ireland: American Mineralogist, v. 72, p. 240–254.

Kistler, R.W., Chappell, B.W., Peck, D.L., and Bateman, P.C., 1986, Isotopic variation in the Tuolumne Intrusive Suite, central Sierra Nevada, California: Contributions to Mineralogy and Petrology, v. 94, p. 205–220.

Kolata, D.R., and Pavlides, Louis, 1986, Echinoderms from the Arvonia Slate, Central Virginia Piedmont: Geologica et Paleontologica, v. 20, p. 1-9.

Kretschman, U. and Scott, S.D, 1976, Phase relations involving arsenopyrite in the system Fe–As–S and their application: Canadian Mineralogist, v. 14, p. 364–386.

Krough, T.E., 1973, A low contamination method for hydrochemical decomposition of zircon and extraction of U and Pb for isotopic age determinations: Geochimica et Cosmochimica Acta, v. 37, p. 485–494.

Kuno, H., 1969, Andesite in time and space, *in* McBirney, A.R., ed., Proceedings of the andesite conference: Oregon Department of Geology and Mineral Industries Scientific Report 16 of the International Upper Mantle Project, p. 13–20.

Lanphere, M.A., and Dalrymple, G.B., 1976, Identification of excess ^{40}Ar by the $^{40}Ar/^{39}Ar$ age spectrum technique: Earth and Planetary Science Letters, v. 32, p. 141–148.

Larsen, E.S., III, 1957, Distribution of uranium in igneous complexes: U.S. Geological Survey TEI–700, p. 249–253.

Larsen, E.S., III, and Gottfried, D., 1960, Uranium and Thorium in selected suites of igneous rocks: American Journal of Sciences, Bradley Volume, v. 258A, p. 151–169.

Leake, B.E., 1971, On aluminous and edenitic hornblendes: Mineralogical Magazine, v. 38, p. 389–407.

———1978, Nomenclature of amphiboles: American Mineralogist, v. 63, p. 1023–1052.

Lee, K.Y., and Froelich, A.J., 1989, Triassic-Jurassic stratigraphy of the Culpeper and Barboursville basins, Virginia and Maryland: U.S. Geological Survey Professional Paper 1472.

Lobjoit, W.M., 1964, Kyanite produced in a granitic aureole: Mineralogical Magazine, v. 88, p. 804–808.

Lusk, J., and Ford, C.E., 1978, Experimental extension of the sphalerite geobarometer to 10 kbar: American Mineralogist, v. 63, p. 516–519.

Mario, A.L., 1984, The petrology of the Ellicott City Granodiorite: Unpublished MS thesis, University of Pittsburg, Pennsylvania, 218 p.

Mason, R.A., Parsons, I., and Long, J.V.P., 1985, Trace and minor element chemistry of alkali feldspars in the Klokken layered syenite series: Journal of Petrology, v. 26, p. 952–970.

Mattinson, J.M., 1972, Preparation of hydrofluoric, hydrochloric and nitric acids at ultralow lead levels: Analytical Chemistry, v. 44, p. 1715–1716.

McDougall, I., and Harrison, T.M., 1988, Geochronology and Thermochronometry by the $^{40}Ar/^{39}Ar$ method: Monographs on Geology and Geophysics, New York, Oxford University Press, v. 9, 212 p.

McGee, J.J., 1983, $ANBA; A rapid, combined data acquisition and correction program for the SEMQ electron microprobe: U.S. Geological Survey Open-File Report 83–817, 47 p.

McIntyre, G.A., Brooks, C., Compston, W., and Turek, A., 1966, The statistical assessment of Rb-Sr isochrons: Journal of Geophysical Research, v. 71, p. 5459–5468.

McSween, H.Y., Vyhnal, C.R., and Speer, J.A., 1991, Pressure significance of magmatic epidote in Alleghanian granitoids of the southern Appalachians: Geological Society of America Abstracts with Programs, v. 23, no. 1, p. 102.

Meen, J.K., 1987, Formation of shoshonites from calc-alkaline basalt magmas: geochemical and experimental constraints from type locality: Contributions to Mineralogy and Petrology, v. 97, p. 333–351.

Miller, E.L., and Sutter, J.F., 1982, Structural geology and $^{40}Ar/^{39}Ar$ geochronology of the Goldstone-Lane Mountain area, Mojave Desert, California: Geological Society of America Bulletin, v. 93, p. 1191–1207.

Miller, J.W., Jr., 1978, The ore mineralogy of the Cofer property, Louisa County, Virginia: A volcanogenic massive sulfide deposit: Unpub. M.Sc. thesis, Blacksburg, Virginia Polytechnic Inst. State Univ., 89 p.

Milson, J., and Smith, I.E., 1975, Southeastern Papua: Generation of thick crust in a tensional environment?: Geology, v. 3, p. 117–120.

Mookherjee, A., 1976, Ores and metamorphism: Temporal and genetic relationships, *in* Wolf, K. H., ed., Handbook of Stratabound and Stratiform Ore Deposits: Amsterdam, Elsevier Scientific Publishing Company, p. 203–260.

Morimoto, N., 1988, Nomenclature of pyroxenes: Mineralogical Magazine, v. 52, p. 535–550.

Morrison, G.W., 1980, Characteristics and tectonic setting of the shoshonite rock association: Lithos, v. 13, p. 97–108.

Naggar, M.H., and Atherton, M.P., 1970, The composition and metamorphic history of some aluminous silicate-bearing-rocks from the aureoles of the Donegal granites: Journal of Petrology, v. 11, p. 549–589.

Nakamura, N., 1974, Determination of REE, Ba, Fe, Mg, Na, and K in carbonaceous and ordinary chondrites: Geochemica et Cosmochimica Acta, v. 38, p. 757–775.

Neuerburg, G.J., 1956, Uranium in igneous rocks of the United States, *in* U.S. Geological Survey Professional Paper 300, p. 55–64.

O'Halloran, D.A., 1985, Ras ed Dom migrating ring complex: A-type granites and syenites from Bayuda Desert, Sudan: Journal of African Earth Sciences, v. 3, p. 61–75.

Pagel, M., and Leterrier, J., 1980, The subalkaline potassium magmatism of the Ballons massif (Southern Vosges, France): shoshonitic affinity: Lithos, v. 13, p. 1–10.

Palmer, A.R., compiler, 1983; The decade of North American Geology 1983 geologic time scale: Geology, v. 11, p. 503–504.

Pavlides, Louis, 1973, Stratigraphic relationships and metamorphism in the Fredericksburg area, Virginia, *in* U.S. Geological Survey Professional Paper 850, p. 37–38.

———1976, Guidebook for field trips 1 and 4: Piedmont geology of the Fredericksburg, Va., area and vicinity: Arlington, Va., Geological Society of America, Northeast-Southeast Meeting, 44 p.

———1980, Revised nomenclature and stratigraphic relationships of the Fredericksburg Complex and Quantico Formation of the Virginia Piedmont: U.S. Geological Survey Professional Paper 1146, 29 p.

———1981, The central Virginia volcanic-plutonic belt: an island arc of Cambrian(?) age: U.S. Geological Survey Professional Paper 1231–A, 34 p.

———1987a, Mountain Run Fault Zone of Virginia, *in* Jacobsen, M.L., and Rodriguez, T.R., compilers, National earthquake hazards reduction program; summaries of technical reports volume XXIII: U.S. Geological Survey Open File Report 87–63, p. 93–94.

———1987b, Mountain Run Fault Zone in Virginia, *in* Jacobsen, M.L., and Rodriguez, T.R., compilers, National earthquake hazards reduction program summaries of technical reports volume XXIV: U.S. Geological Survey Open File Report 87–374, p. 94.

———1989, Early Paleozoic composite melange terrane, central Appalachian Piedmont, Virginia, and Maryland: its origin and tectonic history, *in* Horton, J.W., Jr., and Rast, Nicholas, eds., Melanges and olistostromes of the U.S. Appalachians: Geological Society of America Special Paper, 228 p.

———1990, Geology of part of the northern Virginia Piedmont: U.S. Geological Survey Open File Report 90–548.

Pavlides, Louis, Arth, J.G., Daniels, D.L., and Stern, T.W., 1982a, Island-arc, back-arc, and melange terranes of Northern Virginia—Tectonic, temporal, and regional relationships: Geological Society of America Abstracts with Programs, v. 14, no. 7, p. 584.

Pavlides, Louis, Gair, J.E., and Cranford, L.J., 1982c, Massive sulfide deposits of the southern Appalachians: Economic Geology, v. 77, no. 2, p. 233–272.

Pavlides, Louis, Pojeta, John, Jr., Gordon, Mackenzie, Jr., Parsley, R.L., and Bobyarchick, A.R., 1980, New evidence for the age of the Quantico Formation of Virginia: Geology, v. 8, no. 6, p. 286–290.

Pavlides, Louis, Stern, T.W., Arth, J.G., Muth, K.G., and Newell, M.F., 1982b, Middle and Upper Paleozoic granitic rocks in the Piedmont near Fredericksburg, Virginia; Geochronology: U.S. Geological Survey Professional Paper 1231-B, 9 p.

Phillips, E.R., and Carr, G.R., 1973, Myrmekite associated with alkali feldspar megacrysts in felsic rocks from New South Wales: Lithos, v. 6, no. 3, p. 245–260.

Pitcher, W.S., and Berger, A.R., 1972, The geology of Donegal: A study of granite emplacement and unroofing, 435 p., Wiley, New York.

Pitcher, W.S., and Reed, H.H., 1963, Contact metamorphism in relation to manner of emplacement of the granites of Donegal, Ireland: Journal of Geology, v. 71, p. 261-296.

Robie, R.A., and Hemingway, B.S., 1984, Entropies of kyanite, andalusite and sillimanite: Additional constraints on the pressure and temperature at the Al_2SiO_5 triple point: American Mineralogist, v. 69, p. 298–306.

Rock, N.M.S., and Leake, B.E., 1984, The International Mineralogical Association amphibole nomenclature scheme: computerization and its consequences: Mineralogical Magazine, v. 48, p. 211–217.

Rogers, J.J.W., and Ragland, P.C., 1961, Variation of thorium and uranium in selected granitic rocks: Geochimica and Cosmochimica Acta, v. 25, p. 99–109.

Sandhaus, D.J., 1981, Gahnite in metamorphosed volcanogenic massive sulfides of the Mineral district, Virginia: Unpublished M.Sc. thesis, Blacksburg, Virginia.

Schmidt, M.W., 1991, Experimental calibration of the Al-in-hornblende geobarometer at 650°C, 3.5–13.0 kbar: Terra abstracts, v. 3, Oxford, Blackwell Scientific Publications.

Scott, S.O., 1976, Application of the sphalerite geobarometer of regionally metamorphosed terrains: American Mineralogist, v. 61, p. 161–670.

Seiders, V.M., and Mixon, R.B., 1981, Geologic map of the Occoquan quadrangle and part of the Fort Belvoir quadrangle, Prince William and Fairfax counties, Virginia: U.S. Geological Survey Miscellaneous Investigations Series Map I-1175, scale 1:24,000.

Shand, S.J., 1943, Eruptive rocks: London, Murby and Co.

Shimazaki, Y., 1974, Ore minerals of the Kuroko-type deposits: Society of Mining Geological Japan Special Issue 6, p. 311–322.

Sinha, A.K., Hund, E.A., and Hogan, J.P., 1989, Paleozoic accretionary history of the North American Plate margin (central and southern Appalachians): constraints from the age, origin, and distribution of granitic rocks, *in* Hillhouse, S.W., ed., Deep structure and post-kinematics of accreted terranes: American Geophysical Union Geophysical Monograph 50, p. 219–238.

Slack, J.F., 1982, Tourmaline in Appalachian-Caledonian massive sulfide deposits and its exploration significance: Institute of Mining Metallurgy Transactions; Section B, v. 91, p. 81–89.

Smith, I.E., 1972, High-potassium intrusives from southeastern Papua: contribution to Mineralogy and Petrology: v. 34, p. 167–176.

Snee, L.W., Sutter, J.F., and Kelly, W.C., 1988, Thermochronology of economic mineral deposits: Dating the stages of mineralization at Panasqueira, Portugal, by high-precision $^{40}Ar/^{39}Ar$ age spectrum techniques on muscovite: Economic Geology, v. 83, p. 335–354.

Spry, Alan, 1969, Metamorphic textures: New York, N.Y., Permagon Press, 350 p.

Spry, P.G., and Scott, S.D., 1986, Zincian spinel and staurolite as guides to ore in the Appalachians and Scandinavian Caledonides: Canadian Mineralogist, v. 24, p. 147–163.

Steiger, R.H., and Jager, E., 1977, Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, no. 3, p. 359–362.

Steltenpohl, M.G., Kunk, M.J., and Sutter, J.F., 1990, $^{40}Ar/^{39}Ar$ thermochronology of the southernmost Alabama-Georgia Piedmonts: Implications for Alleghanian tectonometamorphism: Abstracts with Programs, Geological Society of America, v. 22, no. 4, p. 64.

Streckeisen, Albert, 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1–33.

Sutter, J.F., Pavlides, Louis, Kunk, M.J., and Cortesini, Henry, Jr., 1985a, Late Paleozoic metamorphism and uplift in the Piedmont near Virginia: Geological Society of America Abstracts with Programs, v. 17, no. 2, p. 138.

Sutter, J.F., Ratcliffe, N.M., and Mukasa, S.B., 1985b, Metamorphic and tectonic history of western New England based on $^{40}Ar/^{39}Ar$ and K-Ar data: Geological Society of America Bulletin, v. 96, p. 123–136.

Tatsumoto, M., 1966, Isotopic composition of lead in volcanic rocks from Hawaii, Iwo Jima, and Japan: Journal of Geophysical Research, v. 71, p. 1721–1733.

Taylor, B.E., and Slack, J.F., 1984, Tourmaline from Appalachian-Caledonian massive sulfide deposits: textural, chemical, and isotopic relationships: Economic Geology, v. 79, p. 1703–1726.

Taylor, S.R., 1964, The abundances of chemical elements in the continental crust—a new table: Geochimica et Cosmochimica Acta, v. 28, p. 1273–1285.

Tilton, G.R., Patterson, C., Brown, H., Inghrum, M., Hayden, R., Hess, D., and Larsen E., Jr., 1955, Isotopic composition and distribution of lead, uranium, and thorium in a Precambrian granite: Geological Society of America Bulletin, v. 66, p. 1131–1148

Vladykin, N.V., Antipin, V.S., Kovalenko, V.I., and others, 1975, The chemical composition and genetic groups of tourmaline of the Mongolian Mesozoic granitoids (in Russian): Vsesoyuznogo Mineralog. Obshchestva Zapishi, no. 104, Vypusk 4, p. 403–412.

Vokes, F.M., 1969, A review of the metamorphism of sulphide deposits, Earth Sci. Review, 5, p. 99–143.

Wicks, F.J., 1979, Mineralogy, chemistry, and crystallography of chrysotile: Mineralogic Association of Canada Short Course, v. 4, p. 35–78.

Wicks, F.J., and Plant, A.G., 1979, Electron-microprobe and x-ray microbeam studies of serpentine textures: Canadian Mineralogist, v. 17, p. 785–830.

Wier, Karen, 1977, Preliminary geology of the Richardsville and a portion of the Midland quadrangles, Fauquier, Culpeper, and Stafford Counties, Virginia: U.S. Geological Survey Open-File Report 77–699, scale 1:24,000.

Wier, Karen, and Pavlides, Louis, 1985, Piedmont geology of the Spotsylvania quadrangle, Spotsylvania County, Virginia: U.S. Geological Survey Map Miscellaneous Investigations Series 1568, scale 1:24,000.

Williams, H., and Hatcher, R.D., Jr., 1983, Appalachian suspect terranes, *in* Hatcher, R.D., Williams, H., and Zeitz, I., eds., The tectonics and geophysics of mountain chains: Geological Society of America Memoir 158, p. 33–53.

Williams, H., Turner, F.J., and Gilbert, C.H., 1982, Petrography: an introduction to the study of rocks in thin sections: 2nd Ed., W.H. Freeman, Calif., San Francisco, 626 p.

Wyllie, P.J., 1977, Crustal anatexis: An experimental review: Tectonophysics, v. 43, p. 41–71.

York, Derek, 1966, Least-squares fitting of a straight line: Canadian Journal of Physics, v. 44, p. 1079–1086.

———1969, Least-squares fitting of a straight line with corrected errors: Earth and Planetary Science Letters, v. 5, no. 5, p. 320–324.

Yui, S., 1970, Heterogeneity with a single grain of minerals of the tennantite-tetrahedrite series: Society of Mining Geologicals Japan Special Issue 2, p. 22–29.

Zen, E-an, 1988, Tectonic significance of high-pressure plutonic rocks in the Western Cordillera of North America, *in* Ernst, W.G., ed., Metamorphism and crustal evolution of the western United States, Rubey v. VII: Englewood Cliffs, N.J., Prentice Hall, p. 42–67.

Zen, E-an, and Hammarstrom, J.M., 1984, Magmatic epidote and its petrologic significance: Geology, v. 12, p. 515–518.

Zietz, Isidore, Calver, J.L., Johnson, S.S., and Kirby, J.R., 1977, Aeromagnetic map of Virginia: U.S. Geological Survey Geophysical Investigation Map GP 915, scale 1:500,000.

APPENDIX A: ELECTRON MICROPROBE ANALYSES OF MINERALS FROM EXOTIC BLOCKS IN MELANGE ZONE III OF THE MINE RUN COMPLEX

TABLE A-1.—*Electron microprobe analyses (weight percent) of serpentine from exotic serpentinite blocks within melange zone III of the Mine Run Complex and the mafic pluton of the Lahore Complex: cations calculated on the basis of 14 oxygens and that all Fe is FeO*[1]

Specimen number	P-78-7						P-78-29					P-80-86		
Probe number	P1117-23	P1117-24	P1117-25	P1117-26	P1117-27	P1117-28	P1117-34	P1117-35	P1117-36	P1117-37	P1117-38	P1117-75	P1117-79	P1117-81
Analysis type	grain	grain	Av 1-2	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain
Table number	1	2	2A	3	4	5	6	7	8	9	10	11	12	13
Lithologic unit	Melange zone III of Mine Run Complex											Mafic pluton of Lahore Complex		
Oxides														
SiO_2	42.62	42.35	42.48	42.74	41.82	43.99	41.36	40.56	40.26	41.11	41.04	41.58	42.31	41.41
Al_2O_3	1.12	1.79	1.46	.68	2.11	--	.48	1.23	2.06	1.68	1.41	.35	.71	.46
FeO	4.67	4.84	4.76	3.99	5.42	3.38	8.66	9.13	9.52	8.49	9.23	3.75	4.16	3.85
MgO	36.96	35.99	36.48	37.37	36.02	37.72	34.20	33.39	32.60	33.50	33.42	37.40	36.92	36.82
CaO	--	--	--	--	.01	--	--	--	--	--	.01	.04	.04	.05
TiO_2	.01	.02	.01	--	--	--	--	--	--	--	--	.03	--	.05
MnO	.06	.06	.06	.05	.04	--	.03	.04	.08	.06	.07	--	--	--
Sum	85.44	85.05	85.25	84.83	85.42	85.09	84.73	84.35	84.52	84.84	85.18	83.15	84.14	82.64
Cations [2]														
Si	4.078	4.071	4.074	4.104	4.020	4.188	4.083	4.034	4.003	4.045	4.041	4.077	4.101	4.086
Al	.126	.203	.165	.077	.239	--	.056	.144	.241	.195	.164	.040	.081	.054
Fe	.374	.389	.382	.320	.436	.269	.715	.759	.792	.699	.760	.308	.337	.318
Mg	5.274	5.158	5.216	5.351	5.162	5.355	5.034	4.952	4.833	4.915	4.906	5.468	5.336	5.417
Ca	--	--	--	--	.001	--	--	--	--	--	.001	.004	.004	.005
Ti	.001	.001	.001	--	--	--	--	--	--	--	--	.002	--	.004
Mn	.005	.005	.005	.004	.003	--	.003	.003	.007	.005	.006	--	--	--
Catsum	9.858	9.827	9.843	9.857	9.861	9.812	9.889	9.894	9.876	9.858	9.878	9.900	9.859	9.884
Mg/Mg+Fe	.934	.930	.932	.943	.922	.952	.876	.867	.859	.876	.866	.947	.941	.945

1/ Because H_2O^+ and H_2O^- are not analytically determined, the 14 oxygen method is the only one that can be used for cation calculation (Wicks, 1979)
2/ Cation site occupancies calculated by unpublished computer programs of M.J.K. Flohr of the U.S. Geological Survey (Personal commun. 1987)

TABLE A-2.—*Electron microprobe analyses (weight percent) of plagioclase from exotic mafic blocks within melange zone III of the Mine Run Complex: cations calculated on the basis of 32 oxygens*[1]

Specimen number	P-78-6	<------------------		P-80-46C		------------------>
Probe number	D1111-26	P1117-11	P1117-12	P1117-13	P1117-14	P1117-15
Analysis type	grain	grain	grain	grain	grain	grain
Table number	1	2	3	4	5	6
Oxides						
SiO_2	69.28	64.36	63.82	63.00	64.17	64.58
Al_2O_3	20.51	23.35	23.42	23.24	22.68	22.90
FeO[2]	.14	.10	.08	.15	.41	.10
MgO[2]	--	--	--	--	.23	--
CaO	.41	3.29	3.42	3.37	2.57	2.93
Na_2O	7.67	9.15	10.49	9.50	10.53	10.87
K_2O	--	--	--	--	.24	.01
TiO_2[2]	.01	--	--	--	--	--
Sum	98.02	100.25	101.23	99.26	100.83	101.39
Cations						
Si	12.126	11.286	11.163	11.198	11.268	11.267
Al	4.231	4.826	4.828	4.869	4.694	4.709
Ti	.001	--	--	--	--	--
T	16.358	16.112	15.991	16.067	15.962	15.976
Fe^{2+}	.020	.015	.012	.022	.060	.015
Mg	--	--	--	--	.060	--
Ca	.077	.618	.641	.642	.484	.548
Na	2.603	3.111	3.558	3.274	3.585	3.677
K	--	--	--	--	.054	.002
M	2.700	3.744	4.210	3.938	4.243	2.242
Catsum	19.059	19.856	20.202	20.005	20.205	20.218
		Molecular percent				
An	2.87	16.58	15.27	16.39	11.73	12.96
Ab	97.13	83.42	84.73	83.61	86.97	86.99
Or	--	--	--	--	1.30	.05

1/ Cation site occupancies calculated by computer program of Flohr (1983)
2/ Probably impurities within the grain

TABLE A-3.—*Electron microprobe analyses (weight percent) of individually separated grains of amphibole from exotic mafic blocks within melange zone III of the Mine Run Complex: cations calculated on the basis of 23 oxygens and that all Fe is FeO*[1]

Specimen number	P-78-22											P-80-48B			
Analysis number	P1115-83	P1115-84	P1115-85	P1115-86	P1115-87	P1115-88	P1115-89	P1115-90	P1115-91	P1115-92	P1115-93	P1116-5	P1116-6	P1116-7	P1116-8
Analysis site	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	Av 1-10	grain	grain	grain	Av12-14
Mineral analyses	1	2	3	4	5	6	7	8	9	10	11A	12	13	14	15A
Oxides															
SiO_2	49.35	50.41	48.29	50.56	48.73	48.38	52.18	51.38	48.58	50.41	49.83	53.28	50.29	49.20	50.93
Al_2O_3	7.79	7.86	8.83	6.98	9.75	8.77	5.76	6.04	9.60	7.46	7.89	4.05	7.13	7.70	6.30
FeO	14.64	14.56	15.02	14.64	15.69	15.15	13.33	13.61	15.70	14.86	14.72	13.78	15.77	16.33	15.29
MgO	13.17	13.20	12.49	14.17	11.89	12.82	15.58	14.37	11.97	13.63	13.33	15.05	12.97	12.61	13.55
CaO	12.33	12.26	11.88	11.69	12.11	11.54	11.37	11.76	11.82	11.70	11.85	12.38	11.81	11.88	12.02
Na_2O	.98	1.01	1.34	1.24	1.15	1.50	.92	1.14	1.40	1.36	1.20	.69	1.16	1.33	1.06
K_2O	.18	.53	.21	.16	.28	.31	.09	.19	.32	.16	.24	.08	.13	.22	.14
TiO_2	.26	.44	.55	.41	.44	.54	.35	.38	.55	.44	.44	.13	.23	.24	.20
MnO	.20	.23	.24	.25	.21	.28	.26	.28	.24	.25	.24	.41	.40	.37	.39
Sum	98.90	100.50	98.85	100.10	100.25	99.29	99.84	99.15	100.18	100.27	99.74	99.85	99.89	99.88	99.88
H_2O Calc	2.08	2.11	2.07	2.11	2.09	2.07	2.12	2.10	2.09	2.11	2.09	2.11	2.09	2.08	2.09
Sum	100.98	102.61	100.92	102.21	102.34	101.36	101.96	101.25	102.27	102.38	101.83	101.96	101.98	101.96	101.97
Cations															
Si	7.130	7.162	7.005	7.201	6.976	6.993	7.372	7.346	6.968	7.175	7.133	7.555	7.218	7.104	7.293
Al^{iv}	.870	.838	.995	.799	1.024	1.007	.628	.654	1.032	.825	.867	.445	.782	.896	.707
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	.457	.479	.515	.373	.622	.488	.332	.364	.591	.427	.465	.232	.424	.414	.357
Fe^{2+}	1.678	1.679	1.725	1.575	1.794	1.691	1.351	1.534	1.791	1.634	1.644	1.574	1.777	1.846	1.730
Mg	2.836	2.795	2.700	3.008	2.537	2.762	3.281	3.062	2.559	2.891	2.844	3.180	2.774	2.713	2.892
Ti	.028	.047	.060	.044	.047	.059	.037	.041	.059	.047	.047	.014	.025	.026	.022
M1-M3	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Mn	.024	.028	.029	.030	.025	.034	.031	.034	.029	.030	.029	.049	.049	.045	.047
Fe^{2+}	.091	.051	.097	.169	.085	.140	.224	.094	.092	.135	.118	.060	.116	.125	.102
Ca	1.885	1.866	1.846	1.784	1.858	1.787	1.721	1.802	1.817	1.784	1.818	1.881	1.816	1.829	1.844
Na	--	.055	.027	.017	.032	.038	.023	.071	.062	.051	.035	.009	.019	--	.007
M4	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.275	.223	.349	.326	.287	.382	.229	.245	.327	.325	.298	.180	.304	.372	.288
K	.033	.096	.039	.029	.051	.057	.016	.035	.059	.029	.044	.014	.024	.041	.026
Ca	.024	--	--	--	--	--	--	--	--	--	--	--	--	.009	--
A	.332	.320	.388	.355	.339	.439	.245	.280	.385	.354	.342	.195	.328	.422	.313
Catsum	15.332	15.320	15.388	15.355	15.339	15.439	15.245	15.280	15.385	15.354	15.342	15.195	15.328	15.422	15.313
OH Calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.384	.382	.403	.367	.425	.399	.324	.347	.424	.380	.383	.339	.406	.421	.388
Mg:Mg+Fe	.616	.618	.597	.633	.575	.601	.676	.653	.576	.620	.617	.661	.594	.579	.612

TABLE A-3.—*Electron microprobe analyses (weight percent) of individually separated grains of amphibole from exotic mafic blocks within melange zone III of the Mine Run Complex: cations calculated on the basis of 23 oxygens and that all Fe is FeO*[1]—Continued

Specimen number	<------------	------------	------------	------------	------------P-80-46C	------------	------------	------------	------------	------------>
Analysis number	P1117-1	P1117-2	P1117-3	P1117-4	P1117-5	P1117-6	P1117-7	P1117-8	P1117-9	P1117-10
Analysis site	grain	grain	grain	Av16-18	grain	grain	grain	grain	grain	Av20-24
Mineral analyses	16	17	18	19A	20	21	22	23	24	25A
Oxides										
SiO_2	50.70	48.58	47.48	48.93	45.48	46.18	50.25	44.02	48.31	46.86
Al_2O_3	4.60	6.26	7.72	6.19	8.61	7.48	5.09	9.24	6.36	7.36
FeO	11.33	12.39	12.64	12.12	13.29	12.79	11.39	14.83	12.36	12.93
MgO	15.86	14.89	14.14	14.96	13.12	14.05	15.87	12.76	14.85	14.14
CaO	11.82	11.74	11.57	11.71	11.69	11.54	11.60	11.23	11.61	11.53
Na_2O	.97	1.19	1.48	1.22	1.56	1.45	1.02	1.77	1.28	1.41
K_2O	.14	.21	.33	.23	.38	.31	.17	.53	.27	.33
TiO_2	.09	.12	.22	.14	1.12	.18	.21	.32	.14	.40
MnO	.52	.45	.44	.47	.42	.50	.44	.47	.46	.46
Sum	96.03	95.83	96.02	95.97	95.67	94.48	96.04	95.17	95.64	95.42
H_2O Calc	2.05	2.02	2.02	2.03	2.00	1.98	2.05	1.97	2.02	2.00
Sum	98.08	97.85	98.04	98.00	97.67	96.46	98.09	97.14	97.66	97.42
Cations										
Si	7.431	7.199	7.045	7.227	6.829	6.993	7.366	6.715	7.178	7.019
Al^{iv}	.569	.801	.955	.773	1.171	1.007	.634	1.285	.822	.981
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	.226	.292	.396	.305	.353	.328	.246	.377	.292	.319
Fe^{2+}	1.299	1.406	1.453	1.387	1.584	1.480	1.263	1.685	1.403	1.479
Mg	3.465	3.288	3.127	3.293	2.936	3.171	3.467	2.901	3.288	3.157
Ti	.010	.013	.025	.016	.126	.020	.023	.037	.016	.045
M1-M3	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Mn	.065	.056	.055	.059	.053	.064	.055	.061	.058	.058
Fe^{2+}	.089	.130	.116	.110	.085	.139	.133	.207	.133	.141
Ca	1.846	1.814	1.829	1.831	1.862	1.796	1.812	1.732	1.810	1.801
Na	--	--	--	--	--	--	--	--	--	--
M4	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.276	.342	.426	.349	.454	.426	.290	.524	.369	.410
K	.026	.040	.062	.043	.073	.060	.032	.103	.051	.063
Ca	.010	.050	.011	.022	.019	.076	.010	.104	.039	.049
A	.312	.432	.499	.415	.546	.562	.331	.730	.459	.522
Catsum	15.312	15.432	15.499	15.415	15.546	15.562	15.331	15.730	15.459	15.522
OH Calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.286	.318	.334	.313	.362	.338	.287	.395	.318	.339
Mg:Mg+Fe	.714	.682	.666	.687	.638	.662	.713	.605	.682	.661

[1] Cation site occupancies calculated by computer program of Flohr (1983)

TABLE A-4.—*Electron microprobe analyses (weight percent) of chlorite from exotic mafic blocks (1–5) and serpentinite blocks (6–12), within melange zone III of the Mine Run Complex: cations calculated on the basis of 28 oxygens and that all Fe is FeO*[1]

Specimen number	<-----P-78-6---->		<--------P-78-22--------->			<------------------P-78-7------------------>					<----P-78-29---->	
Probe number	D1111-31	D1111-32	P1115-94	P1115-97	P1115-98	P1117-29	P1117-30	P1117-31	P1117-32	P1117-33	P1117-39	P1117-40
Analysis type	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain
Table number	1	2	3	4	5	6	7	8	9	10	11	12
Oxides												
SiO_2	26.49	27.58	27.16	33.57	26.83	34.21	32.38	33.30	37.83	33.29	30.29	30.65
Al_2O_3	23.39	21.63	22.22	21.47	22.59	12.12	15.27	14.20	8.24	14.52	16.76	16.93
FeO	14.66	14.57	21.53	17.13	21.78	5.29	4.19	5.24	5.33	4.77	9.39	9.39
MgO	22.22	22.16	18.10	12.43	17.87	31.27	31.71	31.49	35.07	31.73	28.64	27.97
CaO	.04	.08	.04	.83	.06	.09	.01	.05	.01	.03	.02	.02
Na_2O	.01	.02	--	.07	--	.09	--	.05	.09	.03	--	--
K_2O	--	--	--	.32	.02	.03	.04	.04	--	.03	.03	--
TiO_2	.10	.10	.04	.06	.06	--	--	--	--	--	--	--
MnO	.17	.24	.19	.12	.21	--	--	--	.02	--	--	--
Sum	87.08	86.38	89.28	86.00	89.42	84.10	84.60	84.37	86.59	84.40	85.13	84.96
H_2O calc	12.00	11.91	11.89	11.93	11.89	12.24	12.28	12.26	12.60	12.30	12.06	12.06
Sum	99.08	98.29	101.18	97.93	101.31	96.34	96.88	96.63	99.19	96.70	97.19	97.02
Cations												
Si	5.296	5.552	5.477	6.747	5.412	6.705	6.323	6.513	7.202	6.490	6.024	6.095
Al	2.704	2.448	2.523	1.253	2.588	1.295	1.677	1.487	.798	1.510	1.976	1.905
Z	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	2.808	2.686	2.759	3.835	2.785	1.737	1.838	1.788	1.052	1.828	1.953	2.064
Fe^{2+}	2.451	2.453	3.631	2.879	3.675	.867	.848	.857	.849	.778	1.562	1.562
Mg	6.620	6.649	5.439	3.723	5.372	9.135	9.228	9.179	9.951	9.220	8.488	8.290
Ti	.015	.015	.006	.009	.009	--	--	--	--	--	--	--
Mn	.029	.041	.032	.020	.036	--	--	--	.003	--	--	--
Ca	.009	.017	.009	.179	.013	.019	.002	.010	.002	.006	.004	.004
Na	.004	.008	--	.027	--	.034	--	.019	.033	.011	--	--
K	--	--	--	.082	.005	.008	.010	.010	--	.007	.008	--
Y	11.935	11.869	11.876	10.755	11.895	11.800	11.925	11.864	11.890	11.850	12.015	11.920
Catsum	19.935	19.869	19.876	18.755	19.895	19.800	19.925	19.864	19.890	19.850	20.105	19.920
(OH)	16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000
Fe:Fe+Mg	.270	.270	.400	.436	.406	.087	.084	.085	.079	.078	.155	.159
Mg:Mg+Fe	.730	.730	.600	.564	.594	.913	.916	.915	.921	.922	.845	.941

[1] Cation site occupancies calculated by computer program of Flohr (1983)

TABLE A-5.—*Electron microprobe analyses (weight percent) of clinozoisite-epidote from exotic mafic blocks within melange zone III of the Mine Run Complex: cations calculated on the basis of 12.5 oxygens*[1]

Specimen number	<----------P-78-6	---------->		<----------	----------	P-80-48B	----------	--------->
Probe number	D1111-24	D1111-25	D1111-23	P1116-1	P1116-2	P1116-3	P1116-4	P1116-9
Analysis type	grain	grain	grain	grain	grain	grain	Av. 4-6	grain
Table number	1	2	3	4	5	6	7A	8
	<-------Clinozoisite	------->		<----------	----------	Epidote	----------	--------->
Oxides								
SiO_2	37.91	38.54	39.17	38.64	38.83	38.67	38.71	38.52
TiO_2	.11	.09	--	.09	.08	.02	.06	.32
Al_2O_3	28.17	26.95	32.46	22.78	23.80	24.36	24.36	24.44
[2]Fe_2O_3	7.18	9.23	1.94	15.40	14.35	13.38	14.38	13.25
MnO	.06	.01	--	.11	.16	.09	.12	.63
MgO	.13	.12	.12	.13	.18	.18	.16	.18
CaO	23.44	23.35	23.82	23.91	23.86	23.95	23.91	22.60
Na_2O	--	--	.01	--	--	--	--	--
K_2O	--	.02	--	.02	.01	.04	.02	.02
Sum	97.00	98.31	97.52	101.08	101.27	100.69	101.01	99.96
Cations								
Si	2.975	3.001	2.992	3.000	2.995	2.992	2.996	2.996
Ti	.006	.005	--	.005	.005	.001	.003	.019
Al	2.607	2.474	2.923	2.085	2.164	2.222	2.158	2.241
Fe^{3+}	.424	.541	.112	.900	.833	.779	.837	.776
Mn	.004	.001	--	.007	.010	.006	.008	.042
Mg	.015	.014	.014	.015	.021	.021	.018	.021
Ca	1.971	1.948	1.950	1.989	1.972	1.985	1.983	1.883
Na	--	--	.001	--	--	--	--	--
K	--	.002	--	.002	.001	.004	.002	.002
Catsum	8.003	7.987	7.991	8.003	8.002	8.009	8.005	7.978
[3]Ps	14.	18.	4.	30.	29.	26.	28.	26.

[1] Cation site occupancies calculated by unpublished computer program of Flohr (personal commun., 1987)
[2] Calculated from FeO
[3] Ps (pistacite) calculated as $Fe^{3+}/Fe^{3+} + Al \times 100$

TABLE A-6.—*Electron microprobe analyses (weight percent) of muscovite from an exotic mafic block within melange zone III of the Mine Run Complex: cations calculated on the basis of 11 oxygens and that all Fe is FeO*[1]

Specimen number	<----------P-78-22	---------->	
Probe number	P1115-96	P1115-100	P1115-99
Analysis type	grain	grain	grain
Table number	1	2	3
Oxides			
SiO_2	49.24	53.92	49.50
Al_2O_3	30.69	31.65	35.70
FeO	3.11	2.93	2.22
MgO	2.87	2.80	.94
CaO	.03	.04	.06
Na_2O	.14	.13	.26
K_2O	10.06	6.05	7.40
TiO_2	--	--	.02
Sum	96.14	97.52	96.10
H_2O Calc	4.53	4.76	4.65
Sum	100.67	102.28	100.75
Cations			
Si	3.259	3.400	3.194
Al^{iv}	.741	.600	.806
T	4.000	4.000	4.000
Al^{vi}	1.653	1.752	1.910
Fe^{2+}	.172	.155	.120
Mg	.283	.263	.090
Ti	--	--	.001
M	2.108	2.170	2.122
Ca	.002	.003	.004
Na	.018	.016	.033
K	.849	.487	.609
A	.869	.505	.646
Cat sum	6.978	6.675	6.768
OH Calc	2.000	2.000	2.000
An sum	2.000	2.000	2.000
Fe:Fe+Mg	.378	.370	.570
Mg:Mg+Fe	.622	.630	.430

[1] Cation site occupancies calculated by computer program of Flohr (1983)

APPENDIX B: ELECTRON MICROPROBE ANALYSES: MAFIC PLUTON AND LAHORE PLUTON OF THE LAHORE COMPLEX

TABLE B-1.—*Electron microprobe analyses (weight percent) of pyroxene from the mafic pluton of the Lahore Complex in melange zone III of the Mine Run Complex: cations calculated on the basis of 6 oxygens and that Fe is: A - present entirely as FeO and; B - present as both FeO and* Fe_2O_3[1]

Specimen number	<---------P-80-86---------->			<------------------P-80-87---------------->				
Probe number	P1118-10	P1118-11	P1118-11A	P1118-28	P1118-29	P1118-30	P1118-31	P1118-35
Analysis type	grain	grain	grain	grain	grain	grain	grain	grain
Table number	1	2	3	4	5	6	7	8
[2]Lithology	<---------------------------Metapyroxenites--------------------------->							
	A - all Fe present entirely as FeO							
Oxides								
SiO_2	55.07	54.71	55.44	54.25	54.48	54.80	54.51	53.84
MgO	17.73	17.71	18.00	18.61	17.98	18.13	18.24	18.13
CaO	24.40	23.89	23.63	23.14	24.65	23.70	23.83	24.78
Na_2O	.16	.22	.16	.27	.18	.22	.22	.13
FeO	2.81	2.95	2.89	2.62	2.96	2.98	2.85	2.52
Al_2O_3	.41	.76	.50	.61	.44	.50	.52	.23
MnO	.01	--	--	--	--	--	--	--
TiO_2	.11	.20	.14	.14	.18	.15	.16	.05
Total	100.70	100.44	100.76	99.64	100.87	100.48	100.33	99.68
Cations	Structural formulae							
Si	1.9891	1.9806	1.9955	1.9754	1.9707	1.9827	1.9762	1.9701
Mg	.9545	.9556	.9657	1.0101	.9694	.9777	.9857	.9888
Ca	.9443	.9266	.9113	.9028	.9554	.9187	.9257	.9715
Na	.0112	.0154	.0112	.0191	.0126	.0154	.0155	.0092
Fe^{2+}	.0849	.0893	.0870	.0798	.0895	.0902	.0864	.0771
Al	.0175	.0324	.0212	.0262	.0188	.0213	.0222	.0099
Mn	.0003	--	--	--	--	--	--	--
Ti	.0030	.0054	.0038	.0038	.0049	.0041	.0044	.0014
Cations per 6 anions	4.005	4.005	3.996	4.017	4.021	4.010	4.016	4.028
	Normative composition of pyroxenes							
$Na(MgTi)_{0.5}Si_2O_6$	.597	1.087	.759	.763	.974	.814	.869	.273
$NaAlSi_2O_6$	.522	.455	.359	1.135	.282	.725	.671	.643
$CaAlSiAlO_6$	.611	1.392	.882	.736	.792	.701	.771	.171
$MnMgSi_2O_6$	.031	--	--	--	--	--	--	--
$Ca_2Si_2O_6$	46.852	45.572	45.173	44.579	47.118	45.470	45.713	48.151
$Fe_2Si_2O_6$	4.239	4.459	4.354	3.972	4.453	4.497	4.303	3.829
$Mg_2Si_2O_6$	47.505	47.444	48.148	50.096	47.971	48.558	48.869	49.028
	Ternary Composition							
Wo	47.52	46.75	46.25	45.19	47.33	46.15	46.23	47.67
Fs	4.30	4.57	4.46	4.03	4.47	4.56	4.35	3.79
En	48.18	48.67	49.29	50.78	48.19	49.29	49.42	48.54
	Elements that failed to fit the accepted components							
Si	-.014	-.016	.013	-.051	-.064	-.031	-.048	-.084

TABLE B-1.—*Electron microprobe analyses (weight percent) of pyroxene from the mafic pluton of the Lahore Complex in melange zone III of the Mine Run Complex: cations calculated on the basis of 6 oxygens and that Fe is: A - present entirely as FeO and; B - present as both FeO and Fe_2O_3*[1]—Continued

Specimen number	<----------P-80-86---------		--------->	<-------------------		P-80-87		------------------>
Probe number	P1118-10	P1118-11	P1118-11A	P1118-28	P1118-29	P1118-30	P1118-31	P1118-35
Analysis type	grain	grain	grain	grain	grain	grain	grain	grain
Table number	9	10	11	12	13	14	15	16
	<-------------------------			Metapyroxenites				------------------------>
				B - Fe present as both FeO and Fe_2O_3				
Oxides								
SiO_2	55.0700	54.7100		54.2500	54.4800	54.8000	54.5100	
MgO	17.7300	17.7100		18.6100	17.9800	18.1300	18.2400	
CaO	24.4000	23.8900		23.1400	24.6500	23.7000	23.8300	
Na_2O	.1600	.2200		.2700	.1800	.2200	.2200	
FeO	2.3371	2.4085		.9294	.8461	1.9660	1.2657	
Al_2O_3	.4100	.7600		.6100	.4400	.5000	.52	
MnO	.0100	---		---	---	---	---	
TiO_2	.1100	.2000		.1400	.1800	.1500	.1600	
Fe_2O_3	.5256	.6018		1.8788	2.3493	1.1269	1.7607	
Total	100.753	100.500		99.828	101.105	100.593	100.506	
Cations				Structural formulae				
Si	1.9868	1.9779		1.9670	1.9603	1.9777	1.9684	
Mg	.9534	.9543		1.0057	.9643	.9752	.9817	
Ca	.9431	.9254		.8989	.9503	.9164	.9220	
Na	.0112	.0154		.0190	.0126	.0154	.0154	
Fe^{2+}	.0705	.0728		.0282	.0255	.0593	.0382	
Al	.0174	.0324		.0261	.0187	.0213	.0221	
Mn	.0003	---		---	---	---	---	
Ti	.0030	.0054		.0038	.0049	.0041	.0043	
Fe^{3+}	.0143	.0164		.0513	.0636	.0306	.0478	
Cations per 6 anions	4.000	4.000		4.000	4.000	4.000	4.000	
				Normative composition of pyroxenes				
$Na(MgTi)_{0.5}Si_2O_6$	.597	1.087		.763	.974	.814	.869	
$NaFe{+}3Si_2O_6$	.522	.455		1.135	.282	.725	.671	
$CaFe{+}3SiAlO_6$	.905	1.183		2.607	1.866	2.127	2.213	
$CaAlSiAlO_6$	.419	1.028		---	---	---	---	
$MnMgSi_2O_6$	.031	---		---	---	---	---	
$Ca_2Si_2O_6$	46.495	45.163		43.297	45.528	44.704	44.517	
$CaFe{+}2SiFe{+}3O_6$	---	---		.692	2.107	.104	.950	
$Fe_2Si_2O_6$	3.526	3.641		1.409	1.273	2.967	1.911	
$Mg_2Si_2O_6$	47.505	47.444		50.096	47.971	48.558	48.869	
				Ternary Composition				
Wo	47.67	46.92		45.67	48.04	46.46	46.71	
Fs	3.62	3.78		1.49	1.34	3.08	2.01	
En	48.71	49.29		52.84	50.62	50.46	51.28	

[1] Cation site occupancies for pyroxene by computer program of Freeborn and others (1985).

[2] Whole rock chemical analyses and petrographics descriptions of the rocks from which the listed pyroxenes were obtained are given in Pavlides (1989, table 3).

TABLE B-2.—*Electron microprobe analyses (weight percent) of serpentine from the mafic pluton of the Lahore Complex: cations calculated on the basis of 14 oxygens* [1] *and that all Fe is FeO*

Specimen number	<----------P-80-86--------->		
Probe number	P1117-75	P1117-79	P1117-81
Analysis type	grain	grain	grain
Table number	1	2	3
Oxides			
SiO_2	41.58	42.31	41.41
Al_2O_3	.35	.71	.46
FeO	3.75	4.16	3.85
MgO	37.40	36.92	36.82
CaO	.04	.04	.05
TiO_2	.03	--	.05
Sum	83.15	84.14	82.64
Cations			
Si	4.077	4.101	4.086
Al	.040	.081	.054
Fe	.308	.337	.318
Mg	5.468	5.336	5.417
Ca	.004	.004	.005
Ti	.002	--	.004
Catsum	9.900	9.859	9.884
$Mg/Mg+Fe^{2+}$	.947	.941	.945
P1118-35A			

1/ Cation site occupancies calculated by unpublished computer program of M.J.K. Flohr of the U.S. Geological Survey (Pers. commun., 1987). Because H_2O+ and H_2O- are not analytically determined, the 14 oxygen method is the only one that can be used for cation calculations (Wicks, 1979)

TABLE B-3.—*Electron microprobe analyses (weight percent) of amphibole from the mafic pluton of the Lahore Complex: cations calculated on the basis of 23 oxygens*[1]

Specimen number	<----------	----------	----------	P-80-87	----------	----------	---------->	P-80-86
Probe number	P1118-32	P1118-33	P1118-34	P1118-36	P1118-4A	P1118-4B	P1118-4C	P1118-11E
Analysis type	grain	grain	Av 1-2	grain	grain	grain	grain	grain
Table number	1	2	3A	4	5	6	7	8
Lithology	<----------	----------	----------	Metapyroxenite	----------	----------	----------	---------->
Oxides								
SiO_2	55.23	55.83	55.53	55.40	55.79	56.99	56.75	53.51
Al_2O_3	1.83	1.49	1.66	.82	.47	.25	.49	.91
FeO	3.72	3.23	3.48	3.72	3.09	3.52	3.36	3.14
MgO	23.25	22.14	22.70	21.37	22.46	22.31	22.15	17.57
CaO	11.91	13.17	12.54	13.07	13.29	13.21	13.42	23.42
Na_2O	.18	.41	.29	.26	.20	.13	.21	.21
K_2O	--	.01	.01	--	--	--	.17	--
TiO_2	.01	.18	.09	--	--	.03	.17	.19
MnO	--	--	--	--	--	--	.10	--
Sum	96.13	96.46	96.30	94.64	95.30	96.44	96.82	98.95
H_2O Calc	2.14	2.15	2.15	2.10	2.12	2.15	2.15	2.13
Sum	98.27	98.61	98.45	96.74	97.42	98.59	98.97	101.08
Cations								
Si	7.726	7.793	7.760	7.891	7.877	7.947	7.900	7.549
Al^{iv}	.274	.207	.240	.109	.078	.041	.080	.151
T	8.000	8.000	8.000	8.000	7.955	7.988	7.981	7.701
Al^{vi}	.028	.038	.033	.029	--	--	--	--
Fe^{2+}	.123	.337	.230	.434	.274	.360	.387	.370
Mg	4.847	4.606	4.727	4.537	4.726	4.636	4.595	3.694
Ti	.001	.019	.009	--	--	.003	.018	.020
M1-M3	5.000	5.000	5.000	5.000	5.000	5.000	5.000	4.085
Mn	--	--	--	--	--	--	.012	--
Fe^{2+}	.312	.040	.176	.009	.091	.050	.004	--
Ca	1.688	1.960	1.824	1.991	1.909	1.950	1.984	2.000
M4	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.049	.111	.079	.072	.055	.035	.057	.057
K	--	.002	.002	--	--	--	.030	--
Ca	.097	.009	.054	.004	.101	.024	.018	1.540
A	.146	.122	.134	.076	.156	.059	.105	1.598
Catsum	15.146	15.122	15.134	15.076	15.111	15.047	15.085	15.384
OH Calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.082	.076	.079	.089	.072	.081	.091	
Mg:Mg+Fe	.918	.924	.921	.911	.928	.919	.922	.909

1/ Cation site occupancies calculated by computer program of Flohr (1983)

TABLE B-4.—*Electron microprobe analyses (weight percent) of chlorite from the mafic pluton of the Lahore Complex: cations calculated on the basis of 28 oxygens and that all Fe is FeO*[1]

Specimen number	P-80-87
Probe number	P1117-69
Analysis type	grain
Table number	1
Oxides	
SiO_2	37.97
Al_2O_3	16.89
FeO	6.97
MgO	20.94
CaO	.66
Na_2O	.06
K_2O	.81
TiO_2	.19
MnO	---
Sum	84.49
H_2O Calc	12.37
Sum	96.86
Cations	
Si	7.362
Al	.638
Z	8.000
Al	3.223
Fe^{2+}	1.130
Mg	6.051
Ti	.028
Mn	---
Ca	.137
Na	.023
K	.200
Y	10.791
Catsum	18.791
(OH)	16.000
Fe:Fe+Mg	.157
Mg:Mg+Fe	.843

1/ Cation site occupancies calculated by computer program of Flohr (1983)

TABLE B-5.—*Electron microprobe analyses (weight percent) of pyroxenes from monzonites of the Lahore pluton: cations calculated on the basis that Fe is; A-present entirely as FeO and; B-present as both FeO and* Fe_2O_3[1]

Specimen number	P-78-52						P-80-70												
Analysis number	PAMPH 1	DAMPH 100	DAMPH 99	PAMPH 2	DAMPH 95	DAMPH 96	P1111-38A	P1113-33	P1113-34	P1113-35	P1113-36	P1113-45	P1113-44	P1113-46	P1113-47	P1113-57	P1113-56	P1113-58	P1113-59
[2]Analysis type	edge	center	edge	Av.1-3	edge	center	grain	edge	center	edge	Av.22-24	edge	center	edge	Av.26-28	edge	center	edge	Av.30-32
Table number	1	2	3	4	5	6	7	8	9	10	11A	12	13	14	15A	16	17	18	19A
[3]	<------			------>	<------	------>	<------>	<------			------>	<------			------>	<------			------>
[4]Lithology	I. Amphibole monzonite																		
	A - all Fe present entirely as FeO																		
Oxides																			
SiO_2	52.15	51.89	51.55	51.86	52.41	52.86	52.75	52.62	51.86	53.15	52.55	52.11	51.85	51.58	51.85	52.12	52.31	52.00	52.14
MgO	13.73	13.66	13.80	13.73	13.74	14.51	14.85	15.53	14.92	15.06	15.17	14.72	14.79	14.53	14.68	14.53	14.54	14.11	14.39
CaO	22.79	23.53	21.90	22.74	22.08	22.09	21.97	22.83	22.96	23.11	22.97	21.90	22.02	22.35	22.09	22.54	22.32	21.75	22.20
Na_2O	.77	.93	.81	.94	.91	.93	.78	.62	.79	.66	.69	.79	.81	.78	.79	.87	.78	.85	.83
K_2O	.01	--	--	--	--	--	.02	.02	--	--	--	--	--	--	--	--	--	--	--
FeO	7.73	7.89	8.55	8.06	7.87	7.52	7.24	6.55	7.36	6.86	6.92	7.82	7.72	7.84	7.79	7.53	7.10	7.74	7.46
Al_2O_3	1.06	.99	1.51	1.19	1.52	1.43	1.21	.75	1.19	.84	.92	1.58	1.49	1.47	1.51	1.26	1.31	1.44	1.34
MnO	.42	.49	.40	.43	.29	.38	.32	.33	.32	.34	.33	.30	.28	.29	.29	.27	.21	.25	.24
TiO_2	.07	.05	.14	.09	.18	.18	.22	.03	.08	.08	.06	.15	.12	.13	.14	.06	.10	.08	.08
Total	98.73	99.42	98.65	98.94	99.00	99.90	99.36	99.28	99.48	100.10	99.61	99.37	99.08	98.97	99.14	99.18	98.67	98.22	98.68
Cations	Structural formulae																		
Si	1.9712	1.9570	1.9540	1.9606	1.9700	1.9660	1.9690	1.9660	1.9451	1.9712	1.9611	1.9517	1.9489	1.9450	1.9486	1.9578	1.9672	1.9683	.9645
Mg	.7735	.7679	.7797	.7737	.7698	.8044	.8262	.8648	.8341	.8325	.8438	.8217	.8286	.8167	.8223	.8135	.8150	.7961	.8081
Ca	.9230	.9508	.8894	.9211	.8892	.8802	.8787	.9139	.9226	.9183	.9185	.8788	.8868	.9030	.8895	.9071	.8993	.8821	.8962
Na	.0564	.0680	.0595	.0616	.0663	.0671	.0565	.0449	.0574	.0475	.0499	.0574	.0590	.0570	.0576	.0634	.0569	.0624	.0606
K	.0005	--	--	--	--	--	.0010	.0010	--	--	--	--	--	--	--	--	--	--	--
Fe^{2+}	.2444	.2489	.2710	.2548	.2474	.2339	.2260	.2047	.2309	.2128	.2160	.2449	.2427	.2472	.2448	.2365	.2233	.2450	.2351
Al	.0472	.0440	.0675	.0530	.0673	.0627	.0532	.0330	.0526	.0367	.0405	.0697	.0660	.0653	.0669	.0558	.0581	.0642	.0595
Mn	.0134	.0157	.0128	.0138	.0092	.0120	.0101	.0104	.0102	.0107	.0104	.0095	.0089	.0093	.0092	.0086	.0067	.0080	.0077
Ti	.0020	.0014	.0040	.0026	.0051	.0050	.0062	.0008	.0023	.0022	.0017	.0042	.0034	.0037	.0040	.0017	.0028	.0023	.0023
Cations per 6 anions	4.032	4.054	4.038	4.041	4.024	4.031	4.027	4.040	4.055	4.032	4.042	4.038	4.044	4.047	4.043	4.044	4.029	4.028	4.034
	Normative composition of pyroxenes																		
$K(MgTi)_{0.5}Si_2O_6$	.048	--	--	--	--	--	.095	.094	--	--	--	--	--	--	--	--	--	--	--
$Na(MgTi)_{0.5}Si_2O_6$	.347	.280	.791	.507	1.011	.999	1.132	.073	.445	.443	.333	.837	.671	.729	.783	.335	.561	.452	.450
$KAlSi_2O_6$	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
$NaAlSi_2O_6$	4.685	4.342	5.106	5.248	5.580	5.655	4.475	3.270	5.189	3.643	4.005	4.846	5.167	4.907	4.912	5.517	5.084	5.742	5.563
$CaAlSiAlO_6$	--	--	.788	--	.556	.282	.406	--	--	--	--	1.032	.681	.775	.853	--	.340	.318	.169
$MnMgSi_2O_6$	1.334	1.545	1.272	1.363	.918	1.188	1.005	1.034	1.003	1.060	1.032	.943	.882	.915	.913	.850	.664	.796	.759
$Ca_2Si_2O_6$	45.786	46.911	43.658	45.586	43.914	43.533	43.437	45.247	45.505	45.552	45.446	43.011	43.513	44.235	43.576	44.859	44.470	43.634	44.348
$Fe_2Si_2O_6$	12.122	12.278	13.424	12.612	12.295	11.604	11.225	10.133	11.386	10.554	10.687	12.131	12.001	12.218	12.112	11.697	11.084	12.164	11.654
$Mg_2Si_2O_6$	37.608	37.044	37.784	37.482	37.545	39.063	40.226	42.260	40.524	40.656	41.155	40.019	40.368	39.717	40.027	39.720	39.982	39.012	39.574
	Ternary Composition																		
Wo	47.94	48.75	46.02	47.64	46.84	46.21	45.78	46.34	46.71	47.08	46.71	45.20	45.38	46.00	45.53	46.59	46.55	42.06	46.40
Fs	12.69	12.76	14.15	13.18	13.11	12.32	11.83	10.38	11.69	10.91	10.98	12.75	12.52	12.70	12.65	12.15	11.60	12.83	12.19
En	39.37	38.49	39.83	39.17	40.05	41.47	42.39	43.28	41.60	42.02	42.30	42.05	42.10	41.30	41.82	41.26	41.85	41.15	41.41
	Elements that failed to fit the accepted components																		
Si	.083	.117	.113	.115	.073	.093	.080	.095	.162	.083	.112	.113	.131	.140	.127	.123	.087	.085	.101

TABLE B-5.—*Electron microprobe analyses (weight percent) of pyroxenes from monzonites of the Lahore pluton: cations calculated on the basis that Fe is; A-present entirely as FeO and; B-present as both FeO and Fe_2O_3*[1]—Continued

Specimen number	P-81-10													P-78-53					
Analysis number	PAMPH 3	PAMPH 4	PAMPH 5	PAMPH 6	PAMPH 7	PAMPH 9	PAMPH 10	PAMPH 11	PAMPH 12	PAMPH 13	PAMPH 14	PAMPH 15	PAMPH 16	P1113-65	P1115-26	P1115-27	P1115-28	P1115-29	P1115-30
[2]Analysis type	edge	edge	center	margin	Av.7-10	edge	center	edge	Av.12-14	edge	center	margin	Av.16-18	grain	grain	grain	grain	grain	grain
Table number [3]	20	21	22	23	24A	25	26	27	28A	29	30	31	32A	33	34	35	36	37	38
[4]Lithology	II. Pyroxene monzonite																		
	A (continued)																		
Oxides																			
SiO_2	51.41	51.18	50.85	52.81	51.57	52.07	51.53	50.52	51.38	51.87	51.23	51.65	51.58	51.16	50.60	50.77	51.65	50.35	52.69
MgO	15.84	15.46	14.37	15.89	15.39	14.40	13.62	13.67	13.90	14.01	13.76	14.13	13.97	14.58	14.77	14.55	14.24	14.85	14.74
CaO	22.44	22.87	21.91	17.55	21.19	21.41	22.05	21.06	21.51	21.86	20.70	22.16	21.57	20.54	22.18	22.31	20.63	20.80	20.32
Na_2O	.32	.33	.42	.35	.35	.39	.56	.49	.48	.41	.43	.39	.41	.43	.39	.49	.45	.39	.42
K_2O	--	--	--	--	--	.04	--	.01	.01	--	--	.01	--	--	.01	.03	.01	.01	.03
FeO	6.57	5.84	8.44	11.98	8.21	9.87	9.34	10.44	9.88	9.02	10.11	8.83	9.32	9.70	7.49	7.54	10.81	9.57	10.53
Al_2O_3	1.83	2.50	2.59	1.48	2.10	1.41	2.73	2.79	2.31	1.39	1.96	1.27	1.54	2.45	2.98	3.25	1.98	2.79	1.32
MnO	.15	.13	.27	.43	.25	.42	.33	.39	.38	.37	.39	.36	.38	.39	.16	.20	.39	.27	.45
TiO_2	.22	.27	.27	.13	.22	.17	.41	.49	.35	.18	.39	.20	.26	.37	.39	.42	.28	.57	.17
Total	98.78	98.58	99.12	100.62	99.28	100.18	100.57	99.86	100.20	99.11	98.97	99.00	99.03	99.62	98.97	99.56	100.44	99.60	100.67
Cations	Structural formulae																		
Si	1.9282	1.9187	1.9156	1.9603	1.9309	1.9489	1.9196	1.9041	1.9245	1.9570	1.9405	1.9525	1.9498	1.9208	1.9020	1.8982	1.9325	1.8937	1.9597
Mg	.8855	.8639	.8069	.8791	.8589	.8033	.7563	.7680	.7760	.7879	.7769	.7961	.7871	.8159	.8275	.8108	.7941	.8325	.8171
Ca	.9018	.9186	.8843	.6980	.8501	.8586	.8801	.8505	.8632	.8837	.8401	.8975	.8736	.8263	.8933	.8937	.8270	.8382	.8097
Na	.0233	.0240	.0307	.0252	.0254	.0283	.0404	.0358	.0349	.0300	.0316	.0286	.0300	.0313	.0284	.0355	.0326	.0284	.0303
K	--	--	--	--	--	.0019	--	.0005	.0005	--	--	.0005	--	--	.0005	.0014	.0005	.0005	.0014
Fe^{2+}	.2061	.1831	.2659	.3719	.2571	.3089	.2910	.3291	.3095	.2846	.3203	.2791	.2946	.3046	.2355	.2358	.3382	.3010	.3275
Al	.0809	.1105	.1150	.0647	.0927	.0622	.1199	.1239	.1020	.0618	.0875	.0566	.0686	.1084	.1320	.1432	.0873	.1237	.0579
Mn	.0048	.0041	.0086	.0135	.0079	.0133	.0104	.0125	.0121	.0118	.0125	.0115	.0122	.0124	.0051	.0063	.0124	.00886	.0142
Ti	.0062	.0076	.0076	.0036	.0062	.0048	.0115	.0139	.0099	.0051	.0111	.0057	.0074	.0104	.0110	.0118	.0079	.0161	.0048
Cations per 6 anions	4.037	4.030	4.035	4.016	4.029	4.030	4.029	4.038	4.032	4.022	4.020	4.028	4.023	4.030	4.035	4.037	4.033	4.043	4.023
	Normative composition of pyroxenes																		
$K(MgTi)_{0.5}Si_2O_6$	--	--	--	--	--	.190	--	.048	.047	--	--	.048	--	--	.048	.142	.047	.047	.142
$Na(MgTi)_{0.5}Si_2O_6$	1.230	1.511	1.517	.723	1.230	.760	2.281	2.704	1.908	1.016	2.211	1.081	1.470	2.074	2.138	2.198	1.516	2.814	.804
$NaAlSi_2O_6$	1.076	.870	1.525	1.786	1.292	2.049	1.735	.843	1.549	1.967	.931	1.757	1.518	1.033	.679	1.321	1.722	--	2.208
$CaAlSiAlO_6$	3.470	5.046	4.938	2.331	3.954	2.062	5.082	5.717	4.283	2.090	3.887	1.931	2.652	4.864	6.204	6.435	3.469	5.954	1.773
$MnMgSi_2O_6$	.472	.410	.854	1.346	.787	1.321	1.034	1.233	1.196	1.176	1.245	1.145	1.210	1.231	.505	.628	1.226	.851	1.410
$Ca_2Si_2O_6$	42.943	43.060	41.368	33.591	40.219	41.575	41.145	39.262	40.672	42.898	39.847	43.597	42.101	38.572	41.171	41.060	39.282	38.407	39.373
$Fe_2Si_2O_6$	10.210	9.086	13.181	18.519	12.761	15.331	14.444	16.298	15.350	14.153	15.932	13.860	14.646	15.115	11.670	11.680	16.776	14.892	16.284
$Mg_2Si_2O_6$	43.330	42.285	39.191	42.924	41.933	38.967	36.452	36.730	37.402	38.337	37.471	38.675	38.155	39.357	40.215	39.273	38.382	40.044	39.686
$CaTiAl_2O_6$	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.164	--
	Ternary Composition																		
Wo	44.51	45.60	44.13	35.35	42.37	43.36	44.70	42.54	43.45	44.97	42.73	45.35	44.36	41.46	44.24	44.62	41.59	41.15	41.30
Fs	10.58	9.62	14.06	19.49	13.44	15.99	15.69	17.66	16.43	14.84	17.08	14.42	15.43	16.24	12.54	12.69	17.76	15.95	17.08
En	44.91	44.78	41.81	45.17	44.18	40.64	39.60	39.80	40.03	40.19	40.18	40.23	40.20	42.30	43.22	42.68	40.64	42.90	41.62
	Elements that failed to fit the accepted components																		
Si	.109	.091	.103	.049	.087	.090	.087	.113	.096	.065	.061	.084	.070	1.090	-.105	-.110	-.097	-.127	-.067

TABLE B-5.—*Electron microprobe analyses (weight percent) of pyroxenes from monzonites of the Lahore pluton: cations calculated on the basis that Fe is; A-present entirely as FeO and; B-present as both FeO and Fe_2O_3*[1]—Continued

Specimen number	-----	-----	----- P-78-53 -----	-----	-----	----->	<-----	-----	-----	-----	-----	----- P-81-10 -----	-----	-----	-----	-----	----->
Analysis number	P1115-31	P1115-32	P1115-33	P1115-34	P1115-35	P1115-36	P1115-37	P1115-38	P1115-39	P1115-40	P1115-41	P1115-42	P1115-43	P1115-44	P1115-45	P1115-46	P1115-47
[3]Analysis type	grain	grain	grain	grain	grain	Av.34-43	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	Av.45-54
Table number	39	40	41	42	43	44A	45	46	47	48	49	50	51	52	53	54	55A
[2]	-----	-----	-----	-----	-----	----->	<-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	----->
[4]Lithology								II. Pyroxene monzonite (continued)									
								A (continued)									
Oxides																	
SiO_2	52.73	52.46	52.72	53.23	52.88	52.01	50.98	51.04	52.15	51.38	52.27	52.31	51.74	51.39	50.69	50.84	51.49
MgO	14.43	15.00	14.74	15.01	14.08	14.64	14.10	13.65	16.45	15.20	15.23	15.94	16.28	14.49	15.29	16.82	15.35
CaO	21.18	21.43	20.45	20.86	21.69	21.18	21.64	21.35	21.74	19.00	21.23	20.40	19.78	22.18	21.43	7.86	19.65
Na_2O	.40	.38	.36	.36	.42	.41	.44	.48	.26	.68	.38	.35	.29	.37	.35	.76	.43
K_2O	.02	.02	.03	.01	.03	.02	.03	.01	.01	.16	.02	--	.02	.01	.02	.21	.05
FeO	10.02	8.82	10.66	9.26	9.43	9.41	9.84	10.05	6.40	8.38	8.68	8.77	8.81	8.33	8.50	18.47	9.63
Al_2O_3	1.54	2.34	1.08	2.37	1.92	2.16	1.70	2.43	2.37	3.72	2.76	2.48	2.62	1.43	1.68	4.12	2.53
MnO	.39	.25	.38	.28	.37	.32	.34	.35	.07	.17	.22	.24	.15	.30	.24	.66	.27
TiO_2	.27	.47	.13	.50	.28	.35	.30	.36	.36	.71	.58	.56	.41	.26	.29	.70	.45
Total	100.98	100.17	100.55	101.88	101.10	100.50	99.37	99.72	99.81	99.40	101.37	101.05	100.10	98.76	98.49	100.44	99.85
Cations									Structural formulae								
Si	1.9542	1.9304	1.9644	1.9420	1.9534	1.9331	1.9289	1.9223	1.9254	1.9109	1.9174	1.9215	1.9166	1.9436	1.9225	1.9019	1.9214
Mg	.7971	.8227	.8186	.8162	.7752	.8110	.7952	.7663	.9052	.8426	.8327	.8727	.8989	.8168	.8643	.9379	.8537
Ca	.8410	.8449	.8164	.8154	.8584	.8434	.8772	.8615	.8600	.7571	.8344	.8029	.7850	.8988	.8708	.3150	.7856
Na	.0287	.0271	.0260	.0255	.0301	.0295	.0323	.0350	.0186	.0490	.0270	.0249	.0208	.0271	.0257	.0551	.0311
K	.0009	.0009	.0014	.0005	.0014	.0009	.0014	.0005	.0005	.0076	.0009	--	.0009	.0005	.0010	.0100	.0024
Fe^{2+}	.3105	.2714	.3322	.2825	.2913	.2925	.3114	.3165	.1976	.2606	.2663	.2694	.2729	.2635	.2696	.5778	.3005
Al	.0673	.1015	.0474	.1019	.0836	.0946	.0758	.1079	.1031	.1631	.1193	.1074	.1144	.0637	.0751	.1817	.1113
Mn	.0122	.0078	.0120	.0087	.0116	.0101	.0109	.0112	.0022	.0054	.0068	.0075	.0047	.0096	.0077	.0209	.0085
Ti	.0075	.0130	.0036	.0137	.0078	.0098	.0085	.0102	.0100	.0199	.0160	.0155	.0114	.0074	.0083	.0197	.0126
Cations per 6 anions	4.020	4.020	4.022	4.006	4.013	4.025	4.042	4.031	4.023	4.016	4.021	4.022	4.026	4.031	4.045	4.020	4.027
								Normative composition of pyroxenes									
$K(MgTi)_{0.5}Si_2O_6$	.094	.093	.142	.046	.141	.094	.143	.048	.047	.756	.093	--	.094	.048	.096	.997	.236
$Na(MgTi)_{0.5}Si_2O_6$	1.404	2.495	.583	2.542	1.410	1.850	1.546	1.976	1.851	3.200	2.689	2.479	2.069	1.420	1.540	2.922	2.272
$NaAlSi_2O_6$	1.457	.203	2.004	--	1.589	1.086	1.648	1.502	--	1.684	--	--	--	1.273	1.005	2.563	.818
$CaAlSiAlO_6$	2.619	4.948	1.357	5.012	3.372	4.159	2.927	4.600	6.082	7.278	5.734	5.040	5.630	2.526	3.211	7.756	5.117
$MnMgSi_2O_6$	1.218	.775	1.193	.864	1.154	1.001	1.078	1.108	.218	.533	.680	.743	.468	.954	.762	2.081	.848
$Ca_2Si_2O_6$	40.536	39.563	39.918	38.161	41.099	39.830	41.947	40.441	40.193	34.064	38.535	37.257	36.160	43.329	41.451	11.795	36.457
$Fe_2Si_2O_6$	15.452	13.504	16.517	14.104	14.519	14.534	15.407	15.704	9.825	12.980	13.245	13.398	13.559	13.072	13.330	28.748	14.925
$Mg_2Si_2O_6$	38.677	39.899	39.929	39.667	37.673	39.313	38.388	36.955	44.425	40.705	40.384	42.409	43.882	39.683	41.946	44.640	41.349
$CaTiAl_2O_6$	--	--	--	.075	--	--	--	--	.045	--	.201	.299	.053	--	--	--	--
								Ternary Composition									
Wo	42.82	42.56	41.42	41.51	44.05	42.52	43.81	43.44	42.56	38.82	41.81	40.03	38.63	45.09	42.85	13.85	39.32
Fs	16.32	14.53	17.14	15.34	15.56	15.15	16.19	16.87	10.40	14.79	14.37	14.40	14.49	13.60	13.78	33.75	16.09
En	40.86	42.92	41.44	43.15	40.38	41.97	40.09	39.69	47.04	46.39	43.82	45.57	46.88	41.30	43.37	52.40	44.59
								Elements that failed to fit the accepted components									
Si	-.058	-.059	-.066	-.019	-.038	-.075	.123	.093	.067	.048	.062	.065	.077	.092	.134	.060	.081

TABLE B-5.—*Electron microprobe analyses (weight percent) of pyroxenes from monzonites of the Lahore pluton: cations calculated on the basis that Fe is; A-present entirely as FeO and; B-present as both FeO and* Fe_2O_3[1]—Continued

Specimen number	<-----	-----	P-78-52	----->	<-----	-----	-----	-----	-----	-----	-----	P-80-70	-----	-----	-----	-----	-----	-----	----->
Analysis number	PAMPH 1	DAMPH 100	DAMPH 99	PAMPH 2	DAMPH 95	DAMPH 96	P1111-38A	P1113-33	P1113-34	P1113-35	P1113-36	P1113-45	P1113-44	P1113-46	P1113-47	P1113-57	P1113-56	P1113-58	P1113-59
[3]Analysis type	edge	center	edge	Av.56-58	edge	center	grain	edge	center	edge	Av.77-79	edge	center	edge	Av.81-83	edge	center	edge	Av.85-87
Table number	56	57	58	59A	60	61	62	63	64	65	66	67	68	69	70A	71	72	73	74A
[2]	<-----	-----	-----	----->	<-----	----->	<----->	<-----	-----	-----	----->	<-----	-----	-----	----->	<-----	-----	-----	----->
[2]Lithology									I. Amphibole monzonite										
								B - Fe present as both FeO and Fe_2O_3											
Oxides																			
SiO_2	52.15	51.89	51.55	51.86	52.41	52.86	52.75	52.62	51.86	53.15	52.55	52.11	51.85	51.58	51.85	52.12	52.31	52.00	52.14
MgO	13.73	13.66	13.80	13.73	13.74	14.51	14.85	15.53	14.92	15.06	15.17	14.72	14.79	14.53	14.68	14.53	14.54	14.11	14.39
CaO	22.79	23.53	21.90	22.74	22.08	22.09	21.97	22.83	22.96	23.11	22.97	21.90	22.02	22.35	22.09	22.54	22.32	21.75	22.20
Na_2O	.77	.93	.81	.84	.91	.93	.78	.62	.79	.66	.69	.79	.81	.78	.79	.87	.78	.85	.83
K_2O	.01	--	--	--	--	--	.02	.02	--	--	--	--	--	--	--	--	--	--	--
FeO	4.7272	2.7927	4.9534	4.1582	5.5417	4.5108	4.6583	2.7500	2.0898	3.7731	2.8920	4.1864	3.4975	3.3533	3.7045	3.2955	4.3008	5.0437	4.2384
Al_2O_3	1.06	.99	1.51	1.19	1.52	1.43	1.21	.75	1.19	.84	.92	1.58	1.49	1.47	1.51	1.26	1.31	1.44	1.34
MnO	.42	.49	.40	.43	.29	.38	.32	.33	.32	.34	.33	.30	.28	.29	.29	.27	.21	.25	.24
TiO_2	.07	.05	.14	.09	.18	.18	.22	.03	.08	.08	.06	.15	.12	.13	.14	.06	.10	.08	.08
Fe_2O_3	3.3372	5.6649	3.9971	4.3362	2.5875	3.442	2.8691	4.2231	5.8571	3.4306	4.4765	4.0382	4.6926	4.9863	4.5405	4.7060	3.1109	2.9965	3.5803
Total	99.064	99.998	99.060	99.374	99.259	100.235	99.647	99.703	100.067	100.444	100.059	99.775	99.550	99.470	99.595	99.652	98.982	98.520	99.039
Cations									Structural formulae										
Si	1.9557	1.9311	1.9356	1.9406	1.9581	1.9507	1.9559	1.9467	1.9186	1.9556	1.9408	1.9333	1.9276	1.9223	1.9280	1.9363	1.9529	1.9544	1.9480
Mg	.7675	.7577	.7723	.7658	.7651	.7981	.8207	.8564	.8227	.8259	.8351	.8140	.8195	.8071	.8136	.8046	.8091	.7905	.8013
Ca	.9157	.9382	.8811	.9117	.8838	.8734	.8728	.9049	.9101	.9110	.9089	.8705	.8771	.8924	.8800	.8972	.8928	.8759	.8886
Na	.0560	.0671	.0590	.0609	.0659	.0665	.0561	.0445	.0567	.0471	.0494	.0568	.0584	.0564	.0570	.0627	.0565	.0619	.0601
K	.0005	--	--	--	--	--	.0009	.0009	--	--	--	--	--	--	--	--	--	--	--
Fe^{2+}	.1483	.0869	.1555	.1301	.1731	.1392	.1444	.0851	.0647	.1161	.0893	.1299	.1087	.1045	.1152	.1024	.1343	.1585	.1324
Al	.0469	.0434	.0668	.0525	.0669	.0622	.0529	.0327	.0519	.0364	.0400	.0691	.0653	.0646	.0662	.0552	.0576	.0638	.0590
Mn	.0133	.0154	.0127	.0136	.0092	.0119	.0100	.0103	.0100	.0106	.0103	.0094	.0088	.0092	.0091	.0085	.0066	.0080	.0076
Ti	.0020	.0014	.0040	.0025	.0051	.0050	.0061	.0008	.0022	.0022	.0017	.0042	.0034	.0036	.0039	.0017	.0028	.0023	.0022
Fe^{3+}	.0942	.1586	.1129	.1221	.0727	.0929	.0801	.1176	.1631	.0950	.1244	.1127	.1313	.1398	.1270	.1316	.0874	.0848	.1007
Cations per 6 anions	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
								Normative composition of pyroxenes											
$K(MgTi)_{0.5}Si_2O_6$	.048	--	--	--	--	--	.095	.094	--	--	--	--	--	--	--	--	--	--	--
$Na(MgTi)_{0.5}Si_2O_6$	.347	.280	.791	.507	1.011	.999	1.132	.073	.445	.443	.333	.837	.671	.729	.783	.335	.561	.452	.450
$NaFe^{+3}Si_2O_6$	5.252	6.430	5.106	5.588	5.580	5.655	4.475	4.375	5.221	4.266	4.608	4.846	5.167	4.907	4.912	5.931	5.084	5.742	5.563
$CaFe^{+3}SiAlO_6$	4.166	4.342	6.188	5.248	1.694	3.632	3.530	3.270	5.189	3.643	4.005	6.428	6.528	6.457	6.617	5.517	3.655	2.733	4.503
$CaFe^{+3}SiFeO_6$	--	2.546	--	.687	--	--	.879	--	--	--	--	.240	--	--	--	--	1.054	1.823	.699
$MnMgSi_2O_6$	1.334	1.545	1.272	1.363	.918	1.188	1.005	1.034	1.003	1.060	1.032	.943	.882	.915	.913	.850	.664	.796	.759
$Ca_2Si_2O_6$	43.573	43.467	40.835	42.618	42.095	41.209	41.435	42.584	41.437	43.333	42.487	40.192	40.231	40.739	40.400	41.674	42.285	41.515	41.831
$Fe_2Si_2O_6$	7.413	4.346	7.777	6.507	8.657	6.961	7.222	4.254	3.233	5.805	4.466	6.494	5.437	5.226	5.760	5.119	6.714	7.927	6.621
$Mg_2Si_2O_6$	37.608	37.044	37.784	37.482	37.545	39.063	40.226	42.260	40.524	40.656	41.155	40.019	40.368	39.717	40.027	39.720	39.982	39.012	39.574
$CaAlSiAlO_6$	--	--	.247	--	2.499	1.294	--	2.056	2.948	.795	1.914	--	.716	1.310	.587	.854	--	--	--
								Ternary Composition											
Wo	49.18	51.22	47.26	49.21	47.67	47.24	46.62	47.79	48.64	48.26	48.22	46.35	46.76	47.55	46.87	48.17	47.52	46.93	47.52
Fs	8.37	5.12	9.00	7.51	9.80	7.98	8.13	4.77	3.79	6.46	5.07	7.49	6.32	6.10	6.68	5.32	7.55	8.96	7.52
En	42.45	43.65	43.73	43.28	42.52	44.78	45.26	47.43	47.57	45.28	46.71	46.16	46.92	46.35	46.44	45.91	44.93	44.10	44.96

TABLE B-5.—*Electron microprobe analyses (weight percent) of pyroxenes from monzonites of the Lahore pluton: cations calculated on the basis that Fe is; A-present entirely as FeO and; B-present as both FeO and* Fe_2O_3[1]—Continued

Specimen number	P-81-10													P-78-53						
Analysis number	PAMPH 3	PAMPH 4	PAMPH 5	PAMPH 6	PAMPH 7	PAMPH 9	PAMPH 10	PAMPH 11	PAMPH 12	PAMPH 13	PAMPH 14	PAMPH 15	PAMPH 16	P1113-65	P1115-26	P1115-27	P1115-28	P1115-29	P1115-30
[3]Analysis type	edge	edge	center	margin	Av.62-65	edge	center	edge	Av.67-69	edge	center	margin	Av.71-73	grain	grain	grain	grain	grain	grain
Table number	75	76	77	78	79A	80	81	82	83A	84	85	86	87A	88	89	90	91	92	93
[2]Lithology	II. Pyroxene monzonite																		
	B (continued)																		
Oxides																			
SiO_2	51.41	51.18	50.85	52.81	51.57	52.07	51.53	50.52	51.38	51.87	51.23	51.65	51.58	51.16	50.60	50.77	51.65	50.35	52.69
MgO	15.84	15.46	14.37	15.89	15.39	14.40	13.62	13.67	13.90	14.01	13.76	14.13	13.97	14.48	14.77	14.55	14.24	14.85	14.74
CaO	22.44	22.87	21.91	17.55	21.19	21.41	22.05	21.06	21.51	21.86	20.70	22.16	21.57	20.54	22.18	22.31	20.63	20.80	20.32
Na_2O	.32	.33	.42	.35	.35	.39	.56	.49	.48	.41	.43	.39	.41	.43	.39	.49	.45	.39	.42
K_2O	--	--	--	--	--	.04	--	.01	.01	--	--	.01	--	--	.01	.03	.01	.01	.03
FeO	3.0555	2.9256	5.1445	10.4016	5.4098	6.9658	6.5311	6.8078	6.7803	6.9341	8.1763	6.1631	7.0920	6.8182	4.1147	4.0053	7.6905	5.4916	8.3586
Al_2O_3	1.83	2.50	2.59	1.48	2.10	1.41	2.73	2.79	2.31	1.39	1.96	1.27	1.54	2.45	2.98	3.25	1.98	2.79	1.32
MnO	.15	.13	.27	.43	.25	.42	.33	.39	.38	.37	.39	.36	.38	.39	.16	.20	.39	.27	.45
TiO_2	.22	.27	.27	.13	.22	.17	.41	.49	.35	.18	.39	.20	.26	.37	.39	.42	.28	.57	.17
Fe_2O_3	3.9058	3.2389	3.6624	1.7541	3.1120	3.2276	3.1217	4.0366	3.4449	2.3182	2.1490	2.9638	2.4761	3.2027	3.7511	3.9283	3.4668	4.5325	2.4132
Total	99.171	98.905	99.487	100.796	99.592	100.503	100.883	100.264	100.545	99.342	99.185	99.297	99.278	99.941	99.346	99.954	100.787	100.054	100.912
	Structural formulae																		
Cations																			
Si	1.9107	1.9042	1.8992	1.9523	1.9169	1.9343	1.9057	1.8861	1.9090	1.9464	1.9307	1.9388	1.9385	1.9065	1.8854	1.8809	1.9169	1.8737	1.9487
Mg	.8775	.8573	.7999	.8756	.8527	.7973	.7508	.7607	.7698	.7836	.7729	.7906	.7825	.8098	.8203	.8034	.7877	.8237	.8125
Ca	.8936	.9117	.8767	.6951	.8439	.8521	.8737	.8424	.8563	.8789	.8358	.8912	.8685	.8201	.8855	.8856	.8203	.8293	.8052
Na	.0231	.0238	.0304	.0251	.0252	.0281	.0402	.0355	.0346	.0298	.0314	.0284	.0299	.0311	.0282	.0352	.0324	.0281	.0301
K	--	--	--	--	--	.0019	--	.0005	.0005	--	--	.0005	--	--	.0005	.0014	.0005	.0005	.0014
Fe^{2+}	.0950	.0910	.1607	.3216	.1682	.2164	.2020	.2126	.2107	.2176	.2577	.1935	.2229	.2125	.1282	.1241	.2387	.1709	.2585
Al	.0802	.1096	.1140	.0645	.0920	.0617	.1190	.1228	.1012	.0615	.0871	.0562	.0682	.1076	.1309	.1419	.0866	.1224	.0575
Mn	.0047	.0041	.0085	.0135	.0079	.0132	.0103	.0123	.0120	.0118	.0124	.0114	.0121	.0123	.0050	.0063	.0123	.0085	.0141
Ti	.0061	.0076	.0076	.0036	.0061	.0047	.0114	.0138	.0098	.0051	.0111	.0056	.0073	.0104	.0109	.0117	.0078	.0160	.0047
Fe^{3+}	.1092	.0907	.1029	.0488	.0870	.0902	.0869	.1134	.0963	.0655	.0609	.0837	.0700	.0898	.1052	.1095	.0968	.1269	.0672
Cations per 6 anions	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
	Normative composition of pyroxenes																		
$K(MgTi)_{0.5}Si_2O_6$	--	--	--	--	--	.190	--	.048	.047	--	--	.048	--	--	.048	.142	.047	.047	.142
$Na(MgTi)_{0.5}Si_2O_6$	1.230	1.511	1.517	.723	1.230	.760	2.281	2.704	1.908	1.016	2.211	1.081	1.470	2.074	2.138	2.198	1.516	2.814	.804
$NaFe^{+3}Si_2O_6$	1.076	.870	1.525	1.786	1.292	2.049	1.735	.843	1.549	1.967	.931	1.757	1.518	1.033	.679	1.321	1.722	--	2.208
$CaFe^{+3}SiAlO_6$	8.016	8.199	8.768	3.094	7.412	6.173	6.953	10.497	8.082	4.579	5.163	5.619	5.485	7.948	9.838	9.630	7.960	11.908	4.508
$CaAlSiAlO_6$	.916	1.382	1.316	1.677	.894	.400	--	--	--	.784	1.771	.498	.668	1.406	1.624	2.280	.351	--	.623
$MnMgSi_2O_6$	.472	.410	.854	1.346	.787	1.321	1.034	1.233	1.196	1.176	1.245	1.145	1.210	1.231	.505	.628	1.226	.851	1.410
$Ca_2Si_2O_6$	40.212	40.793	38.795	32.371	38.043	39.320	38.973	36.427	38.264	41.261	38.324	41.504	40.350	36.327	38.542	38.323	36.861	35.234	37.694
$Fe_2Si_2O_6$	4.748	4.551	8.035	16.079	8.409	10.820	10.100	10.628	10.534	10.880	12.884	9.674	11.145	10.624	6.411	6.205	11.935	8.545	12.936
$Mg_2Si_2O_6$	43.330	42.285	39.191	42.924	41.933	38.967	36.452	36.730	37.402	38.337	37.471	38.675	38.155	39.357	40.215	39.273	38.382	40.044	39.686
$CaTiAl_2O_6$	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.164	--
$CaFeSiFeO_6$	--	--	--	--	--	--	2.473	.889	1.017	--	--	--	--	--	--	--	--	.392	--
	Ternary Composition																		
Wo	45.55	46.55	45.10	35.43	43.04	44.13	45.57	43.48	44.39	45.60	43.22	46.19	45.01	42.09	45.25	45.73	42.28	42.03	41.74
Fs	5.38	5.19	9.34	17.60	9.51	12.14	11.81	12.68	12.22	12.02	14.53	10.77	12.42	12.31	7.53	7.40	13.69	10.19	14.31
En	49.08	48.25	45.56	46.98	47.44	43.73	42.62	43.84	43.39	42.37	42.25	43.04	42.56	45.60	47.22	46.87	44.03	47.77	43.95

TABLE B-5.—*Electron microprobe analyses (weight percent) of pyroxenes from monzonites of the Lahore pluton: cations calculated on the basis that Fe is; A-present entirely as FeO and; B-present as both FeO and Fe_2O_3*[1]—Continued

Specimen number	P-78-53						P-81-10										
Analysis number	P1115-31	P1115-32	P1115-33	P1115-34	P1115-35	P1115-36	P1115-37	P1115-38	P1115-39	P1115-40	P1115-41	P1115-42	P1115-43	P1115-44	P1115-45	P1115-46	P1115-47
[2]Analysis type	grain	grain	grain	grain	grain	Av.89-98	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	Av.100-109
Table number	94	95	96	97	98	99A	100	101	102	103	104	105	106	107	108	109	110A
[3]																	
[4]Lithology	II. Pyroxene monzonite (continued)																
	B (continued)																
Oxides																	
SiO_2	52.73	52.46	52.72	53.23	52.88	52.01	50.98	51.04	52.15	51.38	52.27	52.31	51.74	51.39	50.69	50.84	51.49
MgO	14.43	15.00	14.74	15.01	14.08	14.64	14.10	13.65	16.45	15.20	15.23	15.94	16.28	14.49	15.29	16.82	15.35
CaO	21.18	21.43	20.45	20.86	21.69	21.18	21.64	21.35	21.74	19.00	21.23	20.40	19.78	22.18	21.43	7.86	19.65
Na_2O	.40	.38	.36	.36	.42	.41	.44	.48	.26	.68	.38	.35	.29	.37	.35	.76	.43
K_2O	.02	.02	.03	.01	.03	.02	.03	.01	.01	.16	.02	--	.02	.01	.02	.21	.05
FeO	8.1311	6.8864	8.5411	8.6394	8.1868	6.9923	5.8990	7.0637	4.2046	6.8304	6.6348	6.6425	6.3227	5.3924	4.24041	6.5407	7.0216
Al_2O_3	1.54	2.34	.108	2.37	1.92	2.16	1.70	2.43	2.37	3.72	2.76	2.48	2.62	1.43	1.68	4.12	2.53
MnO	.39	.25	.38	.28	.37	.32	.34	.35	.07	.17	.22	.24	.15	.30	.24	.66	.27
TiO_2	.27	.47	.13	.50	.28	.35	.30	.36	.36	.71	.58	.56	.41	.26	.29	.70	.45
Fe_2O_3	2.0992	2.1489	2.354	8.6897	1.3816	2.6869	4.3798	3.3188	2.4399	1.7221	2.2729	2.3644	2.7643	3.2647	4.7339	2.1441	2.8988
Total	101.190	101.385	100.786	101.949	101.238	100.769	99.809	100.053	100.054	99.573	101.598	101.287	100.377	99.087	98.964	100.655	100.140
Cations	Structural formulae																
Si	1.9447	1.9209	1.9536	1.9389	1.9471	1.9211	1.9090	1.9073	1.9146	1.9032	1.9074	1.9111	1.9044	1.9286	1.9011	1.8924	1.9084
Mg	.7932	.8187	.8141	.8149	.7728	.8060	.7870	.7603	.9002	.8392	.8284	.8680	.8931	.8105	.8547	.9332	.8480
Ca	.8369	.8407	.8119	.8141	.8557	.8382	.8682	.8548	.8551	.7541	.8301	.7985	.7800	.8919	.8611	.3135	.7803
Na	.0286	.0270	.0259	.0254	.0300	.0294	.0319	.0348	.0185	.0488	.0269	.0248	.0207	.0269	.0254	.0548	.0309
K	.0009	.0009	.0014	.0005	.0014	.0009	.0014	.0005	.0005	.0076	.0009	--	.0009	.0005	.0010	.0100	.0024
Fe^{2+}	.2508	.2109	.2647	.2632	.2521	.2160	.1847	.2208	.1291	.2116	.2025	.2030	.1946	.1692	.1330	.5149	.2176
Al	.0669	.1010	.0472	.1017	.0833	.0940	.0750	.1070	.1025	.1624	.1187	.1068	.1137	.0633	.0743	.1807	.1105
Mn	.0122	.0078	.0119	.0086	.0115	.0100	.0108	.0111	.0022	.0053	.0068	.0074	.0047	.0095	.0076	.0208	.0085
Ti	.0075	.0129	.0036	.0137	.0078	.0097	.0084	.0101	.0099	.0198	.0159	.0154	.0113	.0073	.0082	.0196	.0125
Fe^{3+}	.0583	.0592	.0657	.0189	.0383	.0747	.1234	.0933	.0674	.0480	.0624	.0650	.0766	.0922	.1336	.0601	.0808
Cations per 6 anions	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
	Normative composition of pyroxenes																
$K(MgTi)_{0.5}Si_2O_6$	.094	.093	.142	.046	.141	.094	.143	.048	.047	.756	.093	--	.094	.048	.096	.997	.236
$Na(MgTi)_{0.5}Si_2O_6$	1.404	2.495	.583	2.542	1.410	1.850	1.546	1.976	1.851	3.200	2.689	2.479	2.069	1.420	1.540	2.922	2.272
$NaFe^{+3}Si_2O_6$	1.457	.203	2.004	--	1.589	1.086	1.648	1.502	--	1.684	--	--	--	1.273	1.005	2.563	.818
$CaFe^{+3}SiAlO_6$	4.369	5.718	4.563	1.890	2.239	6.382	7.503	7.831	6.741	3.116	6.241	6.500	7.656	6.325	7.426	3.443	7.267
$CaAlSiAlO_6$	1.162	2.190	.077	4.067	3.046	1.510	--	1.436	1.712	6.562	2.614	1.790	1.801	--	--	7.316	1.892
$MnMgSi_2O_6$	1.218	.775	1.193	.864	1.154	1.001	1.078	1.108	.218	.533	.680	.743	.468	.954	.762	2.081	.848
$Ca_2Si_2O_6$	39.079	38.083	38.276	37.689	40.142	37.963	38.862	38.108	38.508	32.864	36.975	35.632	34.246	41.024	38.111	10.294	34.436
$Fe_2Si_2O_6$	12.539	10.544	13.234	13.159	12.605	10.799	9.237	11.038	6.455	10.580	10.124	10.148	9.731	8.462	6.650	25.745	10.882
$Mg_2Si_2O_6$	38.677	39.899	39.929	39.667	37.673	39.313	38.388	36.955	44.425	40.705	40.384	42.409	43.882	39.683	41.946	44.640	41.349
$CaTiAl_2O_6$	--	--	--	.075	--	--	--	--	--	--	--	--	--	--	--	--	--
$CaAlSiAlO_6$	--	--	--	--	--	--	--	--	.045	--	.201	.299	.053	--	--	--	--
	Ternary Composition																
Wo	43.28	43.02	41.86	41.64	44.40	43.10	44.93	44.26	43.08	39.05	42.27	40.40	38.98	46.01	43.95	12.76	39.73
Fs	13.89	11.91	14.47	14.54	13.94	12.26	10.68	12.82	7.22	12.57	11.57	11.51	11.08	9.49	7.67	31.91	12.56
En	42.83	45.07	43.67	43.82	41.66	44.64	44.39	42.92	49.70	48.37	46.16	48.09	49.95	44.50	48.38	55.33	47.71

[1] Cation site occupancies calculated by the computer program by Freeborn and others (1985)
[2] edge, center, and margin (inward from edge) are points established visually where probe analysis was made along cross section of grain
[3] Brackets include separate grains
[4] Whole rock chemical analyses and petrographic descriptions of the rocks from which the listed pyroxenes were analyzed are listed in tables 1-4.
[5] Individual grains are from pyroxene concentrate hand picked from crushed and heavy liquid treated rock

TABLE B-6.—*Electron microprobe analyses (weight percent) of plagioclase from monzonites of the Lahore pluton: cations calculated on the basis of 32 oxygens*[1]

A. Pyroxene monzonites

Specimen number	<------	------	------	------	------	P-81-10	------	------	------	------	------>
Analysis number	P-2111-74	P-2111-75	P-2111-76	P-2111-77	P-2111-77A	P-2111-79	P-2111-80	P-2111-81	P-2111-82	P-2111-83	P-2111-84
[2]Analysis type	grain E	grain C	grain I	grain E	Aver 1-4	grain C	grain I	grain E	Aver 6-8	grain C	grain E
Table number	1	2	3	4	5A	6	7	8	9A	10	11
[2]	<------	------	------	------	------>	<------	------	------	------>		
Oxides											
SiO_2	60.14	51.88	58.69	61.05	57.21	50.67	50.11	60.27	53.71	51.02	58.26
Al_2O_3	25.78	31.36	26.88	25.64	27.96	32.19	32.47	25.57	30.71	31.68	26.18
FeO	.12	.16	.12	.11	.13	.10	.16	.07	.11	.14	.07
CaO	7.19	13.67	8.49	6.93	9.70	14.76	15.41	7.11	12.43	14.62	8.33
Na_2O	7.35	3.59	6.59	7.57	5.92	3.14	2.90	7.47	4.53	3.14	6.53
K_2O	.21	.11	.13	.12	.12	.05	.04	.11	.06	.05	.12
TiO_2	.05	.01	--	--	--	--	--	--	--	--	.02
Sum	100.84	100.78	100.90	101.42	101.10	100.91	101.09	100.60	100.94	100.65	99.51
Cations											
Si	10.633	9.349	10.400	10.712	10.160	9.149	9.054	10.671	9.630	9.229	10.459
Al	5.371	6.661	5.614	5.302	5.853	6.850	6.913	5.336	6.360	6.754	5.540
Ti	.006	.002	--	--	.001	--	--	--	--	--	.003
T	16.010	16.012	16.014	16.014	16.014	15.999	15.967	16.007	15.990	15.983	16.002
Fe^{2+}	.018	.025	.017	.017	.019	.015	.023	.010	.016	.021	.011
Ca	1.362	2.640	1.611	1.303	1.845	2.854	2.983	1.349	2.389	2.833	1.603
Na	2.520	1.254	2.266	2.576	2.038	1.099	1.017	2.564	1.575	1.101	2.274
K	.048	.025	.030	.026	.027	.011	.009	.024	.015	.012	.027
M	3.948	3.944	3.924	3.922	3.929	3.979	4.032	3.947	3.995	3.967	3.915
Catsum	19.958	19.956	19.938	19.936	19.943	19.978	19.999	19.954	19.985	19.950	19.917
						Molecular percent					
An	34.66	67.36	41.23	33.37	47.32	72.00	74.41	34.26	60.04	71.79	41.06
Ab	64.12	32.00	58.00	65.97	51.99	27.72	25.37	65.13	39.58	27.90	58.25
Or	1.22	.64	.77	.67	.69	.28	.22	.61	.38	.30	.69

Specimen number	<------	------	------	------	------	P-78-53	------	------	------	------	------>
Analysis number	P1111-67	P1111-68	P1111-69	P1111-70	P1111-73	P1111-74	P1111-75	P1111-76	P1111-77	P1111-78	P1111-81
Analysis type	grain C_1	grain C_2	grain E	aver12-14	grain	grain	grain	aver16-18	grain E	grain C	grain E
Table number	12	13	14	15A	16	17	18	19	20	21	22
	<------	------	------	------>							
Oxides											
SiO_2	49.78	55.53	58.45	54.93	59.06	52.28	54.26	55.22	56.54	57.24	58.17
Al_2O_3	31.59	27.76	26.44	28.18	25.42	29.92	28.71	28.03	26.81	26.42	25.58
FeO	.49	.08	.14	.32	.10	.16	.13	.13	.19	.15	.04
MgO	.06	--	.04	.05	--	.09	.03	.04	.01	--	--
CaO	13.78	9.25	7.42	9.57	6.64	11.43	10.03	9.37	7.32	7.55	6.99
Na_2O	3.58	6.57	7.59	5.91	8.05	4.95	5.90	6.31	7.77	7.32	7.74
K_2O	--	.08	.09	.06	.10	.12	.11	.11	.10	.09	.10
TiO_2	--	--	--	--	--	.01	--	--	--	--	--
Sum	99.28	99.27	100.17	99.02	99.37	98.96	99.17	99.21	98.74	98.77	98.62

TABLE B-6.—*Electron microprobe analyses (weight percent) of plagioclase from monzonites of the Lahore pluton: cations calculated on the basis of 32 oxygens*[1]—Continued

Specimen number	P-78-53										
Analysis number	P1111-67	P1111-68	P1111-69	P1111-70	P1111-73	P1111-74	P1111-75	P1111-76	P1111-77	P1111-78	P1111-81
Analysis type	grain C_1	grain C_2	grain E	aver12-14	grain	grain	grain	aver16-18	grain E	grain C	grain E
Table number	12	13	14	15A	16	17	18	19A	20	21	22
Cations											
Si	9.147	10.066	10.438	9.985	10.610	9.567	9.867	10.018	10.274	10.374	10.537
Al	6.842	5.931	5.565	6.038	5.383	6.454	6.154	5.994	5.743	5.644	5.462
Ti	--	--	--	--	--	.001	--	--	--	--	--
T	15.989	15.997	16.004	16.022	15.992	16.022	16.021	16.011	16.017	16.018	15.999
Fe^{2+}	.075	.012	.021	.049	.015	.024	.020	.020	.029	.023	.006
Mg	.016	--	.011	.014	--	.025	.008	.011	.003	--	--
Ca	2.713	1.797	1.420	1.864	1.278	2.241	1.954	1.821	1.425	1.466	1.357
Na	1.276	2.309	2.628	2.083	2.804	1.756	2.080	2.220	2.738	2.572	2.719
K	--	.019	.021	.014	.023	.028	.026	.025	.023	.021	.023
M	4.080	4.136	4.100	4.023	4.120	4.075	4.088	4.097	4.218	4.082	4.104
Catsum	20.070	20.133	20.104	20.045	20.113	20.097	20.109	20.108	20.235	20.100	20.103
Molecular percent											
An	68.02	43.56	34.90	47.06	31.14	55.67	48.13	44.79	34.05	36.12	33.10
Ab	31.98	55.99	64.60	52.59	68.31	43.63	51.24	54.58	65.40	63.37	66.33
Or	--	.45	.50	.35	.56	.70	.63	.63	.55	.51	.56

Specimen number	P-78-53								
Analysis number	P2111-94	P2111-95	P2111-93	P2111-96	P2111-97	P2111-98	P2111-99	P2111-100	P2112-1
Analysis type	grain C	grain I	grain E	Aver23-25	grain C	grain E	grain E	grain C	grain C
Table number	23	24	25	26A	27	28	29	30	31
Oxides									
SiO_2	57.93	58.02	58.90	58.29	54.81	55.53	55.17	51.15	50.47
Al_2O_3	26.51	26.44	26.10	26.35	29.27	28.66	28.96	31.19	31.48
FeO	.07	.08	.02	.05	.18	.15	.16	.19	.44
CaO	8.21	8.21	7.41	7.94	11.05	10.49	10.77	13.85	14.00
Na_2O	6.83	6.91	7.35	7.03	5.31	5.81	5.56	3.73	3.60
K_2O	.18	.14	.11	.14	.20	.23	.21	.05	.04
TiO_2	.04	.02	.02	.03	.09	.05	.07	.02	.02
Sum	99.77	99.82	99.91	99.83	100.91	100.92	100.90	100.90	100.05
Cations									
Si	10.393	10.404	10.522	10.440	9.809	9.930	9.870	9.227	9.203
Al	5.605	5.587	5.495	5.562	6.173	6.040	6.107	6.784	6.765
Ti	.005	.003	.002	.003	.013	.006	.010	.002	.002
T	16.003	15.994	16.019	16.003	15.995	15.976	15.987	16.013	15.970
Fe^{2+}	.010	.012	.003	.008	.027	.023	.025	.029	.067
Ca	1.578	1.576	1.419	1.524	2.119	2.010	2.064	2.676	2.735
Na	2.375	2.403	2.547	2.442	1.844	2.013	1.929	1.304	1.271
K	.041	.031	.024	.032	.045	.052	.049	.010	.009
M	4.004	4.022	3.993	4.006	4.035	4.098	4.067	4.019	4.082
Catsum	20.007	20.016	20.012	20.011	20.030	20.074	20.054	20.032	20.052
Molecular percent									
An	39.51	39.30	35.56	38.12	52.87	49.33	51.06	67.07	68.12
Ab	59.46	59.93	63.83	61.08	46.01	49.40	47.72	32.68	31.66
Or	1.03	.77	.60	.80	1.12	1.28	1.21	.25	.22

TABLE B-6.—*Electron microprobe analyses (weight percent) of plagioclase from monzonites of the Lahore pluton: cations calculated on the basis of 32 oxygens*[1]—Continued

B. Amphibole monzonites

Specimen number	<----------	----------	----------	----------	P-80-67	----------	----------	----------	----------	---------->	<-----P-80-70	----->
Analysis number	PAMPH 89	PAMPH 93	PAMPH 95	PAMPH 96	PAMPH 98	PAMPH 74	PAMPH 75	PAMPH 76	PAMPH 77	PAMPH 78	P1111-29a	P1111-30
Analysis type	grain	grain	grain	grain	grain	grain	grain	grain	grain	aver. 1-9	grain	grain
Table number	1	2	3	4	5	6	7	8	9	10A	11	12
Oxides												
SiO_2	59.37	57.91	68.78	59.06	66.04	60.07	57.67	56.87	58.08	58.17	62.06	67.39
Al_2O_3	24.93	25.47	20.50	24.64	21.21	24.78	25.92	25.96	25.71	25.59	24.44	19.74
FeO	.10	.11	.30	.13	.09	.09	.12	.22	.13	.14	.14	.04
MgO	.01	.02	.26	--	--	--	--	--	.01	--	--	--
CaO	6.67	7.75	.76	6.51	1.67	6.34	7.73	7.91	7.72	7.43	6.06	.51
Na_2O	7.43	6.91	5.22	7.16	7.85	7.86	6.95	6.84	7.02	7.17	8.19	6.94
K_2O	.23	.16	.05	.19	.08	.11	.13	.15	.11	.12	.25	5.46
TiO_2	.03	.04	--	--	--	.01	.03	.02	.02	.02	.03	--
Sum	98.77	98.37	95.87	97.69	96.94	99.26	98.55	97.97	98.80	98.64	101.17	100.08
Cations												
Si	10.706	10.522	12.204	10.748	11.800	10.767	10.461	10.396	10.505	10.533	10.907	11.949
Al	5.298	5.453	4.287	5.286	4.466	5.235	5.542	5.593	5.481	5.462	5.063	4.126
Ti	.005	.005	--	--	--	.001	.004	.003	.003	.003	.004	--
T	16.009	15.980	16.491	16.034	16.266	16.004	16.007	15.992	15.989	15.998	15.974	16.075
Fe^{2+}	.015	.016	.045	.020	.013	.013	.018	.034	.020	.021	.021	.006
Mg	.002	.006	.068	--	--	--	--	--	.003	--	--	--
Ca	1.289	1.508	.144	1.269	.320	1.218	1.502	1.549	1.496	1.442	1.141	.097
Na	2.599	2.434	1.796	2.527	2.718	2.732	2.444	2.424	2.462	2.517	2.791	2.386
K	.052	.038	.011	.044	.019	.025	.030	.035	.025	.028	.056	1.235
M	3.957	4.002	2.064	3.860	3.070	3.988	3.995	4.042	4.006	4.008	4.009	3.724
Catsum	19.966	19.982	18.555	19.894	19.336	19.992	20.002	20.034	19.995	20.006	19.983	19.799
							Molecular percent					
An	32.72	37.89	7.38	33.05	10.47	30.64	37.78	38.65	37.56	36.16	28.6	2.61
Ab	65.96	61.16	92.06	65.81	88.91	68.73	61.47	60.48	61.80	63.15	69.99	64.17
Or	1.32	.95	.56	1.15	.62	.63	.76	.87	.64	.70	1.40	33.22

Specimen number	<----------	----------	----------	P-78-52	----------	----------	----------	---------->
Analysis number	Damph 86	Damph 87	Damph 88	Damph 89	Damph 90	Damph 91	Damph 92	Damph 93
Analysis type	grain	grain	grain	aver.13-15	grain	grain	grain	grain
Table number	13	14	15	16A	17	18	19	20
Oxides								
SiO_2	56.30	56.24	55.42	56.01	58.58	59.44	58.75	59.56
Al_2O_3	28.07	28.61	29.60	28.76	26.60	26.39	26.30	26.81
FeO	.11	.22	.13	.15	.69	.10	.05	.31
MgO	--	.07	--	.02	.01	--	--	.01
CaO	8.51	8.71	9.53	8.92	7.40	7.21	7.46	7.31
Na_2O	6.62	6.28	5.94	6.28	7.43	7.29	7.36	7.49
K_2O	.12	.10	.07	.10	.13	.08	.16	.15
TiO_2	--	.02	--	--	--	--	.02	--
Sum	99.73	100.25	100.69	100.24	100.84	100.51	100.10	101.64
Cations								
Si	10.125	10.062	9.892	10.028	10.414	10.540	10.485	10.472
Al	5.950	6.033	6.227	6.069	5.574	5.515	5.531	5.556
Ti	--	.002	--	--	--	--	.003	--

TABLE B-6.—*Electron microprobe analyses (weight percent) of plagioclase from monzonites of the Lahore pluton: cations calculated on the basis of 32 oxygens*[1]—Continued

Specimen number	<-------	-------	-------	-------P-78-52	-------	-------	-------	------->
Analysis number	Damph 86	Damph 87	Damph 88	Damph 89	Damph 90	Damph 91	Damph 92	Damph 93
Analysis type	grain	grain	grain	aver.13-15	grain	grain	grain	grain
Table number	13	14	15	16A	17	18	19	20
T	16.075	16.097	16.119	16.097	15.988	16.055	16.019	16.028
Fe^{2+}	.016	.033	.019	.023	.103	.015	.007	.046
Mg	--	.018	--	.005	.003	--	--	.003
Ca	1.640	1.669	1.822	1.710	1.410	1.370	1.427	1.378
Na	2.307	2.179	2.054	2.180	2.561	2.507	2.548	2.553
K	.028	.023	.016	.022	.029	.019	.036	.034
M	3.991	3.922	3.911	3.940	4.106	3.911	4.018	4.014
Catsum	20.066	20.019	20.030	20.037	20.094	19.966	20.037	20.042
				Molecular percent				
An	41.26	43.12	46.81	43.71	35.24	35.16	35.58	34.75
Ab	58.04	56.29	52.77	55.73	64.03	64.35	63.53	64.39
Or	.70	.59	.41	.56	.74	.49	.90	.86

Specimen number	<-------	-------	-------	-------	-------P-81-15	-------	-------	-------	-------	------->
Analysis number	P2115-2	P2115-3	P2115-4	P2115-5	P2115-6	P2115-7	P2115-8	P2115-9	P2115-10	P2115-11
Analysis type	grain E	grain I	grain C	Aver 21-23	grain E	grain I	grain C	Aver 25-27	grain E	grain I
Table number	21	22	23	24A	25	26	27	28A	29	30
2/	<-------	-------	-------	------->	<-------	-------	-------	------->	<-------	-------
Oxides										
SiO_2	61.12	60.47	60.45	60.68	63.51	62.20	60.66	62.12	60.08	59.96
Al_2O_3	24.93	25.21	25.28	25.14	22.84	24.45	24.67	23.99	25.13	25.38
FeO	.06	.04	.03	.05	.02	.04	.03	.03	.05	.06
MgO	--	--	--	--	--	--	--	--	--	--
CaO	5.78	5.96	6.15	5.96	3.34	5.12	5.63	4.70	5.83	6.09
Na_2O	7.61	7.53	7.50	7.55	9.16	7.24	7.88	8.10	7.90	7.69
K_2O	.13	.10	.18	.14	.10	.13	.19	.14	.12	.16
BaO	.05	.01	--	.02	.03	.01	.06	.04	.04	.05
Sum	99.68	99.32	99.59	99.54	99.00	99.19	99.12	99.12	99.15	99.39
Cations										
Si	10.864	10.792	10.771	10.809	11.294	11.043	10.858	11.064	10.763	10.723
Al	5.222	5.303	5.309	5.278	4.786	5.116	5.204	5.036	5.305	5.349
T	16.086	16.095	16.080	16.087	16.080	16.159	16.062	16.100	16.068	16.072
Fe^{2+}	.009	.006	.005	.007	.004	.006	.004	.004	.008	.009
Ca	1.101	1.140	1.174	1.138	.635	.973	1.081	.896	1.119	1.166
Na	2.622	2.607	2.591	2.607	3.158	2.492	2.734	2.796	2.745	2.666
K	.028	.023	.041	.031	.022	.030	.044	.032	.028	.037
Ba	.004	.001	--	.001	.002	.001	.004	.003	.003	.003
M	3.764	3.777	3.811	3.784	3.821	3.502	3.867	3.731	3.903	3.881
Catsum	19.850	19.872	19.891	19.871	19.901	19.661	19.929	19.831	19.971	19.953
				Molecular percent						
An	29.32	30.23	30.85	30.13	16.64	27.83	27.98	24.04	28.73	30.11
Ab	69.83	69.13	68.08	69.02	82.74	71.28	70.77	75.02	70.48	68.85
Or	.75	.61	1.08	.82	.58	.86	1.14	.86	.72	.95
Cn	.11	.03	--	.03	.05	.03	.10	.08	.08	.08

TABLE B-6.—*Electron microprobe analyses (weight percent) of plagioclase from monzonites of the Lahore pluton: cations calculated on the basis of 32 oxygens*[1]—Continued

Specimen number	<----------				P-81-15				---------->
Analysis number	P2115-12	P2115-13	P2115-14	P2115-15	P2115-16	P2115-18	P2115-19	--------	P2115-21
Analysis type	grain C	Aver 29-32	grain E	grain I	grain C	grain I	grain E	Aver 33-37	grain E
Table number	31	32A	33	34	35	36	37	38A	39
2/	---------	------->	<-------	side 1	------->	<-------	side 2	------->	<-------
Oxides									
SiO_2	59.23	59.76	58.55	58.97	59.36	59.95	59.57	59.28	60.14
Al_2O_3	25.67	25.39	26.87	26.22	26.13	25.51	25.73	26.09	25.43
FeO	--	.04	.04	.03	.18	.07	.15	.09	.07
MgO	--	--	--	--	.02	.03	--	.01	--
CaO	6.84	6.25	7.89	7.43	7.18	6.45	6.93	7.18	6.48
Na_2O	7.29	7.63	6.23	6.69	6.73	7.07	6.99	6.74	7.31
K_2O	.18	.15	.13	.17	.32	.19	.19	.20	.18
BaO	.02	.03	.03	.06	.08	.06	.04	.05	--
Sum	99.23	99.25	99.74	99.57	100.00	99.33	99.60	99.65	99.61
Cations									
Si	10.627	10.704	10.454	10.549	10.579	10.716	10.644	10.588	10.726
Al	5.428	5.361	5.654	5.527	5.490	5.374	5.418	5.493	5.345
T	16.055	16.065	16.108	16.076	16.069	16.090	16.062	16.081	16.071
Fe^{2+}	.001	.006	.006	.004	.027	.011	.022	.014	.011
Mg	--	--	--	--	.005	.009	--	.003	--
Ca	1.315	1.200	1.509	1.425	1.371	1.236	1.326	1.373	1.237
Na	2.534	2.649	2.158	2.321	2.326	2.452	2.423	2.336	2.527
K	.041	.035	.031	.038	.072	.042	.044	.045	.040
Ba	.001	.002	.002	.004	.006	.004	.003	.004	--
M	3.892	3.892	3.706	3.792	3.807	3.754	3.818	3.755	3.815
Catsum	19.947	19.957	19.814	19.868	19.876	19.844	19.880	19.865	19.886
				Molecular percent					
An	33.80	30.88	40.78	37.62	36.32	33.10	34.93	36.55	32.52
Ab	65.12	68.17	58.32	61.27	61.62	65.67	63.83	62.14	66.43
Or	1.05	.90	.84	1.00	1.91	1.12	1.16	1.21	1.05
Cn	.03	.05	.05	.11	.16	.11	.08	.10	--

Specimen number	<----------			P-81-15				---------->
Analysis number	P2115-22	P2115-23	P2115-24	P2115-25	P2115-26	P2115-27	P2115-28	P2115-29
Analysis type	grain E	Aver 39-40	grain E	grain I	grain C	grain I	grain E	Aver 42-46
Table number	40	41A	42	43	44	45	46	47A
2/	---------	------->	<-------	side 1	------->	<-------	side 2	------->
Oxides								
SiO_2	61.61	60.88	62.75	60.86	60.81	60.72	60.78	61.18
Al_2O_3	24.34	24.89	23.93	25.19	25.00	25.00	24.99	24.82
FeO	.03	.05	.03	.17	.07	.15	--	.08
MgO	--	--	--	--	--	--	--	--
CaO	4.96	5.72	4.46	6.03	5.67	6.26	5.92	5.67
Na_2O	8.25	7.78	8.44	7.39	7.74	6.97	7.67	7.65
K_2O	.11	.14	.09	.23	.20	.25	.13	.18
BaO	.03	.02	.04	.04	--	.03	.07	.03
Sum	99.33	99.48	99.74	99.91	99.49	99.38	99.56	99.61

TABLE B-6.—*Electron microprobe analyses (weight percent) of plagioclase from monzonites of the Lahore pluton: cations calculated on the basis of 32 oxygens*[1]—Continued

Specimen number	<------------------------------------			P-81-15				------------------------------------>
Analysis number	P2115-22	P2115-23	P2115-24	P2115-25	P2115-26	P2115-27	P2115-28	P2115-29
Analysis type	grain E	Aver 39-40	grain E	grain I	grain C	grain I	grain E	Aver 42-46
Table number	40	41A	42	43	44	45	46	47A
[3]	------------------	------------------>	<----------	side 1	----------->	<-----------	side 2	------------>
Cations								
Si	10.973	10.849	11.102	10.809	10.836	10.830	10.828	10.881
Al	5.109	5.227	4.990	5.272	5.250	5.255	5.246	5.203
T	16.082	16.076	16.092	16.081	16.086	16.085	16.074	16.084
Fe^{2+}	.005	.008	.005	.026	.010	.022	--	.012
Mg	--	--	--	--	--	--	--	--
Ca	.946	1.092	.845	1.147	1.083	1.197	1.130	1.080
Na	2.848	2.688	2.897	2.545	2.675	2.412	2.650	2.637
K	.026	.033	.020	.053	.045	.058	.029	.041
Ba	.002	.001	.003	.003	--	.002	.005	.002
M	3.827	3.822	3.770	3.774	3.813	3.691	3.814	3.772
Catsum	19.909	19.898	19.862	19.855	19.899	19.776	19.888	19.856
				Molecular percent				
An	24.75	28.63	22.44	30.60	28.48	32.62	29.63	28.72
Ab	74.52	70.48	76.95	67.90	70.34	65.74	69.48	70.13
Or	.68	.87	.53	1.41	1.18	1.58	.76	1.09
Cn	.05	.03	.08	.08	--	.05	.13	.05

[1] Cation site occupancies calculated by computer program of Flohr (1983).
[2] Grain C is analysis at center of grain, grain I is analysis at intermediate position between center and edge of grain and grain E is analysis taken at edge. Average analysis is for C, I, and E of a single grain.
[3] Brackets enclose analyses from a single grain.

TABLE B-7.—*Electron microprobe analyses (weight percent) of potassic feldspar from monzonites of the Lahore pluton: cations calculated on the basis of 32 oxygens*

A. Pyroxene monzonite

Specimen number	<------------								P-81-10								------------>
Analysis number	P2111-78	PFELD-56	PFELD-57	PFELD-58	PFELD-59	PFELD-60	PFELD-61	PFELD-62	PFELD-63	PFELD-64	PFELD-65	PFELD-66	PFELD-67	PFELD-68	PFELD-69	PFELD-70	PFELD-71
Analysis type	grain	grain	grain	grain	Av. 2-4	grain	grain	grain	Av. 6-8	grain	grain	grain	Av 10-12	grain	grain	grain	Av 13-16
Table number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Oxides																	
SiO_2	64.86	67.05	65.29	64.40	65.57	65.59	64.63	64.59	64.93	64.98	65.02	64.84	64.95	64.62	64.88	65.29	64.92
Al_2O_3	19.29	19.01	18.78	18.44	18.74	18.61	18.88	18.73	18.74	18.69	18.55	18.52	18.58	18.64	18.23	18.74	18.53
FeO	.08	--	.04	.08	.03	.14	.06	.02	.07	.02	.02	.05	.03	.18	.07	.10	.14
CaO	.31	.21	.01	.03	.08	.20	.01	.03	.08	.05	.19	.02	.08	.24	.09	.15	.16
Na_2O	1.21	1.59	0.96	0.81	1.12	1.79	.64	1.04	1.16	.76	1.88	.76	1.14	1.63	1.27	2.68	1.86
K_2O	14.41	12.15	15.03	15.16	14.11	12.94	15.39	14.77	14.37	14.89	13.27	15.34	14.50	13.64	14.28	12.39	13.43
TiO_2	.03	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
BaO	--	.66	.66	.69	.67	.61	.92	.95	.82	.85	.77	.67	.76	.82	.83	.58	.74
SUM	100.19	100.67	100.77	99.61	100.32	99.88	100.53	100.13	100.17	100.24	99.70	100.20	100.04	99.77	99.65	100.01	99.78
Cations																	
Si	11.886	12.090	11.966	11.966	12.008	12.018	11.919	11.937	11.959	11.975	11.982	11.975	11.978	11.939	12.014	11.956	11.970
Al	4.166	4.040	4.057	4.038	4.044	4.019	4.105	4.081	4.068	4.060	4.030	4.030	4.039	4.058	3.979	4.046	4.027
Ti	.004	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
T	16.056	16.130	16.023	16.004	16.052	16.037	16.024	16.018	16.027	16.035	16.012	16.005	16.017	15.997	15.993	16.002	15.997
Fe^{2+}	.012	--	.006	.012	.005	.021	.010	.003	.011	.003	.003	.007	.004	.028	.011	.027	.022
Ca	.061	.040	.002	.005	.016	.040	.002	.006	.016	.009	.037	.004	.017	.047	.018	.029	.031
Na	.430	.555	.343	.293	.399	.636	.230	.372	.414	.272	.673	.273	.407	.584	.456	.951	.005
Ba	--	.046	.048	.050	.048	.044	.066	.069	.059	.061	.055	.049	.055	.060	.060	.042	.054
M	3.871	3.435	3.913	3.954	3.765	3.765	3.930	3.932	3.875	3.846	3.887	3.947	3.894	3.933	3.917	3.943	3.931
K	3.368	2.794	3.514	3.594	3.297	3.024	3.622	3.482	3.375	3.501	3.119	3.614	3.411	3.214	3.372	2.894	3.159
Molecular percent																	
An	1.58	1.16	.05	.13	.43	1.07	.05	.15	.41	.23	.95	.10	.44	1.20	.46	.74	.79
Ab	11.14	16.16	8.78	7.43	10.61	16.99	5.87	9.47	10.71	7.08	17.33	6.93	10.46	14.96	11.67	24.29	17.01
Or	87.28	81.34	89.94	91.17	87.69	80.77	92.40	88.62	87.34	91.10	80.30	91.73	87.69	82.30	86.33	73.90	80.81
Cn	--	1.34	1.23	1.27	1.28	1.18	1.68	1.76	1.53	1.59	1.42	1.24	1.41	1.54	1.54	1.07	1.38

TABLE B-7.—*Electron microprobe analyses (weight percent) of potassic feldspar from monzonites of the Lahore pluton: cations calculated on the basis of 32 oxygens*—Continued

A. Pyroxene monzonite—continued

Specimen number	<------					P-78-53						------>
Analysis number	PFELD-72	PFELD-73	PFELD-74	PFELD-75	PFELD-76	PFELD-77	PFELD-78	PFELD-79	PFELD-80	PFELD-81	PFELD-82	PFELD-83
Analysis type	grain	grain	grain	Av.18-20	grain	grain	grain	Av.22-24	grain	grain	grain	Av.26-28
Table number	18	19	20	21	22	23	24	25	26	27	28	29
Oxides												
SiO_2	64.94	64.79	64.97	64.90	64.72	64.66	64.83	64.74	64.63	64.66	64.65	64.65
Al_2O_3	18.59	18.51	18.47	18.52	19.19	18.46	19.10	18.91	19.12	19.06	18.88	19.02
FeO	.10	.14	--	.08	.02	.07	.06	.05	.02	.47	.10	.20
CaO	--	--	.06	.01	.07	.05	.02	.05	.07	.10	.02	.06
Na_2O	.99	.80	1.93	1.24	1.00	.61	.46	.69	1.00	1.22	.82	1.01
K_2O	14.79	15.07	13.63	14.50	14.70	14.80	15.47	14.99	14.93	14.48	15.07	14.83
TiO_2	--	--	--	--	--	--	--	--	--	--	--	--
BaO	.92	.78	.85	.85	1.06	1.14	.80	1.00	.80	.89	1.21	.97
SUM	100.33	100.09	99.91	100.10	100.76	99.79	100.74	100.43	100.57	100.88	100.75	100.74
Cations												
Si	11.972	11.976	11.979	11.977	11.888	11.992	11.914	11.932	11.888	11.872	11.913	11.892
Al	4.039	4.032	4.013	4.028	4.154	4.035	4.137	4.108	4.145	4.124	4.100	4.123
T	16.011	16.008	15.992	16.005	16.042	16.027	16.051	16.040	16.033	15.996	16.013	16.015
Fe^{2+}	.015	.022	--	.012	.004	.010	.010	.008	.004	.073	.015	.030
Ca	--	--	.012	.003	.014	.010	.003	.009	.013	.020	.003	.012
Na	.354	.287	.692	.445	.355	.220	.165	.247	.358	.433	.294	.362
K	3.478	3.554	3.206	3.413	3.443	3.501	3.626	3.523	3.504	3.392	3.541	3.479
Ba	.067	.057	.062	.062	.076	.083	.057	.072	.058	.064	.088	.070
M	3.914	3.920	3.972	3.935	3.892	3.824	3.861	3.859	3.937	3.982	3.941	3.953
Catsum	19.925	19.928	19.964	19.940	19.934	19.851	19.912	19.899	19.970	19.978	19.954	19.968
						Molecular percent						
An	--	--	.30	.08	.36	.26	.08	.23	.33	.51	.08	.31
Ab	9.08	7.36	17.42	11.34	9.13	5.77	4.28	6.41	9.10	11.08	7.49	9.23
Or	89.20	91.18	80.72	87.00	88.55	91.79	94.16	94.48	89.09	86.77	90.19	88.68
Cn	1.72	1.46	1.56	1.58	1.95	2.18	1.48	1.87	1.47	1.64	2.24	1.78

TABLE B-7.—*Electron microprobe analyses (weight percent) of potassic feldspar from monzonites of the Lahore pluton: cations calculated on the basis of 32 oxygens*—Continued

B. Amphihole monzonite

Specimen number	<---P-81-15--->											
Analysis number	PFELD-98	PFELD-99	PFELD-100	PFELD2-1	PFELD2-2	PFELD2-3	PFELD2-4	PFELD2-5	PFELD2-6	PFELD2-7	PFELD2-8	PFELD2-9
Analysis type	grain	grain	grain	Av.1-3	grain	grain	grain	Av.5-7	grain	grain	grain	Av.9-11
Table number	1	2	3	4	5	6	7	8	9	10	11	12
Oxides												
SiO_2	65.16	64.54	65.08	64.92	65.62	65.03	65.89	65.51	65.18	65.34	65.07	65.19
Al_2O_3	18.28	18.33	18.35	18.31	18.47	18.09	18.50	18.34	18.94	18.61	18.38	18.63
FeO	.01	.02	--	.01	.02	.05	.01	.03	.03	.03	.10	.05
CaO	.01	.01	.02	.01	.17	.03	.22	.14	.05	--	.03	.03
Na_2O	.79	.72	.64	.72	1.48	.79	3.00	1.76	.46	.29	.38	.38
K_2O	14.77	15.04	15.15	14.98	13.50	14.98	11.77	13.42	15.13	14.68	15.37	15.06
BaO	.78	.67	.58	.67	.36	.51	.31	.39	.43	.83	.53	.59
SUM	99.80	99.33	99.82	99.62	99.62	99.48	99.70	99.59	100.22	99.78	99.86	99.93
Cations												
Si	12.042	12.003	12.029	12.026	12.049	12.054	12.030	12.045	11.974	12.047	12.027	12.017
Al	3.983	4.017	3.997	3.998	3.996	3.952	3.980	3.975	4.100	4.043	4.004	4.048
T	16.025	16.020	16.026	16.024	16.045	16.006	16.010	16.020	16.074	16.090	16.031	16.065
Fe^{2+}	.001	.004	--	.001	.004	.007	.002	.004	.005	.004	.016	.008
Ca	.003	.002	.004	.003	.034	.006	.043	.028	.010	--	.006	.005
Na	.283	.260	.229	.258	.526	.285	1.063	.629	.164	.104	.135	.136
K	3.481	3.568	3.573	3.541	3.163	3.543	2.741	3.147	3.545	3.452	3.625	3.541
Ba	.057	.048	.042	.049	.026	.037	.022	.028	.031	.060	.038	.043
M	3.825	3.882	3.848	3.852	3.753	3.878	3.871	3.836	3.755	3.620	3.820	3.733
Catsum	19.850	19.902	19.874	19.876	19.798	19.884	19.881	19.856	19.829	19.710	19.851	19.798
						Molecular percent						
An	.08	.05	.10	.08	.91	.15	1.11	.73	.27	--	.16	.13
Ab	7.40	6.70	5.95	6.70	14.03	7.36	27.47	16.41	4.37	2.88	3.55	3.65
Or	91.03	92.01	92.85	91.95	84.37	91.53	70.85	82.12	94.53	95.46	95.29	95.06
Cn	1.49	1.24	1.09	1.27	.69	.96	.57	.73	.83	1.66	1.00	1.15

TABLE B-7.—*Electron microprobe analyses (weight percent) of potassic feldspar from monzonites of the Lahore pluton: cations calculated on the basis of 32 oxygens*—Continued

B. Amphihole monzonite—continued

Specimen number	<-----	-----	-----	-----	-----	P-80-70	-----	-----	-----	-----	-----	----->
Analysis number	PFELD-86	PFELD-87	PFELD-88	PFELD-89	PFELD-90	PFELD-91	PFELD-92	PFELD-93	PFELD-94	PFELD-95	PFELD-96	PFELD-97
Analysis type	grain	grain	grain	Av.13-15	grain	grain	grain	Av.17-19	grain	grain	grain	Av.21-23
Table number	13	14	15	16	17	18	19	20	21	22	23	24
Oxides												
SiO_2	65.49	65.37	65.19	65.35	64.70	65.69	65.79	65.39	65.12	64.37	64.85	64.78
Al_2O_3	18.88	18.68	18.62	18.72	18.65	18.76	18.71	18.70	18.99	19.28	19.14	19.13
FeO	.03	.00	.05	.02	--	.09	.03	.04	.07	--	.10	.05
CaO	--	.02	.06	.02	.07	.02	.02	.04	--	--	.03	.01
Na_2O	.45	.62	.54	.54	.84	.54	.54	.65	.43	.65	.63	.57
K_2O	15.09	15.04	14.98	15.04	15.12	14.92	14.25	14.76	15.13	14.79	14.62	14.84
BaO	.69	.82	.91	.80	.82	.68	.79	.76	.82	1.27	.82	.97
SUM	100.63	100.55	100.35	100.49	100.20	100.70	100.13	100.34	100.56	100.36	100.19	100.35
Cations												
Si	11.996	12.002	12.000	12.000	11.951	12.015	12.056	12.008	11.958	11.880	11.932	11.924
Al	4.075	4.042	4.039	4.051	4.061	4.045	4.040	4.047	4.111	4.195	4.151	4.151
T	16.071	16.044	16.039	16.051	16.012	16.060	16.096	16.055	16.069	16.075	16.083	16.075
Fe^{2+}	.005	--	.007	.003	.001	.014	.005	.006	.010	--	.015	.008
Ca	--	.004	.012	.005	.014	.003	.004	.007	--	--	.007	.002
Na	.159	.219	.194	.192	.302	.193	.193	.230	.153	.231	.226	.205
K	3.527	3.521	3.518	3.522	3.563	3.481	3.331	3.458	3.544	3.481	3.432	3.486
Ba	.049	.059	.066	.058	.060	.049	.057	.055	.059	.092	.059	.070
M	3.740	3.803	3.797	3.780	3.940	3.740	3.590	3.756	3.766	3.804	3.739	3.771
Catsum	19.811	19.847	19.836	19.831	19.952	19.800	19.686	19.811	19.835	19.879	19.822	19.846
						Molecular percent						
An	--	.11	.32	.13	.36	.08	.11	.19	--	--	.19	.05
Ab	4.26	5.76	5.12	5.08	7.67	5.18	5.38	6.13	4.07	6.07	6.07	5.45
Or	94.43	92.58	92.82	93.25	90.45	93.42	92.91	92.21	94.36	91.51	92.16	92.64
Cn	1.31	1.55	1.74	1.54	1.52	1.32	1.59	1.47	1.57	2.42	1.58	1.86

TABLE B-8.—*Electron microprobe analysis (weight percent) of biotite from monzonites of the Lahore pluton: cations calculated on the basis of 11 oxygens and that all of the Fe is present as FeO*[1]

A. Pyroxene monzonites

Specimen number	<----------------	----------------	P-81-10	--------------->	<-----P-78-53	---->
Analysis number	PAMPH 20e	PAMPH 20f	PAMPH 20g	PAMPH 20h	P1113-71	P1113-72
Analysis type	grain	grain	grain	Av 1-3	grain	grain
Table number	1	2	3	4	5	6
Oxides						
SiO_2	37.39	36.33	37.44	37.05	36.14	36.80
Al_2O_3	14.32	15.09	14.29	14.57	14.13	14.05
FeO	17.90	17.83	18.78	18.17	18.89	19.40
MgO	13.43	13.21	12.33	13.00	12.76	12.45
CaO	.03	.01	--	.01	.05	.05
Na_2O	.02	.03	.04	.03	.05	.04
K_2O	9.36	8.93	9.16	9.15	9.99	9.91
TiO_2	2.47	2.31	2.99	2.59	3.41	3.31
MnO	.19	.16	.18	.18	.22	.19
Sum	95.11	93.90	95.21	94.75	95.64	96.20
H_2O	3.95	3.91	3.95	3.93	3.92	3.95
Sum	99.06	97.81	99.16	98.68	99.56	100.15
Cations						
Si	2.837	2.789	2.845	2.823	2.763	2.796
Al^{iv}	1.163	1.211	1.155	1.177	1.237	1.204
T	4.000	4.000	4.000	4.000	4.000	4.000
Al^{vi}	.118	.155	.125	.132	.037	.054
Fe^{2+}	1.136	1.145	1.193	1.158	1.208	1.233
Mg	1.159	1.511	1.396	1.476	1.454	1.410
Ti	.141	.133	.171	.148	.196	.189
Mn	.012	.010	.012	.012	.014	.012
M	2.925	2.954	2.897	2.926	2.909	2.898
Ca	.002	.001	--	.001	.004	.004
Na	.003	.004	.006	.004	.007	.006
K	.906	.875	.888	.890	.974	.961
A	.911	.880	.894	.895	.986	.971
Catsum	7.836	7.834	7.791	7.821	7.895	7.869
Oh calc	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.428	.431	.461	.440	.454	.467
Mg:Mg+Fe	.572	.569	.539	.560	.546	.533

TABLE B-8.—*Electron microprobe analysis (weight percent) of biotite from monzonites of the Lahore pluton: cations calculated on the basis of 11 oxygens and that all of the Fe is present as FeO*[1]—Continued

B. Amphibole monzonites

Specimen number	<------------P-80-67------------>								<----P-80-70---->	
Analysis number	PAMPH 79	PAMPH 80	PAMPH 81	PAMPH 82	PAMPH 83	PAMPH 84	PAMPH 85	PAMPH 86	P1111-28	P1111-29
Analysis type	grain	grain	grain	Aver1-3	grain	grain	grain	Aver5-7	grain	grain
Table number	1	2	3	4	5	6	7	8A	9	10
Oxides										
SiO_2	37.19	37.35	37.15	37.23	37.28	37.12	37.27	37.22	39.26	37.92
Al_2O_3	14.17	14.16	14.13	14.15	14.08	14.28	14.20	14.19	14.71	14.83
FeO	16.94	17.07	17.13	17.04	17.16	16.60	16.42	16.73	14.60	14.64
MgO	14.23	14.37	13.97	14.19	14.04	14.70	14.70	14.48	15.87	16.12
CaO	.01	.01	.02	.01	.01	.03	.04	.03	.07	.04
Na_2O	.03	.04	.02	.03	.05	.02	.02	.03	.05	.05
K_2O	9.50	9.34	9.68	9.51	9.45	9.54	9.80	9.60	9.19	10.00
TiO_2	1.75	1.63	1.84	1.74	1.89	1.65	1.38	1.64	1.49	1.69
MnO	.21	.24	.30	.25	.26	.22	.21	.23	.19	.18
Sum	94.03	94.21	94.24	94.15	94.22	94.16	94.04	94.15	95.43	95.47
H_2O	3.92	3.93	3.92	3.92	3.92	3.93	3.92	3.92	4.06	4.02
Sum	97.95	98.14	98.16	98.07	98.14	98.09	97.96	98.07	99.49	99.49
Cations										
Si	2.846	2.851	2.844	2.848	2.850	2.834	2.850	2.844	2.903	2.828
Al^{iv}	1.154	1.149	1.156	1.152	1.150	1.166	1.150	1.156	1.097	1.172
T	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Al^{vi}	.125	.126	.120	.124	.119	.119	.130	.122	.185	.132
Fe^{2+}	1.084	1.090	1.097	1.090	1.097	1.060	1.050	1.069	.903	.913
Mg	1.623	1.635	1.594	1.618	1.600	1.672	1.675	1.649	1.749	1.792
Ti	.101	.094	.106	.100	.109	.095	.079	.094	.083	.095
Mn	.014	.016	.019	.016	.017	.014	.014	.015	.012	.011
M	2.947	2.959	2.936	2.947	2.941	2.960	2.948	2.950	2.931	2.943
Ca	.001	.001	.002	.001	.001	.002	.003	.002	.006	.003
Na	.004	.006	.003	.004	.007	.003	.003	.004	.007	.007
K	.928	.910	.946	.928	.922	.929	.956	.936	.867	.951
A	.933	.916	.950	.933	.930	.935	.962	.943	.880	.962
Catsum	7.880	7.876	7.886	7.881	7.871	7.895	7.910	7.893	7.810	7.905
OH calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.400	.400	.408	.403	.407	.388	.385	.393	.340	.338
Mg:Mg+Fe	.600	.600	.592	.597	.593	.612	.615	.607	.660	.662

[1] Cation site occupancies and calculated by computer program of Flohr (1983).

TABLE B-9.—*Electron microprobe analyses (weight percent) of epidote from monzonites of the Lahore pluton: cations calculated on the basis of 12.5 anions*[1]

	Pyroxene monzonite		Amphibole monzonite
Specimen number	<-----P-81-10----->		P-80-70
Probe number	PAMPH 8A	PAMPH 8B	P1111-38
Analysis type	grain	grain	grain
Table number	1	2	3
Oxides			
SiO_2	36.76	37.39	38.33
TiO_2	.12	.57	.06
Al_2O_3	25.07	24.28	22.61
[2]Fe_2O_3	12.93	12.87	13.74
MnO	.29	.02	.06
MgO	.16	.19	.13
CaO	22.85	23.29	22.93
K_2O	.01	--	.01
Sum	98.19	98.61	97.87
Cations			
Si	2.915	2.951	3.050
Ti	.007	.034	.004
Al	2.344	2.260	2.121
Fe	.772	.764	.823
Mn	.019	.001	.004
Mg	.019	.022	.015
Ca	1.942	1.970	1.955
K	.001	--	.001
Catsum	8.020	8.003	7.974
[3]Ps	25.	25.	28.

[1] Cation site occupancies calculated by unpublished computer program of Flohr (personal commun., 1987)
[2] Calculated from FeO
[3] Ps (pistacite) calculated as (Fe/Fe + Al) x 100

TABLE B-10.—*Electron microprobe analyses (weight percent) of amphibole from amphibole monzonites of the Lahore pluton: cations calculated on the basis of 23 oxygens and that all Fe is FeO*[1]

Specimen number	<------------	------------	------------	P-80-76	------------	------------	------------>	<------------	------------	------------	P-78-52	------------	------------
Analysis number	DAMPH 65	DAMPH 66	DAMPH 67	DAMPH 68	DAMPH 69	DAMPH 70	Damph 70A	DAMPH 76	DAMPH 77	DAMPH 78	DAMPH 79	DAMPH 82	DAMPH 83
Analysis type[2]	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	Av 8-10	grain	grain
Table number	1	2	3	4	5	6	7	8	9	10	11A	12	13
[3]				<------------	------------	------------>		<------------	------------	------------	------------>		<-------
Oxides													
SiO_2	45.84	42.65	47.45	42.89	43.70	43.41	43.33	43.25	43.37	43.49	43.47	43.63	43.80
Al_2O_3	9.70	11.61	7.77	12.19	10.92	11.21	11.44	9.65	9.87	9.70	9.74	9.86	9.94
FeO	13.92	15.21	13.37	15.60	15.44	15.43	15.49	15.29	16.44	16.11	15.95	15.22	15.09
MgO	12.89	11.63	14.23	11.05	11.83	11.66	11.51	12.49	11.69	12.11	12.10	12.74	12.18
CaO	11.69	11.60	11.72	11.70	11.65	11.68	11.68	11.84	11.63	11.71	11.73	12.12	11.65
Na_2O	1.28	1.40	.97	1.50	1.40	1.46	1.45	1.75	1.74	1.70	1.73	1.73	1.69
K_2O	.38	.59	.29	.53	.58	.57	.56	1.19	1.17	1.15	1.17	1.17	1.19
TiO_2	.66	.82	.50	.62	.89	1.05	.85	1.41	1.07	.98	1.15	1.31	1.43
MnO	.16	.19	.16	.13	.17	.16	.15	.20	.26	.18	.21	.22	.21
Sum	96.52	95.70	96.46	96.21	96.58	96.63	96.46	97.07	97.24	97.13	97.15	98.00	97.18
H_2O calc	2.02	1.97	2.03	1.98	1.99	1.99	1.99	1.99	1.98	1.98	1.98	2.01	2.00
Sum	98.54	97.67	98.49	98.19	98.57	98.62	98.45	99.06	99.22	99.11	99.13	100.01	99.18
CATIONS													
Si	6.810	6.477	7.014	6.480	6.572	6.528	6.527	6.527	6.559	6.572	6.552	6.517	6.577
Al^{iv}	1.190	1.523	.986	1.520	1.428	1.472	1.473	1.473	1.441	1.428	1.448	1.483	1.423
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	.509	.556	.368	.652	.508	.516	.559	.244	.318	.300	.287	.253	.337
Fe^{2+}	1.564	1.718	1.442	1.790	1.741	1.752	1.761	1.786	1.925	1.862	1.858	1.763	1.775
Mg	2.854	2.632	3.135	2.488	2.651	2.613	2.584	2.809	2.635	2.727	2.724	2.836	2.726
Ti	.074	.094	.056	.070	.101	.119	.096	.160	.122	.111	.131	.147	.162
M1-M3	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Mn	.020	.024	.020	.017	.022	.020	.019	.026	.033	.023	.027	.028	.027
Fe^{2+}	.166	.214	.211	.182	.201	.189	.191	.143	.154	.174	.158	.138	.120
Ca	1.814	1.761	1.769	1.802	1.777	1.791	1.790	1.831	1.813	1.803	1.816	1.834	1.853
M4	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.369	.412	.278	.439	.408	.426	.424	.512	.510	.498	.507	.501	.492
K	.072	.114	.055	.102	.111	.109	.108	.229	.226	.222	.226	.223	.228
Ca	.047	.126	.087	.093	.100	.091	.095	.084	.072	.093	.083	.106	.021
A	.487	.653	.420	.634	.620	.627	.626	.825	.808	.813	.816	.830	.741
Catsum	15.487	15.653	15.420	15.634	15.620	15.627	15.626	15.825	15.808	15.813	15.816	15.830	15.741
OH calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.377	.423	.345	.442	.423	.426	.430	.407	.441	.427	.425	.401	.410
Mg:Mg+Fe	.623	.577	.655	.558	.577	.574	.570	.593	.559	.573	.575	.599	.590

TABLE B-10.—*Electron microprobe analyses (weight percent) of amphibole from amphibole monzonites of the Lahore pluton: cations calculated on the basis of 23 oxygens and that all Fe is FeO*[1]—Continued

Specimen number	---P-78-52---		--->	P-81-12	<---				P-80-70				--->
Analysis number	DAMPH 84	DAMPH 85	DAMPH 80A	DAMPH 71	P1111-25	P1111-27	P1111-15	P1111-16	P1111-17	P1111-18	P1111-19	P1111-23	P1111-25A
Analysis type[2]	grain	Av 13-14	grain	grain	grain	grain	grain	grain	grain	Av 20-22	grain	grain	grain
Table number[3]	14	15A	16	17	18	19	20	21	22	23A	24	25	26
	--------->		<--->	<--->	<--->	<--->	<---		--->		<--->	<--->	<--->
Oxides													
SiO_2	43.65	43.69	42.75	42.93	44.52	44.38	45.23	45.48	47.40	46.04	46.54	46.76	45.19
Al_2O_3	10.05	9.95	9.94	10.48	9.17	9.27	9.45	9.34	9.24	9.34	9.55	9.42	9.53
FeO	15.67	15.33	15.32	18.53	13.55	14.15	13.95	14.11	14.23	14.10	13.48	13.98	13.65
MgO	12.20	12.38	12.82	10.15	13.47	12.78	13.50	13.54	13.28	13.44	13.73	13.50	13.24
CaO	11.70	11.82	11.64	11.42	11.71	11.78	11.42	11.73	11.51	11.55	11.68	11.67	11.61
Na_2O	1.86	1.76	1.70	1.55	1.90	1.81	1.82	1.86	1.67	1.78	1.89	1.86	1.83
K_2O	1.29	1.22	1.17	1.25	1.35	1.37	1.31	1.36	1.17	1.28	1.26	1.27	1.32
TiO_2	1.49	1.41	1.34	.60	1.46	1.18	1.44	1.38	.91	1.25	1.39	1.33	1.39
MnO	.19	.21	.21	.37	.20	.19	.20	.19	.21	.20	.24	.22	.21
Sum	98.10	97.77	96.89	97.28	97.33	96.91	98.32	98.99	99.62	98.98	99.76	100.01	97.97
H_2O calc	2.01	2.00	1.98	1.97	2.01	2.00	2.04	2.05	2.07	2.05	2.07	2.08	2.03
Sum	100.11	99.77	98.87	99.25	99.34	98.91	100.36	101.04	101.69	101.03	101.8	102.09	100.00
CATIONS													
Si	6.522	6.538	6.466	6.549	6.637	6.662	6.663	6.666	6.853	6.728	6.726	6.752	6.675
Al^{iv}	1.478	1.462	1.534	1.451	1.363	1.338	1.337	1.334	1.147	1.272	1.274	1.248	1.325
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	.293	.293	.239	.434	.249	.302	.304	.279	.428	.337	.353	.355	.335
Fe^{2+}	1.823	1.787	1.719	2.190	1.595	1.705	1.572	1.611	1.611	1.598	1.539	1.596	1.596
Mg	2.717	2.761	2.890	2.308	2.993	2.859	2.964	2.957	2.862	2.927	2.957	2.905	2.915
Ti	.167	.159	.152	.069	.164	.133	.160	.152	.099	.137	.151	.144	.154
M1-M3	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Mn	.024	.027	.027	.048	.025	.024	.025	.024	.026	.025	.029	.027	--
Fe^{2+}	.135	.132	.219	.174	.095	.071	.146	.118	.109	.125	.090	.093	.090
Ca	1.841	1.842	1.754	1.778	1.871	1.895	1.803	1.842	1.783	1.809	1.809	1.805	1.838
Na	--	--	--	--	.010	.010	.026	.016	.082	.042	.071	.075	.046
M4	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.539	.511	.499	.458	.540	.517	.494	.513	.386	.463	.458	.446	.478
K	.246	.233	.226	.243	.257	.262	.246	.254	.216	.239	.232	.234	.249
Ca	.033	.054	.133	.089	--	--	--	--	--	--	--	--	--
A	.817	.797	.857	.791	.796	.779	.740	.767	.602	.701	.690	.680	.727
Catsum	15.817	15.797	15.857	15.791	15.796	15.779	15.740	15.767	15.602	15.701	15.690	15.680	15.727
OH calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.419	.410	.401	.506	.361	.383	.367	.369	.376	.371	.355	.368	.367
Mg:Mg+Fe	.581	.590	.599	.494	.639	.617	.633	.631	.624	.629	.645	.632	.633

TABLE B-10.—*Electron microprobe analyses (weight percent) of amphibole from amphibole monzonites of the Lahore pluton: cations calculated on the basis of 23 oxygens and that all Fe is FeO*[1]—Continued

Specimen number	<--					P-81-15					-->
Analysis number	D1111-97	D1111-98	D1111-99	D1111-100	P1111-1	P1111-2	P1111-3	P1111-4	P1111-5	P1111-6	P1111-7	P1111-8
Analysis type[2]	grain	grain	grain	Av 27-29	grain	grain	grain	grain	grain	grain	Av 34-36	grain
Table number[2]	27	28	29	30A	31	32	33	34	35	36	37A	38
	<----------			---------->	<----------		---------->	<----------			---------->	<----->
Oxides												
SiO_2	45.13	45.11	46.67	45.89	45.87	45.88	45.91	45.23	45.41	46.26	45.63	45.52
Al_2O_3	9.08	9.71	9.05	9.38	9.39	9.45	9.40	7.74	9.52	9.23	8.83	13.23
FeO	14.86	14.83	14.23	14.53	14.14	14.15	14.04	13.28	14.85	14.68	14.27	11.72
MgO	12.35	12.53	13.34	12.94	12.90	12.99	13.01	14.40	12.94	12.92	13.43	8.79
CaO	11.34	11.36	12.01	11.69	11.42	11.31	11.37	11.63	11.08	11.53	11.41	16.22
Na_2O	1.82	1.73	1.76	1.74	1.83	2.00	1.90	1.46	1.96	1.87	1.77	.53
K_2O	1.32	1.41	1.14	1.27	1.40	1.29	1.35	1.03	1.35	1.37	1.25	.32
TiO_2	1.67	1.49	.87	1.18	1.51	1.68	1.59	.44	1.74	1.35	1.18	.09
MnO	.25	.26	.24	.25	.21	.24	.23	.21	.25	.25	.24	.20
Sum	97.82	98.43	99.31	98.87	98.67	98.99	98.80	95.42	99.10	99.46	98.01	96.62
H_2O calc	2.02	2.03	2.06	2.04	2.04	2.05	2.05	1.98	2.04	2.06	2.03	2.03
Sum	99.84	100.46	101.37	100.91	100.71	101.04	100.85	97.40	101.14	101.52	100.04	98.65
Cations												
Si	6.713	6.665	6.796	6.731	6.731	6.710	6.724	6.840	6.660	6.749	6.747	6.722
Al^{iv}	1.287	1.335	1.204	1.269	1.269	1.291	1.276	1.160	1.340	1.251	1.253	1.278
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	.305	.356	.350	.353	.355	.339	.347	.220	.306	.336	.287	1.026
Fe^{2+}	1.771	1.720	1.660	1.689	1.658	1.645	1.639	1.485	1.674	1.707	1.623	1.448
Mg	2.738	2.759	2.895	2.829	2.821	2.831	2.840	3.245	2.828	2.809	2.960	1.935
Ti	.187	.166	.095	.130	.167	.185	.175	.050	.192	.148	.131	.010
M1-M3	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	4.443
Mn	.031	.033	.030	.031	.026	.030	.029	.027	.031	.031	.030	--
Fe	.078	.113	.074	.094	.078	.085	.081	.195	.148	.084	.142	--
Ca	1.807	1.798	1.874	1.837	1.795	1.772	1.784	1.778	1.741	1.802	1.808	2.000
Na	.083	.056	.023	.038	.101	.113	.106	--	.080	.082	.020	--
M4	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.442	.439	.474	.457	.420	.454	.433	.428	.477	.446	.488	.152
K	.250	.266	.212	.238	.262	.241	.252	.199	.253	.255	.236	.060
Ca	--	--	--	--	--	--	--	.107	--	--	--	.567
A	.692	.705	.686	.694	.682	.695	.686	.733	.730	.701	.723	.779
Catsum	15.692	15.705	15.686	15.694	15.682	15.695	15.686	15.733	15.730	15.702	15.723	15.222
OH calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.403	.399	.374	.387	.381	.379	.377	.341	.392	.389	.374	.428
Mg:Mg+Fe	.597	.601	.626	.613	.619	.621	.623	.659	.608	.611	.626	.572

TABLE B-10.—*Electron microprobe analyses (weight percent) of amphibole from amphibole monzonites of the Lahore pluton: cations calculated on the basis of 23 oxygens and that all Fe is FeO*[1]—Continued

Specimen number	<-------------------					P-81-15					------------------->
Analysis number	P1113-93	P1113-94	P1113-95	P1113-96	P1113-97	P1113-98	P1113-99	P1113-100	P1114-1	P1114-2	P1114-3
Analysis type[2]	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	Av 39-48
Table number [2]	39	40	41	42	43	44	45	46	47	48	49A
Oxides											
SiO_2	43.74	42.45	43.86	43.68	43.52	43.34	43.60	43.10	44.01	44.21	43.55
Al_2O_3	9.55	9.75	9.41	9.55	9.59	9.56	9.64	9.71	9.62	9.83	9.62
FeO	14.30	14.25	14.31	14.20	15.17	14.40	13.88	14.94	14.35	13.85	14.37
MgO	12.71	13.87	12.77	12.81	12.32	12.68	13.00	12.27	12.78	13.14	12.82
CaO	11.44	11.25	11.64	11.52	11.61	11.69	11.39	11.25	11.17	11.77	11.47
Na_2O	1.92	2.10	1.81	1.89	1.76	1.88	1.93	1.94	1.88	1.84	1.90
K_2O	1.41	1.34	1.33	1.28	1.37	1.50	1.28	1.31	1.32	1.24	1.34
TiO_2	1.47	1.52	1.49	1.28	1.31	1.75	1.62	1.65	1.57	1.64	1.53
MnO	.18	.21	.16	.18	.18	.19	.20	.21	.20	.19	.19
Sum	96.72	96.54	96.78	96.39	96.83	96.99	96.54	96.38	96.90	97.71	96.79
H_2O calc	1.99	1.98	1.99	1.99	1.98	1.99	1.99	1.98	2.00	2.02	1.99
Sum	98.71	98.52	98.77	98.38	98.81	98.98	98.53	98.36	98.90	99.73	98.78
Cations											
Si	6.590	6.430	6.601	6.597	6.577	6.531	6.566	6.540	6.605	6.569	6.560
Al^{iv}	1.410	1.570	1.399	1.403	1.423	1.469	1.434	1.460	1.395	1.431	1.440
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	.287	.171	.271	.298	.286	.230	.277	.277	.308	.291	.269
Fe^{2+}	1.693	1.570	1.696	1.674	1.791	1.724	1.621	1.760	1.657	1.615	1.680
Mg	2.854	3.086	2.864	2.883	2.775	2.848	2.918	2.775	2.859	2.910	2.878
Ti	.167	.173	.169	.145	.149	.198	.183	.188	.177	.183	.173
M1-M3	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Mn	.023	.027	.020	.023	.023	.024	.026	.027	.025	.024	.024
Fe^{2+}	.109	.235	.106	.120	.127	.091	.127	.135	.145	.106	.130
Ca	1.847	1.738	1.874	1.857	1.850	1.885	1.838	1.829	1.796	1.870	1.845
Na	.021	--	--	--	--	--	.010	.009	.034	--	--
M4	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.540	.617	.528	.553	.516	.549	.554	.562	.514	.530	.555
K	.271	.259	.255	.247	.264	.288	.246	.254	.253	.235	.258
Ca	--	.088	.003	.007	.030	.002	--	--	--	.004	.006
A	.811	.964	.787	.807	.810	.840	.800	.816	.766	.769	.818
Catsum	15.811	15.964	15.787	15.807	15.810	15.840	15.800	15.816	15.766	15.769	15.818
OH calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.387	.369	.386	.384	.409	.389	.375	.406	.387	.372	.386
Mg:Mg+Fe	.613	.631	.614	.617	.591	.611	.625	.594	.613	.628	.614

TABLE B-10.—*Electron microprobe analyses (weight percent) of amphibole from amphibole monzonites of the Lahore pluton: cations calculated on the basis of 23 oxygens and that all Fe is FeO*[1]—Continued

Specimen number	<-----------	-----------	-----------	-----------	-----------	-----------	P-80-70	-----------	-----------	-----------	-----------	----------->
Analysis number	P1113-28	P1113-29	P1113-30	P1113-31	P1113-32	P1113-37	P1113-38	P1113-39	P1113-40	P1113-41	P1113-42	P1113-43
Analysis type[3]	edge	center	edge	Av 50-52	grain	[5]	[5]	[5]	[5]	[5]	[5]	[5]
Table number	50	51	52	53A	54	55	56	57	58	59	60	61
[2]	<-----------	-----------	-----------	----------->		<-----------	-----------	-----------	-----------	-----------	-----------	----------->
Oxides												
SiO_2	43.99	43.89	43.94	43.94	43.07	45.01	44.25	44.56	43.69	44.28	45.15	43.59
Al_2O_3	9.47	9.29	9.48	9.41	9.63	8.82	9.44	9.46	9.65	9.08	7.22	9.54
FeO	14.06	13.63	14.58	14.09	14.70	13.36	13.72	13.46	14.29	14.21	12.39	14.08
MgO	13.56	13.93	13.25	13.58	13.33	14.37	13.93	13.90	13.37	13.97	14.32	13.86
CaO	11.63	11.55	11.48	11.55	11.30	11.64	11.32	11.40	11.70	11.72	11.49	11.33
Na_2O	1.88	1.82	1.88	1.86	1.87	1.80	1.94	1.89	1.78	1.80	1.25	1.79
K_2O	1.27	1.19	1.27	1.24	1.32	1.17	1.25	1.24	1.26	1.19	.86	1.40
TiO_2	1.40	1.44	1.49	1.44	1.32	1.19	1.58	1.46	1.16	1.31	.57	1.34
MnO	.18	.20	.17	.18	.20	.17	.20	.21	.17	.19	.24	.23
Sum	97.44	96.94	97.54	97.29	96.74	97.53	97.63	97.58	97.07	97.75	93.49	97.16
H_2O calc	2.01	2.00	2.01	2.01	1.98	2.02	2.02	2.02	2.00	2.01	1.95	2.00
Sum	99.45	98.94	99.55	99.30	98.72	99.55	99.65	99.60	99.07	99.76	95.44	99.16
Cations												
Si	6.568	6.572	6.567	6.570	6.507	6.674	6.575	6.611	6.556	6.591	6.927	6.533
Al^{iv}	1.432	1.428	1.433	1.430	1.493	1.326	1.425	1.389	1.444	1.409	1.073	1.467
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	.235	.212	.237	.228	.222	.216	.229	.265	.263	.185	.233	.219
Fe^{2+}	1.591	1.517	1.645	1.584	1.627	1.475	1.509	1.499	1.616	1.570	1.426	1.534
Mg	3.017	3.109	2.951	3.026	3.001	3.176	3.085	3.073	2.990	3.099	3.274	3.096
Ti	.157	.162	.167	.162	.150	.133	.177	.163	.131	.147	.066	.151
M1-M3	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Mn	.023	.025	.022	.023	.026	.021	.025	.026	.022	.024	.031	.029
Fe^{2+}	.165	.190	.178	.178	.230	.182	.196	.171	.177	.199	.164	.230
Ca	1.812	1.785	1.801	1.799	1.744	1.797	1.779	1.802	1.801	1.777	1.805	1.740
M4	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.544	.528	.545	.539	.548	.518	.559	.544	.518	.520	.372	.520
K	.242	.227	.242	.237	.254	.221	.237	.235	.241	.226	.168	.268
Ca	.048	.068	.037	.051	.085	.052	.023	.010	.080	.093	.084	.079
A	.834	.824	.824	.827	.887	.791	.819	.788	.839	.838	.624	.867
Catsum	15.835	15.824	15.824	15.827	15.887	15.791	15.819	15.788	15.839	15.838	15.624	15.867
OH calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.368	.354	.382	.368	.382	.343	.356	.352	.375	.363	.327	.363
Mg:Mg+Fe	.632	.646	.618	.632	.618	.657	.644	.648	.625	.637	.673	.637

TABLE B-10.—*Electron microprobe analyses (weight percent) of amphibole from amphibole monzonites of the Lahore pluton: cations calculated on the basis of 23 oxygens and that all Fe is FeO[1]*—Continued

Specimen number	<-------	--------	--------	--------	P-80-70	--------	--------	--------	--------	------->
Analysis number	P1113-48	P1113-49	P1113-50	P1113-51	P1113-52	P1113-53	P1113-54	P1113-55	P1113-61	P1113-62
Analysis type[2]	3/	3/	3/	Av 62-64	3/	3/	3/	Av 66-68	edge	edge
Table number	62	63	64	65A	66	67	68	69A	70	71
3/	<-------	--------	--------	------->	<-------	--------	--------	------->	<-------	------->
Oxides										
SiO_2	43.76	43.48	42.67	43.30	43.19	43.27	43.48	43.31	44.05	43.33
Al_2O_3	9.24	9.42	9.56	9.41	9.21	9.17	9.51	9.29	9.33	9.11
FeO	14.27	14.57	15.16	14.67	14.25	14.14	14.56	14.32	14.54	14.28
MgO	13.62	13.02	12.48	13.04	13.54	13.38	13.45	13.46	13.60	13.49
CaO	11.34	11.42	11.38	11.38	11.59	11.30	11.24	11.38	11.61	11.29
Na_2O	1.91	1.78	1.71	1.80	1.82	1.93	1.76	1.83	1.83	2.01
K_2O	1.29	1.29	1.25	1.28	1.21	1.32	1.18	1.24	1.10	1.25
TiO_2	1.39	1.35	1.07	1.27	1.52	1.42	1.04	1.33	1.03	1.33
MnO	.20	.20	.25	.22	.18	.21	.21	.20	.22	.21
Sum	97.02	96.53	95.53	96.37	96.51	96.14	96.43	96.36	97.31	96.30
H_2O calc	2.00	1.98	1.96	1.98	1.98	1.98	1.98	1.98	2.00	1.98
Sum	99.02	98.51	97.49	98.35	98.49	98.12	98.41	98.34	99.31	98.28
Cations										
Si	6.571	6.571	6.543	6.561	6.529	6.562	6.569	6.553	6.593	6.563
Al^{iv}	1.429	1.429	1.457	1.439	1.471	1.438	1.431	1.447	1.407	1.437
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	.206	.249	.271	.242	.170	.202	.262	.210	.239	.190
Fe^{2+}	1.589	1.665	1.753	1.669	1.607	1.612	1.591	1.604	1.612	1.613
Mg	3.048	2.932	2.852	2.945	3.050	3.042	3.028	3.035	3.033	3.045
Ti	.157	.153	.123	.145	.173	.162	.118	.151	.116	.152
M1-M3	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Mn	.025	.026	.032	.028	.023	.027	.027	.026	.028	.027
Fe^{2+}	.203	.177	.191	.190	.194	.181	.248	.208	.208	.196
Ca	1.772	1.798	1.777	1.782	1.783	1.792	1.725	1.766	1.764	1.777
M4	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.556	.522	.508	.529	.533	.568	.516	.537	.531	.590
K	.247	.249	.245	.247	.233	.255	.227	.239	.210	.242
Ca	.053	.051	.093	.066	.095	.045	.095	.079	.098	.056
A	.856	.822	.846	.842	.861	.868	.838	.855	.839	.888
Catsum	15.856	15.822	15.846	15.842	15.861	15.868	15.838	15.855	15.839	15.888
OH calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.370	.386	.405	.387	.371	.372	.378	.374	.375	.373
Mg:Mg+Fe	.630	.614	.595	.613	.629	.628	.622	.626	.625	.627

TABLE B-10.—*Electron microprobe analyses (weight percent) of amphibole from amphibole monzonites of the Lahòre pluton: cations calculated on the basis of 23 oxygens and that all Fe is FeO*[1]—Continued

Specimen number	<------	------	------	------	------	P-81-12	------	------	------	------	------>
Analysis number	P1113-82	P1113-83	P1113-84	P1113-85	P1113-86	P1113-87	P1113-88	P1113-89	P1113-90	P1113-91	P1113-92
Analysis type[4]	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	Av 72-81
Table number	72	73	74	75	76	77	78	79	80	81	82A
[3]	<------	------	------	------	------	------	------	------	------	------	------>
Oxides											
SiO_2	44.05	42.69	41.20	41.19	42.65	41.50	41.31	41.31	42.71	42.54	42.12
Al_2O_3	9.70	10.50	11.15	11.28	10.32	11.05	11.34	11.14	10.56	10.48	10.75
FeO	17.41	17.97	18.58	18.79	17.71	18.52	19.73	18.43	17.29	18.39	18.28
MgO	10.95	10.57	9.48	9.56	10.47	9.57	8.90	10.03	10.66	10.17	10.04
CaO	11.78	11.71	11.38	11.53	11.48	11.50	11.48	11.42	11.63	11.69	11.56
Na_2O	1.59	1.66	1.68	1.73	1.66	1.71	1.66	1.75	1.62	1.52	1.66
K_2O	1.27	1.22	1.54	1.61	1.32	1.55	1.75	1.57	1.31	1.40	1.45
TiO_2	.61	.63	.71	.64	.75	.76	.69	.73	.69	.68	.69
MnO	.30	.31	.32	.35	.29	.30	.35	.28	.31	.31	.31
Sum	97.66	97.26	96.04	96.68	96.65	96.46	97.21	96.66	96.78	97.18	96.86
H_2O calc	1.99	1.97	1.93	1.94	1.96	1.94	1.94	1.94	1.96	1.96	1.94
Sum	99.65	99.23	97.97	98.62	98.61	98.40	99.15	98.60	98.74	99.14	98.81
Cations											
Si	6.653	6.508	6.406	6.375	6.536	6.421	6.385	6.379	6.522	6.509	6.470
Al^{iv}	1.347	1.492	1.594	1.625	1.464	1.579	1.615	1.621	1.478	1.491	1.530
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	.380	.395	.450	.433	.400	.436	.452	.407	.424	.399	.417
Fe^{2+}	2.085	2.131	2.271	2.287	2.122	2.269	2.518	2.200	2.071	2.204	2.204
Mg	2.465	2.401	2.197	2.205	2.391	2.207	2.050	2.308	2.426	2.319	2.299
Ti	.069	.072	.083	.074	.086	.088	.080	.085	.079	.078	.080
M1-M3	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Mn	.038	.040	.042	.046	.038	.039	.046	.037	.040	.040	.040
Fe^{2+}	.114	.160	.145	.145	.147	.128	.133	.180	.137	.149	.144
Ca	1.848	1.800	1.813	1.809	1.815	1.833	1.821	1.784	1.823	1.811	1.816
Na	--	--	--	--	--	--	--	--	--	--	--
M4	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.466	.491	.506	.519	.493	.513	.498	.524	.480	.451	.494
K	.245	.237	.305	.318	.258	.306	.345	.309	.255	.273	.284
Ca	.059	.112	.083	.103	.070	.074	.080	.106	.080	.106	.087
A	.769	.840	.895	.940	.821	.892	.923	.939	.815	.830	.866
Catsum	15.769	15.840	15.895	15.940	15.821	15.893	15.923	15.939	15.815	15.830	15.866
OH calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.472	.488	.524	.524	.487	.521	.554	.508	.476	.504	.505
Mg:Mg+Fe	.528	.512	.476	.476	.513	.479	.446	.492	.524	.496	.495

[1] Cation site occupancies calculated by computer program of Flohr (1983)
[2] Edge and center are points established visually probe analyses were made along cross-section of grain
[3] Brackets enclose analyses from single grains separated for $^{39}Ar/^{40}Ar$ studies
[4] Individual grains are from amphibole concentrate hand-picked from crushed and heavy liquid treated rock

APPENDIX C: ELECTRON MICROPROBE ANALYSES OF MINERALS FROM THE ELLISVILLE PLUTON

TABLE C-1.—*Electron microprobe analyses (weight percent) of plagioclase from granitoids of the Ellisville pluton: cations calculated on the basis of 32 oxygens*[1]

Specimen number	<--------P-80-8	--------	-------->	<--------P-80-20	--------	--------	-------->	<--------P-80-23	--------	--------	--------	-------->
Probe number	D507N-1	D507N-2	D1111-1	DIIII-30	DIIII-31	DIIII-32	DIIII-33	P1111-56	P1111-57	P1111-58	P1111-59	P1111-60
Analysis type	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	Av 8-11
Table number	1	2	3	4	5	6	7	8	9	10	11	12
Oxides												
SiO_2	60.56	60.50	59.81	61.55	61.11	60.78	61.16	62.92	60.32	60.59	63.33	61.49
Al_2O_3	24.45	24.27	23.77	25.63	25.00	24.71	25.12	25.38	25.43	24.89	23.64	24.67
FeO	--	--	--	--	.02	.06	.02	.13	.14	.07	.14	.13
MgO	--	--	--	--	--	.01	--	.01	.01	--	--	--
CaO	6.02	6.30	6.41	6.01	5.56	5.32	5.63	6.68	7.18	6.21	6.15	6.47
Na_2O	7.74	7.13	7.39	6.88	7.66	8.65	8.07	5.31	7.73	8.22	8.34	7.47
K_2O	.15	.15	.14	.10	.10	.11	.10	.18	.15	.08	.07	.13
TiO_2	--	--	--	--	--	--	--	.01	--	.01	--	.01
Sum	98.92	98.35	97.52	100.17	100.45	99.64	100.10	100.62	100.96	100.07	101.67	100.37
Cations												
Si	10.863	10.897	10.980	10.847	10.813	10.837	10.833	10.985	10.664	10.776	11.057	10.873
Al	5.169	5.152	5.100	5.324	5.214	5.193	5.244	5.223	5.299	5.217	4.864	5.141
Ti	--	--	--	--	--	--	--	.002	--	.001	--	.001
T	16.032	16.049	15.990	16.170	16.027	16.030	16.077	16.210	15.963	15.994	15.921	16.015
Fe^{2+}	--	--	--	--	.003	.009	.003	.019	.020	.010	.021	.019
Mg	--	--	--	--	--	.003	--	.004	.002	--	--	--
Ca	1.156	1.216	1.251	1.135	1.054	1.016	1.068	1.249	1.361	1.183	1.150	1.225
Na	2.693	2.488	2.608	2.351	2.971	2.991	2.772	1.797	2.649	2.836	2.822	2.562
K	.035	.035	.033	.022	.023	.025	.023	.041	.033	.017	.016	.030
M	3.884	3.739	3.892	3.508	4.051	4.044	3.866	3.110	4.065	4.046	4.009	3.836
Catsum	19.916	19.788	19.882	19.678	20.077	20.074	19.942	19.320	20.028	20.040	19.930	19.851
Molecular percent												
An	29.76	32.52	32.14	32.35	26.04	25.21	27.66	40.46	33.66	29.31	28.84	32.09
Ab	69.34	66.54	67.01	67.01	73.40	74.17	71.75	58.21	65.52	70.27	70.76	67.12
Or	.90	.94	.85	.64	.56	.62	.59	1.33	.82	.42	.40	.79

TABLE C-1.—*Electron microprobe analyses (weight percent) of plagioclase from granitoids of the Ellisville pluton: cations calculated on the basis of 32 oxygens*[1]—Continued

Specimen number	<------	------	------	P-80-32	------	------	------>	<-----	P-80-41---->
Probe number	P1111-72	P1111-73	P1111-74	P1111-75	P1111-76	P1111-77	P1118-96	P1113-19	P1113-21
Analysis type	grain	grain	grain	grain	grain	Av 13-17	grain	grain	grain
Table number	13	14	15	16	17	18	19	20	21
Oxides									
SiO_2	62.51	59.98	60.20	61.48	60.61	60.95	67.97	62.48	60.60
Al_2O_3	24.61	23.68	23.76	24.07	24.67	24.16	19.51	22.89	25.02
FeO	.02	.04	.03	.04	.09	.04	--	.03	.11
MgO	--	--	--	.01	--	--	--	--	--
CaO	6.24	5.33	5.24	5.76	6.13	5.74	.49	3.87	6.16
Na_2O	8.23	7.93	8.46	8.49	7.96	8.21	11.02	9.24	8.11
K_2O	.14	.07	.11	.15	.14	.12	.03	.05	.01
TiO_2	.02	--	--	--	--	--	--	--	--
Sum	101.77	97.03	97.80	100.00	99.60	99.22	99.02	98.56	100.01
Cations									
Si	10.911	10.948	10.926	10.927	10.818	10.906	11.973	11.195	10.774
Al	5.064	5.095	5.082	5.041	5.190	5.095	4.051	4.834	5.242
Ti	.002	--	--	--	--	--	--	--	--
T	15.977	16.043	16.008	15.968	16.008	16.001	16.024	16.029	16.016
Fe^{2+}	.003	.007	.004	.005	.014	.007	--	.005	.016
Mg	--	--	--	.003	--	--	--	--	--
Ca	1.167	1.043	1.019	1.096	1.173	1.101	.092	.743	1.174
Na	2.784	2.807	2.978	2.925	2.754	2.850	3.764	3.209	2.796
K	.031	.016	.025	.034	.032	.028	.007	.012	.003
M	3.985	3.873	4.026	4.063	3.973	3.986	3.863	3.969	3.989
Catsum	19.962	19.916	20.034	20.031	19.981	19.987	19.887	19.998	20.005
				Molecular percent					
An	29.31	26.98	25.34	27.03	29.63	27.67	2.39	18.74	29.55
Ab	69.91	72.61	74.04	72.13	69.56	71.63	97.43	80.95	70.38
Or	.78	.41	.62	.84	.81	.70	.17	.30	.08

TABLE C-1.—*Electron microprobe analyses (weight percent) of plagioclase from granitoids of the Ellisville pluton: cations calculated on the basis of 32 oxygens* [1]—Continued

Specimen number	P-80-39																
Probe number	P2113-24	P2113-25	P2113-26	P2113-27	P2113-28	P2113-29	P2113-30	P2113-31	P2113-32	P2113-33	P2113-34	P2113-35	P2113-36	P2113-37	P2113-38	P2113-39	P2113-40
Analysis type[2]	grain C	grain I	grain I	grain E	Av 22-25	grain E	grain I	grain C	Av 27-29	grain E	grain I	grain I	grain C	Av 31-34	grain	grain I	grain E
Table number	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
[3]	<------	------	------	------	------>	<------	------	------	------>	<------	------	------	------	------>		<------	------>
Oxides																	
SiO_2	61.16	58.25	60.27	61.57	60.32	63.96	59.99	60.05	61.33	59.54	60.12	59.31	58.55	59.38	60.53	59.95	60.12
Al_2O_3	24.94	26.28	25.42	24.01	25.16	22.62	25.66	25.59	24.63	25.46	25.61	26.25	26.34	26.91	25.30	25.42	25.69
FeO	.04	.07	.04	.01	.04	.01	.09	.11	.07	.07	.09	.04	.05	.06	.09	.08	.06
CaO	6.22	8.06	7.02	6.14	6.86	3.32	6.35	6.58	5.42	6.81	6.69	7.44	7.78	7.18	6.05	6.44	6.43
Na_2O	7.73	6.83	7.38	7.86	7.45	9.62	7.69	7.93	8.42	7.68	7.69	7.28	7.13	7.44	8.33	7.83	7.71
K_2O	.10	.10	.08	.10	.09	.11	.17	.21	.16	.11	.13	.09	.08	.11	.09	.12	.14
BaO	.06	.05	--	.02	.03	--	.04	--	.01	.03	--	.04	--	.01	.01	--	.01
Sum	100.25	99.64	100.21	99.71	99.95	99.64	99.99	100.47	100.04	99.70	100.33	100.45	99.93	100.09	100.40	99.84	100.16
Cations																	
Si	10.831	10.451	10.701	10.954	10.735	11.315	10.677	10.658	10.883	10.646	10.670	10.535	10.467	10.580	10.732	10.689	10.678
Al	5.206	5.557	5.319	5.035	5.278	4.717	5.381	5.352	5.150	5.365	5.358	5.495	5.549	5.442	5.287	5.342	5.377
T	16.037	16.008	16.020	15.989	16.013	16.032	16.058	16.010	16.033	16.011	16.028	16.030	16.016	16.022	16.019	16.031	16.055
Fe^{2+}	.005	.010	.005	.001	.005	.002	.014	.016	.011	.011	.013	.006	.008	.009	.014	.011	.009
Ca	1.180	1.550	1.335	1.171	1.309	0.630	1.212	1.252	1.031	1.304	1.272	1.415	1.491	1.371	1.149	1.231	1.225
Na	2.656	2.376	2.541	2.712	2.572	3.299	2.654	2.728	2.896	2.662	2.645	2.506	2.470	2.571	2.865	2.706	2.657
K	.022	.023	.018	.023	.021	.025	.038	.048	.037	.026	.030	.021	.019	.024	.020	.027	.031
Ba	.004	.004	--	.001	.002	--	.003	--	--	.002	--	.003	--	.001	--	--	--
M	3.867	3.963	3.899	3.908	3.909	3.956	3.921	4.044	3.975	4.005	3.960	3.951	3.988	3.976	4.048	3.975	3.922
Catsum	19.904	19.971	19.919	19.897	19.922	19.988	19.979	20.054	20.008	20.016	19.988	19.981	20.004	19.998	20.067	20.006	19.977
									Molecular percent								
An	30.55	39.21	34.28	29.97	33.53	15.93	31.02	31.08	26.01	32.65	32.23	35.87	37.46	34.56	28.48	31.05	31.31
Ab	68.77	60.11	65.25	69.41	65.88	83.43	67.93	67.73	73.06	66.65	67.01	63.52	62.06	64.81	71.02	68.26	67.90
Or	.57	.58	.46	.59	.54	.63	.97	1.19	.93	.65	.76	.53	.48	.60	.50	.68	.79
Cn	.10	.10	--	.03	.05	--	.08	--	--	.05	--	.08	--	.03	--	--	--

TABLE C-1.—*Electron microprobe analyses (weight percent) of plagioclase from granitoids of the Ellisville pluton: cations calculated on the basis of 32 oxygens*[1]—Continued

Specimen number	<----							P-25								----
Probe number	P2113-42	P2113-43	P2113-44	P2113-45	P2113-46	P2113-47	P2113-48	P2113-49	P2113-50	P2113-51	P2113-52	P2113-53	P2112-54	P2113-55	P2113-56	P2113-57
Analysis type	grain C	grain I	grain E	Av 39-41	grain E	grain I	grain C	Av 43-45	grain C	grain I	grain E	Av 47-49	grain C	grain I	grain E	Av 51-53
Table number	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
	<----			---->	<----			---->	<----			---->	<----			---->
Oxides																
SiO_2	60.33	60.78	60.46	60.51	60.52	60.24	58.97	59.91	58.29	59.45	60.28	59.34	59.72	58.99	61.68	60.12
Al_2O_3	25.44	24.84	24.94	25.07	25.00	25.48	25.82	25.43	26.54	25.97	24.80	25.77	25.54	25.77	24.09	25.14
FeO	.04	--	.02	.02	.04	.08	--	.04	--	.01	.14	.05	.02	.01	.02	.02
CaO	5.83	5.26	5.89	5.66	5.50	6.05	6.82	6.12	7.61	6.53	5.89	6.68	6.06	6.80	4.82	5.90
Na_2O	8.03	8.60	8.27	8.30	8.49	8.19	7.60	8.09	7.22	7.76	8.22	7.73	8.27	7.91	8.96	8.38
K_2O	.20	.13	.13	.16	.12	.21	.15	.16	.13	.18	.17	.16	.16	.13	.07	.12
BaO	--	.02	--	--	--	.10	--	.02	.03	.04	.02	.03	--	--	--	--
Sum	99.87	99.63	99.71	99.72	99.67	100.35	99.36	99.77	99.82	99.94	99.52	99.76	99.77	99.61	99.64	99.68
Cations																
Si	10.736	10.833	10.781	10.783	10.791	10.698	10.581	10.691	10.436	10.600	10.782	10.606	10.663	10.570	10.974	10.736
Al	5.335	5.218	5.243	5.266	5.254	5.333	5.460	5.348	5.599	5.457	5.228	5.428	5.375	5.442	5.052	5.290
T	16.071	16.051	16.024	16.049	16.045	16.031	16.041	16.039	16.035	16.057	16.010	16.034	16.038	16.012	16.026	16.026
Fe^{2+}	.006	--	.003	.003	.006	.012	--	.006	--	.001	.020	.007	.003	.002	.002	.002
Ca	1.112	1.004	1.125	1.080	1.050	1.151	1.310	1.170	1.460	1.248	1.129	1.279	1.160	1.306	.919	1.128
Na	2.770	2.972	2.860	2.868	2.936	2.820	2.643	2.800	2.507	2.683	2.849	2.680	2.862	2.747	3.090	2.901
K	.045	.030	.031	.035	.027	.047	.035	.037	.030	.041	.038	.036	.037	.030	.015	.027
Ba	--	.002	--	--	--	.007	--	.001	.002	.003	.002	.002	--	--	--	--
M	3.933	4.008	4.019	3.986	4.019	4.037	3.988	4.014	3.999	3.976	4.038	4.004	4.062	4.085	4.026	4.058
Catsum	20.004	20.059	20.043	20.035	20.064	20.068	20.029	20.053	20.034	20.033	20.048	20.038	20.100	20.097	20.052	20.084
								Molecular percent								
An	28.32	25.05	28.01	27.12	26.17	28.60	32.85	29.19	36.51	31.40	28.10	32.00	28.58	31.99	22.84	27.81
Ab	70.54	74.15	71.22	72.01	73.16	70.06	66.27	69.86	62.69	67.50	70.91	67.05	70.51	67.28	76.79	71.52
Or	1.15	.75	.77	.88	.67	1.17	.88	.92	.75	1.03	.95	.90	.91	.73	.37	.67
Cn	--	.05	--	--	--	.17	--	.02	.05	.08	.05	.05	--	--	--	--

[1] Cation site occupancies calculated by computer program of Flohr (1983).
[2] Grain C is analysis at center of grain, grain I is analysis at intermediate position between center and edge of grain, and grain E is analysis taken at edge. Average analysis is C, I, and E of a single grain.
[3] Brackets enclose analyses from a single grain.

TABLE C-2.—*Electron microprobe analyses (weight percent) of potassic feldspar from granitoids of the Ellisville pluton: cations calculated on the basis of 32 oxygens*[1]

Specimen number	<------	------	------	------	P-80-8	------	------	------	------	------>	<------	------	P-80-32	------>
Probe number	PFELD-5	PFELD-6	PFELD-7	PFELD-8	PFELD-9	PFELD-10	PFELD-31	PFELD-32	PFELD-33	PFELD-34	PFELD-20	PFELD-21	PFELD-22	PFELD-23
Analyses type	grain	grain	grain	grain	Aver2-4	grain	grain	grain	grain	Aver7-9	grain	grain	grain	Av11-13
Table number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2/	<------	------	------	------	------>		<------	------	------	------>	<------	------	------	------>
Oxides														
SiO_2	64.86	63.93	65.31	65.16	64.81	64.97	64.24	64.09	64.35	64.23	64.48	64.84	65.15	64.83
Al_2O_3	18.50	18.62	18.38	18.28	18.42	18.70	18.90	18.95	18.82	18.89	19.05	18.50	18.46	18.67
FeO	.07	.05	.08	.01	.05	.02	.05	.05	.05	.05	.03	--	--	--
CaO	--	.02	--	--	--	--	--	.01	.01	.01	.01	--	--	--
Na_2O	.56	.94	.63	.62	.73	.89	.61	.92	.71	.75	.67	.49	.57	.58
K_2O	15.58	15.00	15.33	15.49	15.27	15.25	16.08	15.21	16.02	15.77	15.96	16.21	15.99	16.05
BaO	.41	.33	.28	.20	.27	.45	.32	.46	.27	.35	.54	.51	.48	.51
Sum	99.98	98.89	100.01	99.76	99.55	100.28	100.20	99.69	100.23	100.05	100.74	100.55	100.65	100.64
Cations														
Si	11.989	11.933	12.034	12.040	12.003	11.963	11.889	11.889	11.900	11.893	11.878	11.966	11.990	11.946
Al	4.030	4.096	3.991	3.980	4.021	4.059	4.122	4.142	4.103	4.122	4.135	4.023	4.005	4.054
T	16.019	16.029	16.025	16.020	16.024	16.022	16.011	16.031	16.003	16.015	16.013	15.989	15.995	16.000
Fe^{2+}	.011	.008	.013	.001	.007	.003	.007	.008	.008	.007	.004	--	--	--
Ca	--	.003	--	--	--	.001	--	.003	.002	.001	.002	--	--	--
Na	.201	.341	.224	.221	.262	.318	.219	.332	.253	.268	.238	.176	.204	.206
K	3.673	3.571	3.602	3.650	3.608	3.582	3.797	3.600	3.780	3.726	3.752	3.816	3.753	3.774
Ba	.030	.024	.020	.015	.019	.032	.023	.034	.019	.025	.039	.037	.035	.037
M	3.915	3.947	3.859	3.887	3.896	3.936	4.046	3.977	4.062	4.027	4.035	4.029	3.992	4.017
Catsum	19.934	19.976	19.884	19.907	19.920	19.958	20.057	20.008	20.065	20.042	20.048	20.018	19.987	20.017
								Molecular percent						
An	--	.08	--	--	--	.03	--	.08	.05	.02	.05	--	--	--
Ab	5.15	8.66	5.82	5.69	6.74	8.09	5.42	8.36	6.24	6.67	5.90	4.37	5.11	5.13
Or	94.08	90.66	93.66	93.93	92.77	91.08	94.01	90.70	93.24	92.69	93.08	94.71	94.01	93.95
Cn	.77	.61	.52	.39	.49	.81	.57	.86	.47	.62	.97	.92	.88	.92

TABLE C-2.—*Electron microprobe analyses (weight percent) of potassic feldspar from granitoids of the Ellisville pluton: cations calculated on the basis of 32 oxygens*[1]—Continued

Specimen number	<-----	-----	-----	-----	P-80-32	-----	----->	<-----	-----	-----	P-80-19	-----	----->
Probe number	PFELD-24	PFELD-25	PFELD-26	PFELD-27	PFELD-28	PFELD-29	PFELD-30	PFELD-35	PFELD-36	PFELD-37	PFELD-38	PFELD-39	PFELD-40
Analyses type	grain	grain	grain	grain	grain	grain	Av18-20	grain	grain	grain	Av22-24	grain	grain
Table number	15	16	17	18	19	20	21	22	23	24	25	26	27
2/				<-----	-----	-----	----->	<-----	-----	-----	----->		
Oxides													
SiO_2	64.41	65.52	65.05	65.03	64.66	65.15	64.95	64.51	64.23	64.44	64.40	64.21	64.10
Al_2O_3	18.83	17.89	18.42	18.85	19.11	18.99	18.98	19.06	19.04	18.98	19.02	19.08	19.07
FeO	.01	--	--	--	--	--	--	--	.07	.04	.03	--	--
CaO	--	--	--	.01	.01	--	--	.01	.04	.02	.02	.03	--
Na_2O	.97	.87	.81	.76	1.39	1.29	1.15	.77	.66	.96	.80	1.27	.94
K_2O	15.21	15.73	15.67	15.64	14.91	14.90	15.15	15.44	15.73	15.34	15.50	15.06	15.18
BaO	.86	.17	.45	.34	.38	.48	.40	.90	.83	.80	.84	.69	1.03
Sum	100.29	100.18	100.40	100.63	100.46	100.81	100.63	100.69	100.60	100.58	100.61	100.34	100.32
Cations													
Si	11.907	12.076	11.989	11.943	11.883	11.926	11.918	11.886	11.866	11.884	11.880	11.857	11.863
Al	4.103	3.887	4.001	4.081	4.139	4.097	4.105	4.140	4.145	4.125	4.136	4.153	4.160
T	16.010	15.963	15.990	16.024	16.022	16.023	16.023	16.026	16.011	16.009	16.016	16.010	16.023
Fe^{2+}	.002	.001	--	--	--	.001	--	--	.011	.006	.004	--	--
Ca	--	--	--	.002	.002	--	.001	.002	.008	.005	.005	.005	--
Na	.348	.311	.291	.269	.495	.458	.408	.274	.237	.344	.285	.455	.337
K	3.587	3.698	3.685	3.664	3.496	3.480	3.546	3.629	3.706	3.608	3.648	3.547	3.584
Ba	.062	.012	.032	.025	.028	.034	.029	.065	.060	.058	.061	.050	.074
M	3.999	4.022	4.008	3.960	4.021	3.973	3.984	3.970	4.022	4.021	4.003	4.057	3.995
Catsum	20.009	19.985	19.998	19.984	20.043	19.996	20.007	19.996	20.033	20.030	20.019	20.067	20.018
						Molecular percent							
An	--	--	--	.05	.05	--	.03	.05	.20	.12	.13	.12	--
Ab	8.71	7.73	7.26	6.79	12.31	11.53	10.24	6.90	5.91	8.57	7.13	11.22	8.44
Or	89.74	91.97	91.94	92.53	86.94	87.61	89.01	91.41	92.40	89.86	91.22	87.43	89.71
Cn	1.55	.30	.80	.63	.70	.86	.73	1.64	1.50	1.44	1.53	1.23	1.85

TABLE C-2.—*Electron microprobe analyses (weight percent) of potassic feldspar from granitoids of the Ellisville pluton: cations calculated on the basis of 32 oxygens*[1]—Continued

Specimen number	<----P-80-19	----->	<------------					-----P-80-20-----					------------>
Probe number	PFELD-41	PFELD-42	PFELD-43	PFELD-44	PFELD-45	PFELD-46	PFELD-47	PFELD-48	PFELD-49	PFELD-50	PFELD-51	PFELD-52	PFELD-53
Analyses type	grain	grain	grain	grain	grain	grain	grain	grain	Av34-35	grain	grain	grain	Av37-39
Table number	28	29	30	31	32	33	34	35	36	37	38	39	40
2/							<--------	--------	-------->	<--------	--------	--------	-------->
Oxides													
SiO_2	64.61	64.31	63.56	63.72	63.45	63.58	63.90	64.31	64.17	64.30	63.65	63.84	63.94
Al_2O_3	19.01	19.05	19.23	19.27	19.03	19.18	18.87	19.51	19.09	18.78	18.97	19.20	18.98
FeO	--	--	--	--	.04	--	.22	.02	.08	--	--	.01	--
CaO	--	--	.02	.07	.05	.05	--	.28	.09	--	.01	.01	--
Na_2O	.67	.96	.81	1.08	1.02	.97	.76	3.25	1.55	.85	.81	.74	.80
K_2O	15.64	15.29	15.09	14.63	15.03	14.92	15.56	11.81	14.41	15.37	15.24	15.63	15.41
BaO	.82	.84	1.37	1.49	.97	1.27	.87	1.04	.92	.83	1.03	.71	.86
Sum	100.75	100.45	100.08	100.26	99.59	99.97	100.18	100.22	100.31	100.13	99.71	100.14	99.99
Cations													
Si	11.899	11.874	11.819	11.817	11.833	11.825	11.865	11.792	11.849	11.911	11.860	11.836	11.870
Al	4.125	4.145	4.215	4.213	4.183	4.203	4.130	4.216	4.154	4.099	4.165	4.196	4.153
T	16.024	16.019	16.034	16.030	16.016	16.028	15.995	16.008	16.003	16.010	16.025	16.032	16.023
Fe^{2+}	--	--	--	--	.006	--	.034	.003	.012	--	--	.001	--
Ca	--	--	.004	.015	.009	.009	--	.055	.018	--	.002	.001	.001
Na	.239	.343	.292	.387	.370	.349	.273	1.156	.555	.305	.292	.265	.288
K	3.674	3.602	3.580	3.460	3.576	3.538	3.685	2.762	3.395	3.633	3.621	3.695	3.650
Ba	.059	.061	.100	.108	.071	.093	.063	.074	.067	.060	.075	.052	.062
M	3.972	4.006	3.976	3.970	4.032	3.989	4.055	4.050	4.047	3.998	3.990	4.014	4.001
Catsum	19.996	20.025	20.010	20.000	20.048	20.017	20.050	20.058	20.050	20.008	20.015	20.046	20.024
Molecular percent													
An	--	--	.10	.38	.22	.23	--	1.36	.45	--	.05	.02	.02
Ab	6.02	8.56	7.34	9.75	9.19	8.75	6.79	28.56	13.75	7.63	7.32	6.60	7.20
Or	92.50	89.92	90.04	87.15	88.82	88.69	91.64	68.25	84.14	90.87	90.75	92.08	91.23
Cn	1.49	1.52	2.52	2.72	1.76	2.33	1.57	1.83	1.66	1.50	1.88	1.30	1.55

1/ Cation site occupancies calculated by computer program for Flohr (1983).
2/ Brackets enclose analyses from a single grain.

TABLE C-3.—*Electron microprobe analyses (weight percent) of biotite from granitoids of the Ellisville pluton: cations calculated on the basis of 11 oxygens and that all of the Fe is present as FeO*[1]

Specimen number	P-80-20						P-80-8				P-80-23		
Analysis number	DIIII-34	DIIII-36	DIIII-38	DIIII-39	DIIII-40	DIIII-41	DIlll-3	DIlll-4	DIlll-5	DIlll-6	PIlll-51a	PIlll-52	PIlll-53
Analysis type	grain	grain	grain	grain	grain	Av 3-5	grain	grain	grain	grain	grain	grain	grain
Table number	1	2	3	4	5	6	7	8	9	10	11	12	13
Oxides													
SiO_2	35.89	37.84	35.75	35.74	36.35	35.95	36.63	36.56	36.86	36.87	36.23	38.13	36.91
Al_2O_3	18.13	17.52	17.78	18.09	17.58	17.82	16.44	16.16	16.19	16.73	15.73	15.74	15.95
FeO	22.29	21.97	23.14	22.77	23.94	23.28	18.93	18.65	18.08	18.38	18.56	18.45	18.56
MgO	8.97	8.79	8.35	8.53	8.48	8.45	12.30	11.43	11.65	11.88	10.83	11.20	11.76
CaO	.05	.09	.09	.05	.03	.06	.04	.02	.04	.23	.03	.06	.03
Na_2O	.03	.02	.02	.02	.02	.02	.05	.03	.05	.06	.05	.06	.06
K_2O	9.63	9.61	9.07	9.26	9.55	9.29	9.55	9.78	9.31	6.86	8.96	8.66	9.20
TiO_2	2.31	2.30	2.46	2.40	2.43	2.43	1.98	1.97	2.26	2.21	1.98	1.74	1.83
MnO	.23	.25	.27	.27	.30	.28	.24	.28	.26	.27	.31	.26	.25
Sum	97.53	98.39	96.93	97.13	98.68	97.58	96.16	94.88	94.70	93.49	92.68	94.30	94.55
H_2O calc	3.97	4.04	3.94	3.95	3.99	3.96	3.98	3.92	3.94	3.94	3.84	3.94	3.92
Sum	101.50	102.43	100.87	101.08	102.67	101.54	100.14	98.80	98.64	97.43	96.52	98.24	98.47
Cations													
Si	2.709	2.811	2.720	2.710	2.729	2.720	2.762	2.796	2.806	2.804	2.827	2.899	2.820
Al^{iv}	1.291	1.189	1.280	1.290	1.271	1.280	1.238	1.204	1.194	1.196	1.173	1.101	1.180
T	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Al^{vi}	.322	.346	.315	.328	.286	.310	.224	.253	.259	.304	.274	.309	.256
Fe^{2+}	1.407	1.365	1.473	1.444	1.503	1.473	1.194	1.193	1.151	1.169	1.211	1.173	1.186
Mg	1.009	.973	.947	.964	.949	.953	1.382	1.303	1.322	1.347	1.259	1.269	1.339
Ti	.131	.129	.141	.137	.137	.138	.112	.113	.129	.126	.116	.099	.105
Mn	.015	.016	.017	.017	.019	.018	.015	.018	.017	.017	.020	.017	.016
M	2.884	2.829	2.893	2.890	2.894	2.892	2.928	2.881	2.879	2.964	2.881	2.867	2.902
Ca	.004	.007	.007	.004	.002	.005	.003	.002	.003	.019	.003	.005	.002
Na	.004	.003	.003	.003	.003	.003	.007	.004	.007	.009	.008	.009	.009
K	.927	.911	.880	.896	.915	.897	.919	.954	.904	.666	.892	.840	.897
A	.936	.921	.891	.903	.920	.905	.929	.960	.915	.693	.902	.854	.908
Catsum	7.819	7.750	7.783	7.793	7.814	7.797	7.858	7.841	7.794	7.657	7.783	7.721	7.810
OH calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.582	.584	.609	.600	.613	.607	.463	.478	.465	.465	.490	.480	.470
Mg:Mg+Fe	.418	.416	.391	.400	.387	.393	.537	.522	.535	.535	.510	.520	.530

TABLE C-3.—*Electron microprobe analyses (weight percent) of biotite from granitoids of the Ellisville pluton: cations calculated on the basis of 11 oxygens and that all of the Fe is present as FeO*[1]—Continued

Specimen number	P-80-23------------------>			<-----------------------P-80-32---------------------->					
Analysis number	P1111-54	P1111-55	P1111-56	P1111-78	P1111-79	P1111-80	P1111-81	P1111-82	P1111-82a
Type of analysis	grain	grain	Av 11-15	grain	grain	grain	grain	grain	Av 17-20
Mineral analyses	14	15	16	17	18	19	20	21	21
Oxides									
SiO_2	36.91	36.90	37.06	37.35	36.18	36.62	38.24	37.27	37.13
Al_2O_3	15.95	16.15	16.02	16.72	16.38	16.53	16.28	16.57	16.50
FeO	18.56	18.75	18.43	17.47	18.25	17.50	18.25	18.21	17.94
MgO	11.76	11.33	11.28	11.90	11.97	12.21	11.35	11.41	11.77
CaO	.03	.05	.04	.04	.02	.04	.04	.01	.03
Na_2O	.06	.21	.08	.04	.06	.08	.06	.06	.06
K_2O	9.20	9.55	9.13	9.54	9.85	9.73	9.30	9.39	9.56
TiO_2	1.83	2.08	1.89	1.88	2.04	1.69	1.92	1.58	1.82
MnO	.25	.33	.28	.30	.31	.36	.34	.29	.32
Sum	94.55	95.35	94.21	95.24	95.06	94.76	95.78	94.79	95.13
H_2O calc	3.92	3.94	3.92	3.98	3.93	3.94	4.00	3.95	3.96
Sum	98.47	99.29	98.13	99.22	98.99	98.70	99.78	98.74	99.09
Cations									
Si	2.820	2.805	2.837	2.817	2.761	2.788	2.868	2.832	2.813
Al^{iv}	1.180	1.195	1.163	1.183	1.239	1.212	1.132	1.168	1.187
T	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Al^{vi}	.256	.253	.283	.303	.235	.272	.308	.317	.287
Fe^{2+}	1.186	1.192	1.180	1.102	1.165	1.114	1.145	1.157	1.137
Mg	1.339	1.284	1.287	1.337	1.362	1.385	1.269	1.292	1.329
Ti	.105	.119	.109	.107	.117	.097	.108	.090	.104
Mn	.016	.021	.018	.019	.020	.023	.022	.019	.021
M	2.902	2.869	2.876	2.868	2.899	2.892	2.851	2.875	2.877
Ca	.002	.004	.003	.003	.002	.003	.003	.001	.002
Na	.009	.031	.012	.006	.009	.012	.009	.009	.009
K	.897	.926	.892	.918	.959	.945	.890	.910	.924
A	.908	.961	.907	.927	.970	.960	.902	.920	.935
Catsum	7.810	7.830	7.783	7.795	7.869	7.852	7.753	7.795	7.813
OH calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.470	.482	.478	.452	.461	.446	.474	.472	.461
Mg:Mg+Fe	.530	.518	.522	.548	.539	.554	.526	.528	.539

TABLE C-3.—*Electron microprobe analyses (weight percent) of biotite from granitoids of the Ellisville pluton: cations calculated on the basis of 11 oxygens and that all of the Fe is present as FeO*[1]—Continued

Specimen number	<-----	-----	-----	P-80-15	-----	-----	-----	----->	<-----	P-80-4	----->
Analysis number	P1113-11	P1113-12	P1113-13	P1113-14	P1113-15	P1113-16	P1113-17	P1113-18	P1113-23	P1113-24	P1113-25
Type of analysis	edge	center	edge	Av22-(1-3)	grain	grain	grain	Av23-25	grain	grain	grain
Mineral analyses	22-1	22-2	22-3	22A	23	24	25	26A	27	28	29
[2]	<-----	-----	-----	----->							
Oxides											
SiO_2	35.87	36.35	36.34	36.19	36.34	35.30	36.38	36.00	36.63	36.15	37.11
Al_2O_3	16.69	17.30	16.85	16.95	16.67	17.01	16.64	16.78	16.20	16.15	16.09
FeO	19.45	18.78	19.22	19.15	19.03	19.75	19.28	19.36	20.10	19.52	20.07
MgO	10.14	9.60	10.13	9.96	10.39	9.92	9.99	10.10	10.69	10.81	10.62
CaO	--	.04	.04	.03	--	.07	--	.02	.02	.03	.03
Na_2O	.06	.04	.03	.04	.05	.05	.05	.05	.09	.05	.05
K_2O	9.24	8.83	9.48	9.18	8.81	9.14	9.42	9.12	9.35	9.47	9.58
TiO_2	2.60	2.52	2.51	2.54	2.75	2.39	2.82	2.65	2.17	1.93	1.81
MnO	.32	.29	.24	.28	.31	.33	.31	.32	.28	.30	.27
Sum	94.37	93.75	94.84	94.32	94.35	93.96	94.89	94.40	95.53	94.41	95.63
H_2O calc	3.89	3.90	3.92	3.90	3.91	3.87	3.92	3.90	3.93	3.89	3.94
Sum	98.26	97.65	98.76	98.22	98.26	97.83	98.81	98.30	99.46	98.30	99.57
Cations											
Si	2.764	2.795	2.781	2.780	2.783	2.738	2.784	2.768	2.794	2.789	2.826
Al^{iv}	1.236	1.205	1.219	1.220	1.217	1.262	1.216	1.232	1.206	1.211	1.174
T	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Al^{vi}	.280	.363	.301	.315	.288	.294	.285	.289	.250	.258	.271
Fe^{2+}	1.253	1.208	1.230	1.230	1.219	1.281	1.234	1.245	1.282	1.260	1.278
Mg	1.164	1.100	1.155	1.140	1.186	1.147	1.139	1.157	1.215	1.243	1.205
Ti	.151	.146	.144	.147	.158	.139	.162	.153	.124	.112	.104
Mn	.021	.019	.016	.018	.020	.022	.020	.021	.018	.020	.017
M	2.869	2.836	2.846	2.850	2.872	2.883	2.840	2.866	2.890	2.892	2.876
Ca	--	.003	.003	.002	--	.006	--	.002	.002	.002	.002
Na	.009	.006	.004	.006	.007	.008	.007	.007	.013	.007	.007
K	.908	.866	.926	.900	.861	.905	.920	.895	.910	.932	.931
A	.917	.875	.933	.908	.868	.918	.927	.904	.925	.942	.941
Catsum	7.786	7.711	7.780	7.759	7.740	7.801	7.767	7.769	7.815	7.834	.7817
OH calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.518	.523	.516	.519	.507	.528	.520	.518	.513	.503	.515
Mg:Mg+Fe	.482	.477	.484	.481	.493	.472	.480	.482	.487	.497	.485

[1] Cation site occupancies calculated by computer program of Flohr (1983)
[2] Brackets enclose analyses from a single grain

TABLE C-4.—*Electron microprobe analyses (weight percent) of epidote from granitoids of the Ellisville pluton: cations calculated on the basis of 12.5 anions*[1]

Specimen number	<--------P-80-8-------->			P-80-20	P-80-23	P-80-32
Analysis number	D1111-9	D1111-8	D1111-7	DIIII 42	P1111-61	P1111-83
Analysis type	grain	grain	grain	grain	grain	grain
Table number	1	2	3	4	5	6
Oxides						
SiO_2	37.49	39.68	38.97	38.05	37.33	36.60
MgO	.07	.05	.12	.14	.15	.13
CaO	22.76	22.68	23.35	26.67	23.25	23.10
Na_2O	.02	.02	.02	--	.03	.01
K_2O	--	--	--	--	.02	--
[2]Fe_2O_3	15.47	14.26	7.17	14.15	14.58	14.07
Al_2O_3	21.54	21.73	27.45	24.29	22.68	22.72
MnO	.20	.26	.15	.24	.16	.30
TiO_2	.06	.05	.04	.05	.10	.10
Total	97.61	98.73	97.27	100.19	98.30	97.03
Cations						
Si	3.02	3.13	3.09	2.88	2.98	2.96
Mg	.01	.01	.01	.02	.02	.02
Ca	1.96	1.92	1.92	2.17	1.99	2.00
Fe^{3+}	.94	.85	.42	.84	.87	.86
Al	2.04	2.02	2.50	2.17	2.13	2.16
Mn	.01	.02	.01	.02	.01	.02
Ti	--	--	.01	--	.02	.02
Total	7.98	7.95	7.96	8.1	8.0	8.0
[3]Ps	32	30	14	28	29	28

[1] Calculated by the method of Deer, Howie and Zussman (1966, p. 515-517)
[2] Calculated from FeO
[3] Ps (pistacite) calculated as $Fe^{+3}/Fe^{+3} + Al \times 100$

TABLE C-5.—*Electron microprobe analyses (weight percent) of titanite from granitoids of the Ellisville pluton: cations calculated on the basis of 20 oxygens and that all the Fe is present as FeO*[1]

Specimen number	<---------P-80-41--------->	
Probe number	P1113-26	P1113-26a
Analysis type	grain	grain
Table number	1	2
Oxides		
SiO_2	29.43	29.68
MgO	.16	.20
CaO	27.27	27.36
Na_2O	.04	--
FeO	1.46	1.09
Al_2O_3	1.37	1.00
MnO	.05	.04
TiO_2	34.98	36.18
Total	94.76	95.55
Cations		
Si	4.0691	4.0630
Mg	0.0330	0.0408
Ca	4.0397	4.0128
Na	0.0107	--
Fe	0.1688	0.1248
Al	0.2232	0.1613
Mn	0.0059	0.0046
Ti	3.6371	3.7245
Total	12.188	12.132

[1] Cation site occupancies calculated by the computer program of Freeborn and others (1985)

TABLE C-6.—*Electron microprobe analyses (weight percent) of amphibole from granitoids of the Ellisville pluton: cations calculated on the basis of 23 oxygens and that all Fe is present as FeO* [1]

Specimen number	<------					P-80-41						------>
Analysis number	P1115-4	P1115-5	P1115-6	P1115-7	P1115-8	P1115-9	P1115-10	P1115-11	P1115-12	P1115-13	P1115-13A	P1115-13B
Analysis type	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	Av 1-11
Table number	1	2	3	4	5	6	7	8	9	10	11	12A
Oxides												
SiO_2	39.72	40.63	43.59	44.71	44.44	43.02	41.50	45.66	42.31	42.30	42.16	42.73
Al_2O_3	11.65	11.24	11.22	10.70	10.58	11.71	11.40	10.32	11.60	11.31	11.23	11.18
FeO	20.85	20.73	20.03	20.16	20.12	20.53	20.03	19.75	20.32	20.48	20.59	20.33
MgO	8.52	8.97	9.04	9.39	9.47	8.70	8.98	9.76	8.84	9.06	8.90	9.06
CaO	11.52	11.49	11.65	11.64	11.63	11.66	11.60	11.78	11.62	11.62	11.50	11.61
Na_2O	1.50	1.42	1.43	1.44	1.48	1.53	1.49	1.43	1.52	1.49	1.51	1.48
K_2O	1.45	1.36	1.25	1.12	1.22	1.42	1.37	1.07	1.39	1.27	1.26	1.29
TiO_2	.86	.71	.92	.87	.93	.88	.90	.82	.98	.95	.96	.89
MnO	.39	.42	.39	.41	.40	.44	.41	.42	.40	.47	.42	.41
Sum	96.46	96.97	99.52	100.44	100.27	99.89	97.68	101.01	98.98	98.95	98.53	98.98
H_2O Calc	1.91	1.93	2.00	2.03	2.02	2.00	1.95	2.05	1.98	1.98	1.97	1.98
Sum	98.37	98.90	101.52	102.47	102.29	101.89	99.63	103.06	100.96	100.93	100.50	100.96
Cations												
Si	6.235	6.322	6.526	6.616	6.597	6.448	6.374	6.693	6.405	6.411	6.419	6.461
Al^{iv}	1.765	1.678	1.474	1.384	1.403	1.552	1.626	1.307	1.595	1.589	1.581	1.539
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	.391	.384	.506	.482	.448	.517	.439	.476	.476	.431	.435	.453
Fe	2.514	2.453	2.373	2.350	2.353	2.441	2.402	2.301	2.418	2.414	2.435	2.404
Mg	1.993	2.080	2.017	2.071	2.095	1.943	2.056	2.132	1.994	2.046	2.020	2.042
Ti	.102	.083	.104	.097	.104	.099	.104	.090	.112	.108	.110	.101
M1-M3	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Mn	.052	.055	.049	.051	.050	.056	.053	.052	.051	.060	.054	.053
Fe	.223	.244	.135	.145	.145	.132	.171	.120	.154	.182	.187	.167
Ca	1.725	1.701	1.816	1.804	1.805	1.812	1.776	1.828	1.794	1.758	1.759	1.781
M4	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.457	.428	.415	.413	.426	.445	.444	.406	.446	.438	.446	.434
K	.290	.270	.239	.211	.231	.272	.268	.200	.268	.246	.245	.249
Ca	.212	.215	.053	.042	.045	.061	.134	.022	.091	.129	.117	.100
A	.959	.913	.707	.666	.702	.777	.846	.628	.805	.812	.808	.783
Catsum	15.959	15.914	15.707	15.666	15.702	15.777	15.846	15.628	15.805	15.812	15.808	15.783
OH Calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.579	.565	.554	.546	.544	.570	.556	.532	.563	.559	.565	.557
Mg:Mg+Fe	.421	.435	.446	.454	.456	.430	.444	.468	.437	.441	.435	.443

TABLE C-6.—*Electron microprobe analyses (weight percent) of amphibole from granitoids of the Ellisville pluton: cations calculated on the basis of 23 oxygens and that all Fe is present as FeO* [1]—Continued

Specimen number	<----------					P-80-42					---------->
Analysis number	P1115-15	P1115-16	P1115-17	P1115-18	P1115-19	P1115-20	P1115-21	P1115-22	P1115-23	P1115-24	P1115-25
Analysis site	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	Av 13-22
Mineral analyses	13	14	15	16	17	18	19	20	21	22	23
Oxides											
SiO_2	41.87	45.55	44.11	44.87	43.94	41.67	43.20	44.22	43.01	42.15	43.46
Al_2O_3	12.22	10.15	10.48	10.06	11.76	12.01	11.89	11.37	11.92	11.91	11.38
FeO	20.30	18.90	19.19	19.09	19.89	20.09	19.85	19.63	19.78	20.03	19.67
MgO	8.77	10.21	9.96	10.14	9.23	8.83	9.21	9.56	9.12	9.19	9.42
CaO	11.57	11.62	11.60	11.69	11.65	11.62	11.60	11.50	11.68	11.60	11.61
Na_2O	1.49	1.34	1.32	1.34	1.50	1.44	1.46	1.45	1.45	1.46	1.42
K_2O	1.42	1.06	1.15	1.10	1.29	1.45	1.33	1.21	1.39	1.40	1.28
TiO_2	.77	.92	.86	.81	.90	.94	.94	.90	.92	.86	.88
MnO	.39	.42	.40	.38	.41	.37	.38	.40	.37	.39	.39
Sum	98.80	100.17	99.07	99.48	100.57	98.42	99.86	100.24	99.64	98.99	99.51
H_2O Calc	1.98	2.04	2.00	2.02	2.03	1.97	2.01	2.03	2.00	1.98	2.01
Sum	100.78	102.21	101.07	101.50	102.60	100.39	101.87	102.27	101.64	100.97	101.52
Cations											
Si	6.351	6.705	6.600	6.672	6.498	6.345	6.444	6.545	6.435	6.371	6.498
Al^{iv}	1.649	1.295	1.400	1.328	1.502	1.655	1.556	1.455	1.566	1.629	1.502
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	.536	.467	.448	.436	.548	.502	.535	.529	.537	.493	.504
Fe	2.394	2.191	2.234	2.227	2.317	2.387	2.312	2.263	2.326	2.339	2.298
Mg	1.983	2.240	2.221	2.247	2.034	2.004	2.048	2.109	2.033	2.070	2.099
Ti	.088	.102	.097	.091	.100	.108	.105	.100	.104	.098	.099
M1-M3	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Mn	.050	.052	.051	.048	.051	.048	.048	.050	.047	.050	.049
Fe	.182	.136	.167	.148	.143	.172	.165	.167	.149	.193	.162
Ca	1.768	1.812	1.782	1.805	1.806	1.781	1.787	1.783	1.804	1.757	1.788
M4	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.438	.382	.383	.386	.430	.425	.422	.416	.421	.428	.412
K	.275	.199	.220	.209	.243	.282	.253	.228	.265	.270	.244
Ca	.112	.021	.078	.058	.040	.115	.067	.041	.068	.121	.072
A	.825	.603	.680	.653	.713	.822	.742	.686	.754	.819	.728
Catsum	15.825	15.603	15.680	15.653	15.713	15.822	15.742	15.686	15.754	15.819	15.728
OH Calc	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.565	.510	.520	.514	.547	.561	.547	.535	.549	.550	.540
Mg:Mg+Fe	.435	.490	.480	.486	.453	.439	.453	.453	.451	.450	.460

[1] Cation site occupancies calculated by computer program of Flohr (1983)

APPENDIX D: ELECTRON MICROPROBE ANALYSES OF SELECTED MINERALS IN CONTACT METAMORPHOSED ROCKS WITHIN THE THERMAL AUREOLE OF THE ELLISVILLE PLUTON

TABLE D-1.—*Electron microprobe analyses (weight percent) of biotite from contact metamorphosed schist within the Chopawamsic Formation of the Mineral district, Virginia: cations calculated on the basis of 22 oxygens*[1]

Specimen number	<-----------V1884 [2]------------>				<-----------------------------------V1810 [2]												--------------------------------->
Probe number	P3111-10	P3111-11	P3111-15	P3111-47	P3111-48	P3111-49	P3111-50	P3111-51	P3111-55	P3111-56	P3111-57	P3111-73	P3111-76	P3111-79	P3111-86	P3111-87	P3111-88
Analysis type	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain
Table number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Oxides																	
SiO_2	36.26	36.81	36.81	38.07	38.77	38.42	38.35	38.41	37.86	37.99	38.02	37.69	37.98	37.62	37.90	37.72	37.97
Al_2O_3	16.64	17.71	17.67	17.94	17.86	17.90	18.52	18.79	18.30	18.69	18.98	18.09	18.52	16.81	16.02	17.16	16.60
FeO	16.63	16.45	16.10	12.55	12.83	12.69	12.49	12.46	12.45	12.70	12.98	12.91	13.13	12.34	12.34	12.73	12.52
MgO	12.66	12.75	13.38	15.16	15.11	15.13	14.95	14.84	14.55	14.88	14.73	17.70	17.63	17.64	17.39	17.48	17.51
CaO	.01	--	.01	--	.02	.01	.02	--	.01	.01	--	.03	.01	.01	.02	--	.01
Na_2O	.45	.48	.45	.44	.43	.44	.36	.39	.44	.40	.44	.52	.42	.47	.53	.50	.51
K_2O	8.34	8.48	8.36	9.14	9.03	9.09	9.03	8.85	8.74	8.80	9.05	10.62	10.65	10.66	10.63	10.79	10.65
TiO_2	1.03	1.09	.98	.85	.75	.80	.71	.76	.89	.78	.77	.96	.91	.96	.94	.84	.80
MnO	.10	.09	.05	.19	.15	.17	.14	.18	.13	.17	.18	.24	.24	.24	.20	.22	.22
Sum	92.12	93.86	93.81	94.34	94.95	94.65	94.57	94.68	93.37	94.42	95.15	98.76	99.49	96.75	95.97	97.44	96.79
H_2O CALC	3.87	3.96	3.97	4.05	4.08	4.07	4.07	4.09	4.02	4.07	4.09	4.18	4.22	4.10	4.07	4.12	.10
Sum	95.99	97.82	97.78	98.39	99.03	98.72	98.64	98.77	97.39	98.49	99.24	102.94	103.71	100.85	100.04	101.56	100.89
Cations																	
Si	5.613	5.574	5.563	5.634	5.693	5.664	5.644	5.537	5.642	5.603	5.579	5.402	5.399	5.500	5.586	5.485	5.549
Al^{iv}	2.387	2.426	2.437	2.366	2.307	2.336	2.356	2.363	2.358	2.397	2.421	2.598	2.601	2.500	2.414	2.515	2.451
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	.650	.735	.711	.764	.785	.775	.857	.888	.856	.853	.863	.458	.503	.397	.370	.426	.408
Fe^{2+}	2.153	2.083	2.035	1.553	1.576	1.565	1.537	1.529	1.552	1.567	1.593	1.547	1.561	1.509	1.521	1.548	1.530
Mg	2.921	2.877	3.014	3.344	3.307	3.324	3.279	3.246	3.231	3.271	3.221	3.781	3.735	3.843	3.820	3.788	3.813
Ti	.120	.124	.111	.095	.083	.089	.079	.084	.100	.087	.085	.103	.097	.106	.104	.092	.088
Mn	.013	.012	.006	.024	.019	.021	.017	.022	.016	.021	.022	.029	.029	.030	.025	.027	.027
M	5.856	5.832	5.878	5.780	5.768	5.773	5.769	5.770	5.755	5.798	5.784	5.919	5.926	5.884	5.840	5.881	5.867
Ca	.002	--	.002	--	.003	.002	.003	--	.002	.002	--	.005	.002	.002	.003	--	.002
Na	.135	.141	.132	.126	.122	.126	.103	.111	.127	.114	.125	.145	.116	.133	.151	.141	.145
K	1.647	1.638	1.612	1.726	1.692	1.710	1.695	1.657	1.662	1.656	1.694	1.942	1.932	1.988	1.999	2.002	1.986
A	1.784	1.779	1.745	1.852	1.817	1.837	1.801	1.768	1.790	1.772	1.819	2.091	2.049	2.123	2.153	2.143	2.132
Catsum	15.640	15.611	15.623	15.632	15.586	15.610	15.570	15.538	15.546	15.570	15.604	16.010	15.975	16.007	15.993	16.024	15.999
OH CALC	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Ansum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Fe:Fe+Mg	.424	.420	.403	.317	.323	.320	.319	.320	.324	.324.	.331	.290	.295	.282	.285	.290	.286
Mg:Mg+Fe											.669	.710	.705	.718	.715	.710	.714

TABLE D-1.—*Electron microprobe analyses (weight percent) of biotite from contact metamorphosed schist within the Chopawamsic Formation of the Mineral district, Virginia: cations calculated on the basis of 22 oxygens*[1]—Continued

Specimen number	<---------- V18830[2] ----------							---------->	<---------- P-77-99 ----------				---------->
Probe number	P3112-1	P3112-2	P3112-5	P3112-6	P3112-7	P3112-11	P3112-12	P3112-13	P3112-14	P3112-15	P3112-16	P3112-22	P3112-26
Analysis type	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain
Table number	18	19	20	21	22	23	24	25	26	27	28	29	30
Oxides													
SiO_2	36.73	37.13	37.24	36.82	37.11	36.92	37.54	37.75	38.41	38.63	38.67	39.12	39.78
Al_2O_3	19.23	18.48	19.66	17.68	18.02	18.17	19.53	19.57	19.04	18.81	19.00	18.64	17.96
FeO	17.26	17.59	16.60	16.79	16.48	15.54	16.65	16.64	11.77	11.89	11.98	12.19	12.34
MgO	12.28	12.52	12.93	12.91	13.18	13.11	13.12	13.24	15.81	15.77	16.11	15.87	14.96
CaO	.02	.01	.01	---	---	.01	---	---	---	.02	.07	.05	.04
Na_2O	.41	.35	.43	.45	.39	.44	.42	.41	.25	.20	.23	.25	.19
K_2O	8.00	8.19	8.41	8.41	8.47	8.29	8.51	8.46	9.10	9.43	9.26	9.07	9.35
TiO_2	.54	.57	.54	.51	.56	.38	.39	.48	1.06	1.15	1.06	1.08	1.11
MnO	.09	.09	.06	.08	.08	.07	.07	.08	.14	.13	.15	.15	.17
Sum	94.56	94.93	95.88	93.65	94.29	92.93	96.23	96.63	95.58	96.03	96.53	96.42	95.90
H_2O CALC	4.00	4.00	4.06	3.95	3.98	3.95	4.08	4.10	4.13	4.14	4.17	4.17	4.14
Sum	98.56	98.93	99.94	97.60	98.27	96.88	100.31	100.73	99.71	100.17	100.70	100.59	100.04
Cations													
Si	5.512	5.564	5.497	5.593	5.584	5.607	5.521	5.524	5.572	5.590	5.564	5.629	5.760
Al^{iv}	2.488	2.436	2.504	2.407	2.416	2.393	2.479	2.476	2.428	2.410	2.436	2.371	2.240
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	.000
Al^{vi}	.913	.828	.917	.760	.781	.860	.908	.900	.828	.798	.787	.792	.826
Fe^{2+}	2.166	2.204	2.049	2.133	2.074	1.974	2.048	2.036	1.428	1.439	1.442	1.467	1.494
Mg	2.746	2.796	2.844	2.923	2.956	2.967	2.876	2.887	3.418	3.401	3.455	3.403	3.228
Ti	.061	.064	.060	.058	.063	.043	.043	.053	.116	.125	.115	.117	.121
Mn	.011	.011	.008	.010	.010	.009	.009	.010	.017	.016	.018	.018	.021
M	5.898	5.904	5.878	5.884	5.884	5.854	5.884	5.887	5.807	5.779	5.817	5.797	5.690
Ca	.003	.002	.002	---	---	.002	---	---	---	.003	.011	.008	.006
Na	.119	.102	.123	.133	.114	.130	.120	.116	.070	.056	.064	.070	.053
K	1.532	1.566	1.584	1.630	1.626	1.606	1.597	1.579	1.684	1.741	1.700	1.665	1.727
A	1.654	1.669	1.708	1.762	1.740	1.737	1.717	1.696	1.754	1.800	1.775	1.743	1.787
Catsum	15.552	15.573	15.586	15.647	15.624	15.591	15.601	15.583	15.562	15.579	15.592	15.540	15.477
OH CALC	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Ansum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Fe:Fe+Mg	.441	.441	.419	.422	.412	.399	.416	.414	.295	.297	.294	.301	.316
Mg:Mg+Fe	.559	.559	.581	.578	.588	.601	.584	.586	.705	.703	.706	.699	.684

[1] Cation site occupancies calculated by computer program of Flohr (1983)
[2] Specimen is from the geologic collection of A.S. Katz stored at the University of Virginia

TABLE D-2.—*Electron microprobe analyses (weight percent) of muscovite from contact metamorphosed schists within the Chopawamsic Formation in the Mineral district, Virginia: cations calculated on the basis of 22 oxygens*[1]

Specimen number	<----	----	----	----	V1810 d[2]	----	----	----	---->
Probe number	P3111-60	P3111-74	P3111-77	P3111-80	P3111-84	P3111-85	P3111-89	P3111-90	P3111-91
Analysis type	grain	mat	mat	mat	mat	grain	mat	mat	grain
Table number	1	2	3	4	5	6	7	8	9
Oxides									
SiO_2	45.81	45.28	45.26	44.89	44.82	44.57	45.39	45.55	45.44
Al_2O_3	33.51	32.40	33.69	32.20	32.47	31.38	31.78	33.05	32.78
FeO	1.88	1.83	.192	1.94	2.25	2.13	1.92	1.93	2.14
MgO	.90	1.01	1.12	1.20	1.08	1.10	1.08	1.00	1.43
CaO	.06	.01	.02	.01	.02	.08	.03	.01	.07
Na_2O	.99	1.27	1.25	1.21	1.24	1.16	1.24	1.30	1.22
K_2O	9.25	10.83	10.68	10.76	10.65	10.90	10.57	10.86	10.39
TiO_2	.23	.25	.25	.25	.23	.24	.25	.23	.24
MnO	.03	.03	.02	.04	.05	.03	.03	.03	.04
Sum	92.66	92.91	94.21	92.50	92.81	91.59	92.29	93.96	93.75
H_2O CALC	4.39	4.35	4.41	4.32	4.33	4.27	4.32	4.39	4.39
Sum	97.05	97.26	98.62	96.82	97.14	95.86	96.61	98.35	98.14
Cations									
Si	6.256	6.248	6.154	6.227	6.203	6.261	6.297	6.216	6.207
Al^{iv}	1.744	1.752	1.846	1.773	1.797	1.739	1.703	1.784	1.793
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	3.652	3.518	3.554	3.493	3.501	3.458	3.495	3.533	3.486
Fe^{2+}	.215	.211	.218	.225	.260	.250	.223	.220	.244
Mg	.183	.208	.227	.248	.223	.230	.223	.203	.291
Ti	.024	.026	.026	.026	.024	.025	.026	.024	.026
Mn	.003	.004	.002	.005	.006	.004	.004	.003	.005
M	4.077	3.967	4.027	3.997	4.014	3.968	3.971	3.983	4.051
Ca	.009	.001	.003	.001	.003	.012	.004	.001	.010
Na	.262	.340	.330	.325	.333	.316	.334	.344	.323
K	1.612	1.906	1.853	1.904	1.881	1.954	1.871	1.891	1.811
A	1.883	2.248	2.185	2.231	2.216	2.282	2.209	2.236	2.144
Catsum	13.959	14.214	14.212	14.229	14.231	14.250	14.180	14.220	14.195
OH CALC	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Ansum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Fe:Fe+Mg	.540	.504	.490	.476	.539	.521	.499	.520	.456
Mg:Mg+Fe	.460	.496	.510	.524	.461	.479	.501	.480	.544

1/ Cation site occupancies calculated by computer program of Flohr (1983)

2/ Specimen is from the geologic collection of A.S. Katz stored at the University of Virginia

TABLE D-3.—*Electron microprobe analyses (weight percent) of margarite from contact metamorphosed schist within the Chopawamsic Formation at the Sulfur deposit of the Mineral district, Virginia: cations calculated on the basis of 22 oxygens*[1]

Specimen number	<--------------------------------				V1810 d[2]				------------------------------->
Probe number	P3111-52	P3111-58	P3111-59	P3111-72	P3111-75	P3111-78	P3111-92	P3111-93	P3111-94
Analysis type	grain	grain[3]	grain[3]	grain	grain	grain[4]	grain[4]	grain[4]	grain[4]
Table number	1	2	3	4	5	6	7	8	9
Oxides									
SiO_2	33.63	31.62	31.58	31.15	31.51	31.82	40.30	31.62	32.04
Al_2O_3	48.04	50.21	48.20	48.04	49.13	47.78	38.94	50.96	50.43
FeO	.63	.93	.82	.77	.58	.47	1.40	.61	.67
MgO	.30	.51	.45	.50	.39	.37	.75	.43	.43
CaO	11.22	10.60	10.83	13.80	13.34	13.01	5.39	13.85	13.35
Na_2O	1.10	1.62	1.44	1.08	1.28	1.33	1.28	1.26	1.41
K_2O	.16	.14	.12	.29	.26	.26	6.72	.21	.25
TiO_2	.07	.10	.08	.11	.08	.07	.20	.09	.09
MnO	---	.02	.01	.03	.03	.03	.04	.03	.01
Sum	95.15	95.75	93.53	95.77	96.60	95.14	95.02	99.06	99.68
H_2O CALC	4.54	4.55	4.44	4.49	4.55	4.49	4.45	---	---
Sum	99.69	100.30	97.97	100.26	101.15	99.63	99.47	99.06	99.68
Cations									
Si	4.444	4.172	4.263	4.157	4.156	4.253	5.426	4.071	4.136
Al^{iv}	3.556	3.828	3.737	3.843	3.844	3.747	2.574	3.929	3.864
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	3.928	3.981	3.935	3.715	3.794	3.781	3.608	3.807	3.810
Fe^{2+}	.070	.103	.093	.086	.064	.053	.158	.066	.072
Mg	.059	.100	.091	.099	.077	.074	.151	.083	.083
Ti	.007	.010	.008	.011	.008	.007	.020	.009	.009
Mn	---	.002	.001	.003	.003	.003	.005	.003	.001
M	4.064	4.196	4.127	3.915	3.946	3.918	3.941	3.967	3.975
Ca	1.589	1.498	1.567	1.973	1.885	1.863	.778	1.911	1.846
Na	.282	.414	.377	.279	.327	.345	.334	.315	.353
K	.027	.024	.021	.049	.044	.044	1.154	.034	.041
A	1.898	1.936	1.964	2.302	2.256	2.252	2.266	2.260	2.241
Catsum	13.961	14.133	14.092	14.217	14.203	14.170	14.207	14.227	14.215
OH CALC	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Ansum	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Fe:Fe+Mg	.541	.506	.506	.464	.455	.416	.512	.443	.466
Mg:Mg+Fe	.459	.494	.494	.536	.545	.584	.488	.557	.534

1/ Cation site occupancies calculated by computer program of Flohr (1983)
2/ Specimen is from the geologic collection of A.S. Katz stored at the University of Virginia
3/ Fascicles enclosed in green biotite (table D-1, no. 10)
4/ Enclosed in fine-grained groundmass of white mica (table D-2, no. 4)

TABLE D-4.—*Electron microprobe analyses (weight percent) of kyanite from contact metamorphosed schists within the Chopawamsic Formation of the Mineral district, Virginia: cations calculated on the basis of 20 oxygens*[1]

Specimen number	<--------	P-76-122	-------->
Probe number	P3112-20	P3112-23	P3112-27
Analysis type	grain	grain	grain
Table number	1	2	3
Oxides			
SiO_2	37.21	37.08	37.18
TiO_2	.01	---	.01
Al_2O_3	63.72	62.88	63.74
FeO	.35	.41	.41
ZnO	---	---	---
MnO	---	---	---
CaO	---	.01	.01
Na_2O	.01	---	.01
K_2O	---	.01	---
Sum	101.30	100.39	101.36
Cations			
Si	3.971	3.993	3.967
Ti	.001	---	.001
Al	8.016	7.983	8.017
Fe	.031	.037	.037
Zn	---	---	---
Mn	---	---	---
Ca	---	.001	.001
Na	.002	---	.002
K	---	.001	---
Catsum	12.021	12.016	12.025

1/ Cation site occupancies calculated by unpublished computer program of Flohr (personal commun., 1987)

TABLE D-5.—*Electron microprobe analyses (weight percent) of staurolite from contact metamorphosed schists within the Chopawamsic Formation of the Mineral district of Virginia: cations calculated on the basis of 48 oxygens*[1]

Specimen number	<------------				V1884 d[2]				------------>	<------------			V1810 d[2]				------------
Probe number	P3111-3	P3111-4	P3111-5	P3111-6	P3111-7	P3111-8	P3111-12	P3111-13	P3111-14	P3111-44	P3111-45	P3111-46	P3111-53	P3111-54	P3111-81	P3111-82	P3111-83
Analysis type	grain[3]	grain[3]	grain[4]	grain[4]	grain[4]	grain[4]	grain[4]	grain[4]	grain[4]	grain	grain	grain	grain	grain	grain	grain	grain
Table number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Oxides																	
SiO_2	27.77	27.51	27.99	28.10	28.09	28.03	27.82	27.77	27.81	28.11	27.95	28.08	28.32	27.97	27.47	27.53	27.63
TiO_2	.30	.29	.29	.34	.29	.38	.38	.36	.18	.26	.25	.16	.32	.36	.34	.50	.30
Al_2O_3	51.68	52.63	52.62	53.16	53.48	52.51	52.93	53.27	53.37	52.72	54.43	52.05	54.59	53.02	53.69	51.61	53.78
FeO	13.73	13.63	13.43	13.70	13.70	13.80	13.60	13.60	13.55	10.04	10.30	9.88	10.92	10.53	10.49	10.39	10.59
ZnO	1.82	1.81	1.75	1.72	1.68	1.70	1.67	1.90	1.81	4.04	3.95	3.90	3.32	3.35	4.73	4.27	4.38
MnO	.26	.26	.26	.27	.27	.27	.27	.26	.24	.55	.54	.53	.61	.57	.69	.62	.68
MgO	1.99	2.00	1.97	2.03	2.11	2.18	2.14	2.09	1.98	1.97	2.18	2.28	2.22	2.26	2.64	2.74	2.66
CaO	---	.01	---	---	---	---	---	---	.01	---	.01	.01	.01	.01	---	.01	---
Na_2O	.16	.15	.20	.17	.15	.14	.16	.16	.17	.35	.34	.35	.31	.31	.42	.40	.42
K_2O	.01	---	---	---	---	---	---	---	---	---	---	.01	---	.01	.01	.01	.01
Sum	97.72	98.29	98.51	99.49	99.77	99.01	98.97	99.41	99.12	98.04	99.95	97.25	100.62	98.39	100.48	98.08	100.45
Cations																	
Si	8.150	8.021	8.126	8.083	8.054	8.110	8.045	8.003	8.028	8.179	7.981	8.229	8.025	8.103	7.867	8.061	7.901
Ti	.066	.064	.063	.074	.063	.083	.083	.078	.039	.057	.054	.035	.068	.078	.073	.110	.065
Al	17.881	18.092	18.009	18.028	18.078	17.911	18.044	18.099	18.164	18.085	18.322	17.983	18.238	18.108	18.128	17.815	18.130
Fe	3.370	3.324	3.261	3.296	3.285	3.339	3.289	3.278	3.271	2.443	2.460	2.421	2.588	2.551	2.513	2.544	2.533
Zn	.394	.390	.375	.365	.356	.363	.357	.404	.386	.868	.833	.844	.695	.717	1.000	.923	.925
Mn	.065	.064	.064	.066	.066	.066	.066	.063	.059	.136	.131	.132	.146	.140	.167	.154	.165
Mg	.871	.870	.853	.871	.902	.940	.923	.898	.852	.855	.928	.996	.938	.976	1.127	1.196	1.134
Ca	---	.003	---	---	---	---	---	---	.003	---	.003	.003	.003	.003	---	.003	---
Na	.091	.085	.113	.095	.083	.079	.090	.089	.095	.197	.188	.199	.170	.174	.233	.227	.233
K	.004	---	---	---	---	---	---	---	---	---	---	.004	---	.004	.004	.004	.004
Catsum	30.891	30.912	30.863	30.877	30.886	30.891	30.896	30.914	30.898	30.820	30.899	30.846	30.872	30.854	31.114	31.037	31.088
Mg:Mg+Fe	.205	.207	.207	.209	.215	.220	.219	.215	.207	.259	.274	.292	.266	.277	.310	.320	.309

TABLE D-5.—*Electron microprobe analyses (weight percent) of staurolite from contact metamorphosed schists within the Chopawamsic Formation of the Mineral district of Virginia: cations calculated on the basis of 48 oxygens*[1]—Continued

Specimen number	----------V1810d[3]-------->			<---------------V1883d[3]------------->				<----------------------P-76-122---------------------->						
Probe number	P3112-81	P3112-82	P3112-83	P3112-97	P3112-98	P3112-99	P311-2-100	P3111-19	P3111-20	P3111-21	P3111-34	P3111-36	P3111-37
Analysis type	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain	grain
Table number	18	19	20	21	22	23	24	25	26	27	28	29	30
Oxides													
SiO_2	27.47	27.53	27.63	27.86	26.97	27.76	27.36	28.38	28.34	28.41	28.32	28.12	27.92
TiO_2	.34	.50	.30	.15	.10	.17	.13	.41	.44	.39	.49	.41	.49
Al_2O_3	53.69	51.61	53.78	53.80	52.33	54.22	53.26	55.59	54.93	54.14	56.52	56.74	56.69
FeO	10.49	10.39	10.59	13.91	13.36	13.90	13.63	13.64	13.62	13.29	13.52	13.51	13.49
ZnO	4.73	4.27	4.38	2.05	2.22	2.10	2.16	.11	.05	.15	.09	.14	.11
MnO	.69	.62	.68	.28	.28	.28	.28	.23	.19	.22	.21	.20	.19
MgO	2.64	2.74	2.66	2.07	1.96	2.08	2.02	.70	.68	.67	.66	.68	.69
CaO	---	.01	---	.01	---	---	---	---	---	---	---	---	---
Na_2O	.42	.40	.42	.18	.19	.17	.18	---	.01	---	---	.01	---
K_2O	.01	.01	.01	---	---	---	---	---	---	---	---	---	---
Sum	100.48	98.08	100.45	100.31	97.41	100.68	99.02	99.06	98.26	97.27	99.81	99.81	99.58
Cations													
Si	7.867	8.061	7.901	7.972	7.952	7.916	7.934	8.089	8.141	8.237	8.003	7.950	7.912
Ti	.073	.110	.065	.032	.022	.036	.028	.088	.095	.085	.104	.087	.104
Al	18.128	17.815	18.130	18.150	18.191	18.227	18.209	18.679	18.603	18.505	18.829	18.911	18.940
Fe	2.513	2.544	2.533	3.329	3.295	3.315	3.306	3.251	3.272	3.222	3.195	3.194	3.197
Zn	1.000	.923	.925	.433	.483	.442	.463	.023	.011	.032	.019	.029	.023
Mn	.167	.154	.165	.068	.070	.068	.069	.056	.046	.054	.050	.048	.046
Mg	1.127	1.196	1.134	.883	.862	.884	.873	.297	.291	.290	.278	.287	.292
Ca	---	.003	---	.003	---	---	---	---	---	---	---	---	---
Na	.233	.227	.233	.100	.109	.094	.101	---	.006	---	---	.005	---
K	.004	.004	.004	---	---	---	---	---	---	---	---	---	---
Catsum	31.114	31.037	31.088	30.971	30.984	30.982	30.983	30.484	30.465	30.426	30.479	30.511	30.514
Mg:Mg+Fe	.310	.320	.309	.210	.207	.211	.209	.084	.082	.082	.080	.082	.084

1/ Cation site occupancies calculated by unpublished computer program of Flohr (personal commun., 1987)
2/ Specimen is from the Sulfur mine geologic collection of A. S. Katz stored at the University of Virginia
3/ Anhedral grain
4/ Euhedral grain

TABLE D-6.—*Electron microprobe analyses (weight percent) of chloritoid from contact metamorphosed schists within the Chopawamsic Formation of the Mineral district, Virginia: cations calculated on the basis of 14 oxygens*[1]

Specimen number	<----------	----------	P-77-86	----------	----------	---------->
Probe number	P3111-61	P3111-62	P3111-64	P3111-65	P3111-66	P3111-67
Analysis type	grain	grain	grain	grain	grain	grain
Table number	1	2	3	4	5	6
Oxides						
SiO_2	24.81	24.48	24.81	24.71	24.49	24.63
TiO_2	.14	---	---	.01	---	.01
Al_2O_3	41.30	42.81	41.39	41.92	41.57	41.64
FeO	23.87	24.13	23.85	23.92	23.96	23.99
ZnO	---	---	---	.02	---	---
MnO	.50	.53	.49	.53	.51	.53
MgO	2.88	3.01	2.97	2.97	2.89	2.97
CaO	---	---	---	---	---	---
Sum	93.50	94.96	93.51	94.08	93.42	93.77
Cations						
Si	2.354	2.288	2.353	2.330	2.328	2.332
Ti	.010	---	---	.001	---	.001
Al	4.620	4.717	4.628	4.660	4.659	4.648
Fe	1.894	1.886	1.892	1.886	1.905	1.900
Zn	---	---	---	.001	---	---
Mn	.040	.042	.039	.042	.041	.043
Mg	.407	.419	.420	.418	.410	.419
Ca	---	---	---	---	---	---
Catsum	9.326	9.353	9.333	9.339	9.343	9.343
Mg:Mg+Fe	.177	.182	.182	.181	.177	.181

[1] Cation site occupancies calculated by unpublished computer program of Flohr (personal comm., 1987).

TABLE D-7.—*Electron microprobe analyses (weight percent) of chlorite from contact metamorphosed schists within the Chopawamsic Formation of the Mineral district, Virginia: cations calculated on the basis of 28 oxygens and that all the Fe is FeO*[1]

Specimen number	<P-77-86>	<---------------	----------	V1883 D[2]/	----------	--------------->	<-----P-77-99	----->
Probe number	P3111-68	P3112-3	P3112-4	P3112-8	P3112-9	P3112-10	PS112-19	P3112-25
Analysis type	grain	grain	grain	grain	grain	grain	grain	grain
Table number	1	2	3	4	5	6	7	8
Oxides								
SiO_2	23.23	25.00	25.67	25.80	25.70	26.04	26.02	26.51
Al_2O_3	24.92	23.41	22.66	23.07	21.84	24.11	24.17	24.34
FeO	26.04	21.54	20.93	21.08	21.19	21.34	17.02	14.48
MgO	14.40	16.10	18.36	18.14	18.12	18.61	20.69	21.44
CaO	.04	.01	---	---	---	.01	.01	.10
Na_2O	.01	---	---	.02	---	---	.02	.22
K_2O	.01	.03	.05	.01	.01	.01	.07	.23
TiO_2	.08	.02	.03	.02	.01	.04	.05	.05
MnO	.17	.13	.14	.13	.14	.13	.26	.23
Sum	88.90	86.24	87.84	88.27	87.01	90.29	88.31	87.60
H_2O CALC	11.49	11.44	11.69	11.76	11.55	12.03	12.01	12.07
Sum	100.39	97.68	99.53	100.03	98.56	102.32	100.32	99.67
Cations								
Si	4.851	5.240	5.267	5.264	5.335	5.190	5.196	5.270
Al	3.149	2.760	2.733	2.736	2.665	2.810	2.804	2.730
Z	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al	2.986	3.026	2.748	2.814	2.680	2.855	2.886	2.973
Fe^{2+}	4.548	3.776	3.591	3.597	3.679	3.557	2.842	2.407
Mg	4.481	5.030	5.614	5.516	5.606	5.528	6.157	6.351
Ti	.013	.003	.005	.003	.002	.006	.008	.007
Mn	.030	.023	.024	.022	.025	.022	.044	.039
Ca	.009	.002	---	---	---	.002	.002	.021
Na	.004	---	---	.008	---	---	.008	.085
K	.003	.008	.013	.003	.003	.003	.018	.058
Y	12.073	11.868	11.995	11.963	11.993	11.973	11.965	11.943
Catsum	20.073	19.868	19.995	19.963	19.993	19.973	19.965	19.943
OH	16.000	16.000	16.000	16.000	16.000	16.000	16.000	16.000
Fe:Fe+Mg	.504	.429	.390	.395	.396	.392	.316	.275
Mg:Mg+Fe	.496	.571	.610	.605	.604	.608	.684	.725

1/ Cation site occupancies calculated by computer program of Flohr (1983)
2/ Specimen is from the geologic collection a A.S. Katz, stored at the University of Virginia

TABLE D-8.—*Electron microprobe analyses (weight percent) of titanite from contact metamorphosed schist within the Chopawamsic Formation of the Mineral district, Virginia: cations calculated on the basis of 20 oxygens*[1]

Specimen number	<------------	P-84-20	------------	----------->
Probe number	P3113-8	P3113-9	P3113-10	P3113-11
Analysis type	grain	grain	grain	Aver.1-3
Table number	1	2	3	4
Oxides				
SiO_2	30.56	30.48	30.40	30.48
TiO_2	35.27	35.21	35.13	35.21
Al_2O_3	2.28	2.07	2.40	2.25
FeO	.79	.75	.86	.80
MnO	.06	.08	.04	.06
MgO	.13	.11	.08	.11
CaO	28.95	28.68	28.66	28.76
Na_2O	.01	.01	.01	.01
Sum	98.05	97.39	97.58	97.68
Cations				
Si	4.071	4.086	4.068	4.075
Ti	3.533	3.550	3.535	3.540
Al	.358	.327	.379	.355
Fe	.088	.084	.096	.089
Mn	.007	.009	.005	.007
Mg	.026	.022	.016	.022
Ca	4.132	4.120	4.109	4.120
Na	.003	.003	.003	.003
Catsum	12.218	12.201	12.209	12.210

1/ Cation site occupancies calculated by unpublished computer program of Flohr (personal commun., 1987)

TABLE D-9.—*Electron microprobe analyses (weight percent) of amphibole from contact metamorphosed greenschists of the Chopawamsic Formation of the Mineral district, Virginia: cations calculated on the basis of 23 oxygens*[1]

Specimen number	<----	----	----	P-84-17A	----	----	----	---->	<----	----	----	P-84-20	----	----	----	----
Probe number	P3112-28	P3112-29	P3112-30	P3112-31	P3112-33	P3112-34	P3112-35	P3112-36	P3113-13	P3113-14	P3113-15	P3113-16	P3113-17	P3113-18	P3113-19	P3113-20
Analysis type	grain	grain	grain	grain	grain	grain	grain	grain	C-grain	C-grain	C-grain	C-grain	Av 9-12	C-grain	C-grain	C-grain
Table number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Oxides																
SiO_2	46.71	43.79	44.51	43.47	41.52	40.69	41.67	42.96	43.81	42.48	43.64	43.55	43.37	44.34	43.39	42.88
Al_2O_3	9.57	13.13	11.27	13.40	14.85	17.89	16.57	14.29	13.85	15.90	14.22	14.87	14.71	13.41	15.16	15.64
FeO	17.11	18.22	17.63	18.30	18.36	17.90	17.33	17.76	15.58	16.32	16.09	15.66	15.91	14.95	15.28	15.74
MgO	11.89	9.94	10.23	9.99	8.90	8.40	9.16	9.67	11.18	10.29	10.88	10.31	10.67	11.86	10.93	10.60
CaO	10.42	10.59	10.73	10.77	10.10	9.99	10.04	10.20	11.45	11.63	11.63	11.35	11.51	11.79	11.64	11.45
Na_2O	1.63	2.19	1.90	2.04	2.53	2.73	2.65	2.37	1.83	1.98	1.76	1.80	1.84	1.60	1.84	1.86
K_2O	.08	.15	.13	.34	.17	.19	.19	.18	.33	.37	.36	.38	.36	.40	.34	.32
TiO_2	.35	.33	.35	.37	.25	.33	.36	.30	.38	.43	.35	.43	.40	.48	.32	.47
MnO	.38	.37	.31	.26	.30	.29	.30	.36	.34	.33	.28	.27	.30	.30	.27	.28
Sum	98.14	98.71	97.06	98.94	96.98	98.41	98.27	98.09	98.75	99.73	99.21	98.62	99.07	99.13	99.17	99.24
H_2O CALC	2.03	2.02	2.00	2.02	1.98	2.02	2.02	2.01	2.05	2.05	2.05	2.05	2.05	2.06	2.06	2.05
Sum	100.17	100.73	99.06	100.97	98.96	100.43	100.29	100.11	100.80	101.78	101.26	100.67	101.12	101.19	101.23	101.29
Cations																
Si	6.886	6.488	6.684	6.436	6.285	6.049	6.182	6.393	6.421	6.199	6.383	6.385	6.347	6.455	6.323	6.258
Al^{iv}	1.114	1.512	1.316	1.564	1.715	1.951	1.818	1.607	1.579	1.801	1.617	1.615	1.653	1.545	1.677	1.742
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	.549	.782	.680	.775	.936	1.184	1.080	.900	.815	.935	.834	.955	.885	.757	.927	.949
Fe^{2+}	1.800	1.986	1.991	1.979	2.028	1.918	1.854	1.922	1.701	1.780	1.756	1.745	1.744	1.618	1.664	1.694
Mg	2.612	2.195	2.290	2.204	2.008	1.861	2.025	2.145	2.442	2.238	2.372	2.253	2.327	2.573	2.374	2.305
Ti	.039	.037	.040	.041	.028	.037	.040	.034	.042	.047	.038	.047	.044	.053	.035	.052
M1-M3	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Mn	.047	.046	.039	.033	.038	.037	.038	.045	.042	.041	.035	.034	.037	.037	.033	.035
Fe^{2+}	.310	.272	.223	.287	.297	.307	.296	.289	.209	.212	.213	.175	.203	.203	.198	.227
Ca	1.643	1.681	1.727	1.681	1.638	1.591	1.596	1.626	1.749	1.747	1.753	1.783	1.759	1.760	1.769	1.738
Na	---	.001	.011	---	.027	.065	.070	.039	---	---	---	.009	---	---	---	---
M4	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.466	.628	.543	.586	.716	.722	.692	.645	.520	.560	.499	.503	.522	.452	.520	.526
K	.015	.028	.025	.064	.033	.036	.036	.034	.062	.069	.067	.071	.067	.074	.063	.060
Ca	.003	---	---	.028	---	---	---	---	.049	.071	.070	---	.045	.079	.049	.052
A	.484	.657	.567	.678	.749	.758	.728	.679	.631	.700	.636	.574	.635	.605	.632	.638
Catsum	15.484	15.657	15.568	15.678	15.749	15.789	15.728	15.679	15.631	15.700	15.636	15.574	15.635	15.605	15.632	15.638
OH CALC	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.447	.507	.492	.507	.537	.545	.515	.508	.439	.471	.454	.460	.456	.414	.440	.455
Mg:Mg+Fe	.553	.493	.508	.493	.463	.455	.485	.492	.561	.529	.546	.540	.544	.586	.560	.545

TABLE D-9.—*Electron microprobe analyses (weight percent) of amphibole from contact metamorphosed greenschists of the Chopawamsic Formation of the Mineral district, Virginia: cations calculated on the basis of 23 oxygens*[1]—Continued

Specimen number	--------	--------	--------	P-84-20	--------	--------	------->	<--------	--------	--------	--------	P-84-23	--------	--------	--------
Probe number	P3113-21	P3113-22	P3113-23	P3113-24	P3113-25	P3113-26	P3113-27	P3113-31	P3113-32	P3113-33	P3113-34	P3113-35	P3113-36	P3113-37	P3113-39
Analysis type	C-grain	F-grain	F-grain	C-grain	F-grain	C-grain	C-grain	C-grain	C-grain	C-grain	C-grain	F-grain	F-grain	F-grain	C-grain
Table number	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Oxides															
SiO_2	42.17	44.84	43.44	43.30	46.81	43.78	44.54	46.88	45.24	45.70	44.98	45.61	45.93	44.68	45.27
Al_2O_3	15.70	13.36	15.17	14.50	10.75	14.56	13.27	11.04	12.54	12.35	13.64	12.54	12.58	13.15	12.46
FeO	16.02	14.30	15.02	15.14	13.73	15.40	15.23	13.97	14.94	13.96	14.70	13.81	14.38	14.29	14.19
MgO	10.04	11.60	10.81	10.89	13.41	10.86	11.16	13.13	12.27	12.82	12.14	12.81	12.64	12.06	12.53
CaO	11.40	11.73	11.28	11.72	11.65	11.03	11.50	10.62	10.64	10.74	10.19	10.87	10.55	10.91	10.49
Na_2O	1.94	1.71	1.93	1.85	1.53	2.00	1.82	1.71	1.97	1.98	2.21	1.88	1.90	2.00	2.10
K_2O	.33	.25	.23	.35	.16	.21	.31	.15	.18	.16	.14	.17	.16	.29	.15
TiO_2	.33	.37	.29	.50	.26	.36	.36	.35	.33	.38	.35	.39	.35	.38	.45
MnO	.34	.31	.34	.36	.31	.41	.33	.30	.28	.29	.30	.25	.25	.25	.29
Sum	98.27	98.47	98.51	98.61	98.61	98.61	98.52	98.15	98.39	98.38	98.65	98.35	98.74	98.01	97.93
H_2O CALC	2.03	2.06	2.05	2.04	2.07	2.05	2.05	2.07	2.05	2.06	2.06	2.07	2.07	2.05	2.05
Sum	100.30	100.53	100.56	100.65	100.68	100.66	100.57	100.22	100.44	100.44	100.72	100.42	100.81	100.06	99.98
Cations															
Si	6.235	6.537	6.355	6.353	6.779	6.407	6.524	6.805	6.602	6.637	6.531	6.621	6.646	6.540	6.615
Al^{iv}	1.765	1.463	1.645	1.647	1.221	1.593	1.476	1.195	1.398	1.363	1.469	1.379	1.354	1.460	1.385
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{vi}	.972	.834	.972	.861	.614	.920	.816	.694	.760	.752	.866	.767	.792	.809	.761
Fe^{2+}	1.779	1.605	1.639	1.703	1.463	1.672	1.709	1.427	1.535	1.432	1.468	1.419	1.445	1.518	1.461
Mg	2.212	2.520	2.357	2.381	2.894	2.369	2.436	2.840	2.669	2.775	2.627	2.771	2.726	2.631	2.729
Ti	.037	.041	.032	.055	.028	.040	.040	.038	.036	.042	.038	.043	.038	.042	.049
M1-M3	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
Mn	.043	.038	.042	.045	.038	.051	.041	.037	.035	.036	.037	.031	.031	.031	.036
Fe^{+2}	.202	.138	.199	.155	.200	.213	.157	.269	.289	.264	.317	.258	.296	.231	.273
Ca	1.756	1.823	1.759	1.800	1.762	1.730	1.802	1.652	1.664	1.671	1.585	1.694	1.636	1.711	1.642
Na	---	---	---	---	---	.007	---	.042	.013	.029	.061	.017	.038	.027	.049
M4	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.556	.483	.547	.526	.430	.561	.517	.439	.544	.528	.561	.512	.495	.541	.546
K	.062	.047	.043	.066	.030	.039	.058	.028	.034	.030	.026	.031	.030	.054	.028
Ca	.051	.009	.009	.042	.046	---	.003	---	---	---	---	---	---	---	---
A	.669	.539	.600	.634	.505	.600	.578	.467	.578	.558	.587	.543	.524	.595	.574
Catsum	15.669	15.539	15.600	15.634	15.505	15.600	15.578	15.467	15.578	15.558	15.587	15.544	15.525	15.595	15.574
OH CALC	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Fe:Fe+Mg	.472	.409	.438	.438	.365	.443	.434	.374	.406	.379	.405	.377	.390	.399	.389
Mg:Mg+Fe	.528	.591	.562	.562	.635	.557	.566	.626	.594	.621	.595	.623	.610	.601	.611

TABLE D-9.—*Electron microprobe analyses (weight percent) of amphibole from contact metamorphosed greenschists of the Chopawamsic Formation of the Mineral district, Virginia: cations calculated on the basis of 23 oxygens*[1]—Continued

Specimen number	----------	----------	----------	----------	----------	----------	P-84-23	----------	----------	----------	----------	----------	--------->
Probe number	P3113-41	P3113-42	P3113-43	P3113-44	P3113-45	P3113-47	P3113-49	P3113-50	P3113-51	P3113-52	P3113-53	P3113-54	P3113-56
Analysis type	C-grain	C-grain	C-grain	F-grain	F-grain	C-grain	C-grain	C-grain	C-grain	C-grain	F-grain	F-grain	F-grain
Table number	32	33	34	35	36	37	38	39	40	41	42	43	44
Oxides													
SiO_2	44.39	45.42	45.25	45.44	45.26	45.10	44.83	45.27	44.00	45.14	45.59	45.08	45.98
Al_2O_3	13.36	12.38	12.41	13.12	13.13	13.07	13.62	13.14	13.35	13.26	12.32	13.16	12.67
FeO	14.21	13.68	14.07	14.15	14.64	14.00	14.20	14.57	14.00	14.43	14.14	13.94	14.32
MgO	12.11	12.93	12.68	12.64	12.40	12.53	12.24	12.55	12.18	12.36	12.69	12.44	12.70
CaO	10.76	10.42	10.51	10.48	10.85	10.57	10.29	10.38	11.01	10.88	10.80	10.71	10.69
Na_2O	2.01	2.00	2.05	2.09	2.09	2.09	2.16	2.12	2.02	2.15	1.89	.07	2.00
K_2O	.29	.16	.16	.19	.18	.16	.15	.14	.26	.16	.14	.16	.14
TiO_2	.35	.37	.35	.40	.40	.35	.36	.37	.40	.38	.37	.38	.35
MnO	.23	.30	.30	.28	.24	.27	.30	.31	.20	.28	.22	.26	.26
Sum	97.71	97.66	97.78	98.79	99.19	98.14	98.15	98.85	97.42	99.04	98.16	98.20	99.11
H_2O CALC	2.04	2.05	2.05	.207	2.07	2.06	2.06	2.07	2.04	2.07	2.06	.06	2.08
Sum	99.75	99.71	99.83	100.86	101.26	100.20	100.21	100.92	99.46	101.11	100.22	100.26	101.19
Cations													
Si	6.515	6.634	6.619	6.574	6.546	6.546	6.531	6.559	6.480	6.535	6.639	.562	6.630
Al^{iv}	1.485	1.366	1.381	1.426	1.454	1.431	1.469	1.441	1.520	1.465	1.361	.438	1.370
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	.000	8.000
Al^{vi}	.826	.766	.759	.812	.784	.814	.870	.803	.799	.798	.754	.820	.784
Fe^{2+}	1.487	1.378	1.439	1.419	1.500	1.428	1.433	1.447	1.484	1.494	1.451	.439	1.448
Mg	2.649	2.815	2.764	2.725	2.673	2.720	2.658	2.710	2.674	2.667	2.754	.699	2.729
Ti	.039	.041	.039	.044	.044	.038	.039	.040	.044	.041	.041	.042	.038
M1-M3	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	.000	5.000
Mn	.029	.037	.037	.034	.029	.033	.037	.038	.025	.034	.027	.032	.032
Fe^{2+}	.257	.293	.283	.293	.271	.277	.297	.319	.241	.253	.271	.258	.279
Ca	1.692	1.631	1.647	1.625	.1681	.1650	1.606	1.611	1.734	1.688	1.685	.670	1.652
Na	.022	.039	.033	.048	.018	.040	.059	.032	---	.024	.017	.040	.038
M4	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	.000	2.000
Na	.550	.527	.548	.539	.568	.551	.551	.564	.577	.579	.517	.544	.521
K	.054	.030	.030	.035	.033	.030	.028	.026	.049	.030	.026	.030	.026
Ca	---	---	---	---	---	---	---	---	.003	---	---	---	---
A	.604	.557	.578	.574	.601	.580	.579	.589	.629	.609	.543	.574	.547
Catsum	15.604	15.557	15.578	15.574	15.601	15.580	15.579	15.590	15.629	15.609	15.543	15.574	15.547
OH CALC	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	.000	2.000
Ansum	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	.000	2.000
Fe:Fe+Mg	.397	.373	.384	.386	.399	.385	.394	.394	.392	.396	.385	.386	.388
Mg:Mg+Fe	.603	.627	.616	.614	.601	.615	.606	.606	.608	.604	.615	.614	.612

[1] Cation site occupancies calculated by the computer program of Flohr (1983)

TABLE D-10.—*Electron probe analyses (weight percent) of tourmaline in schists from the Sulfur mine[1] of the Mineral District, Virginia: calculated on the basis of 29 oxygens and assuming a stoichiometric 3.000 B atoms per formula unit[2]*

Specimen number	<------------------------			V 1883 D		------------------------>	<------------------------							V 1810 D					------------------------>
Probe number	P-3112-43	P-3112-44	P-3112-48	P-3112-49	P-3112-50	P-3112-51	P-3112-52	P-3112-55	P-3112-56	P-3112-58	P-3112-59	P-3112-60	P-3112-61	P-3112-62	P-3112-63	P-3112-64	P-3112-65	P-3112-66	P-3112-67
Analysis type	grain	grain	grain	grain	grain	grain	center	center	edge	center	edge	Av. 10-11	center	interior	edge	Av 13-15	center	edge	Av 17-18
Table number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Oxides																			
SiO_2	35.81	35.7	35.88	36.43	36.71	36.44	36.68	36.73	36.54	36.84	36.05	36.44	36.47	36.37	36.35	36.40.	37.26	36.78	37.02
Al_2O_3	31.93	31.91	32.46	33.26	33.87	33.23	33.84	34.33	34.20	33.88	32.20	33.04	33.07	33.20	32.70	32.99	35.18	33.87	34.52
TiO_2	.23	.12	.14	.13	.14	.16	.20	.37	.28	.15	.38	.27	.37	.42	.39	.39	.13	.41	.27
FeO	6.95	6.71	7.15	6.65	6.90	7.08	5.7	5.72	5.35	5.63	5.59	5.61	5.18	5.56	5.80	5.51	5.66	5.84	5.75
MnO	.01	---	.01	.01	.03	.01	.03	.04	.02	.01	.03	.02	.03	---	.04	.02	.03	.01	.02
MgO	7.72	8.08	8.19	8.02	8.12	7.87	7.86	8.33	8.57	7.50	8.58	8.03	8.62	8.48	8.90	8.66	7.57	8.26	7.91
CaO	1.06	1.19	1.33	.90	1.18	1.15	.77	1.03	1.39	.47	1.49	.98	.78	1.14	1.35	1.09	.41	1.47	.94
Na_2O	1.87	1.80	1.87	1.83	1.86	1.86	1.57	1.88	1.72	1.55	1.58	1.56	1.98	1.84	1.76	1.86	1.61	1.56	1.58
K_2O	.03	.02	.02	.02	.01	.02	.03	.03	.03	.02	.04	.03	.03	.02	.04	.03	.03	.04	.04
Total	85.61	85.53	87.05	87.25	88.82	87.82	86.68	88.46	88.10	86.05	85.94	85.98	86.53	87.03	87.33	86.95	87.88	88.24	88.05
Calc B_2O_3	10.55	10.55	10.70	10.79	10.96	10.82	10.81	10.99	10.95	10.76	10.66	10.71	10.78	10.81	10.81	10.80	10.99	10.97	10.97
Total	96.16	96.08	97.75	98.04	99.78	98.64	97.49	99.45	99.05	96.81	96.60	96.69	97.31	97.84	98.14	97.75	98.87	99.21	99.02
Cations																			
Si	5.900	5.883	5.829	5.867	5.822	5.851	5.900	5.810	5.798	5.949	5.879	5.914	5.881	5.848	5.843	8.858	5.891	5.837	5.865
Al^{iv}	.100	.117	.171	.133	.180	.149	.101	.190	.202	.050	.121	.086	.119	.152	.157	.142	.109	.163	.135
Total T	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
Al^{vi}	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
Al^{vi}	.100	.080	.044	.180	.153	.140	.312	.210	.194	.397	.067	.234	.165	.139	.037	.116	.446	.173	.310
Ti	.028	.015	.017	.016	.017	.019	.024	.040	.033	.018	.047	.033	.045	.051	.047	.047	.015	.049	.032
Fe^{2+}	.958	.925	.971	.896	.915	.951	.767	.757	.710	.760	.762	.761	.699	.748	.780	.742	.748	.775	.762
Mn	.001	---	.001	.007	.004	.001	.004	.005	.003	.001	.004	.003	.004	---	.005	.003	.004	.001	.003
Mg	1.896	1.985	1.983	1.925	1.919	1.883	1.884	1.964	2.027	1.805	2.085	1.943	2.072	2.032	2.132	2.077	1.784	1.954	1.868
Total Y	2.983	3.004	3.018	3.018	3.008	2.995	2.980	2.980	2.967	2.982	2.967	2.974	2.985	2.970	3.002	2.985	3.000	2.952	2.974
Ca	.187	.210	.232	.155	.200	.198	.133	.175	.236	.081	.260	.170	.135	.196	.232	.188	.069	.250	.160
Na	.597	.575	.589	.571	.572	.579	.489	.597	.529	.485	.500	.491	.619	.574	.489	.580	.493	.480	.485
K	.006	.004	.004	.004	.002	.004	.006	.006	.006	.004	.008	.006	.006	.004	.008	.006	.006	.008	.008
Total X	.791	.789	.825	.731	.774	.781	.628	.757	.772	.571	.768	.668	.760	.774	.789	.775	.569	.738	.653
Total TZYX	15.774	15.793	15.843	15.749	15.783	15.776	15.619	15.737	15.738	15.553	15.734	15.641	15.745	15.744	15.791	15.759	15.566	15.690	15.627
B	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Total cations	18.774	18.783	18.843	18.749	18.783	18.776	18.619	18.737	18.738	18.553	18.734	18.641	18.745	18.744	18.791	18.759	18.566	18.690	18.627
Fe/(Fe+Mg)	.34	.32	.33	.32	.32	.34	.29	.28	.26	.30	.35	.28	.25	.27	.27	.26	.30	.29	.29
Mg/Fe	1.98	2.15	2.04	2.14	2.09	1.98	2.44	2.58	2.86	2.38	2.75	2.55	2.96	2.71	2.73	2.81	2.37	2.50	2.46
Na/(Na+Ca)	.76	.73	.72	.78	.74	.74	.79	.77	.69	.86	.66	.74	.83	.81	.71	.75	.88	.66	.75

[1] See pl 2B for location of the Sulfur mine

[2] Calculated by the method of Henry and Guidotti (1985) using the computer program of P. M. Okita of the U.S. Geological Survey (unpublished data)

APPENDIX E: PETROGRAPHIC DESCRIPTIONS OF ROCKS CITED IN THE TEXT AND TABLES IN WHICH ROCKS ANALYZED BY THE ELECTRON MICROPROBE ARE LISTED.

TABLE E-1. *Petrographic Descriptions*

P-77-86 —	Strongly foliated rock with small crystals of chlorite, that may be pseudomorphous after muscovite, define the foliation. Abundant fine-grained quartz has granoblastic texture. Coarse-grained highly poikilitic chloritoid of contact metamorphic origin overprints the rock fabric. Mineral Quadrangle at lat 38°03′51″N. and long 77°53′22″W.
P-77-99 —	Strongly foliated phyllite with long thin fine-grained muscovite whose dimensional orientation defines the foliation is interspersed with fine-grained granoblastic textured quartz. Pleochroic yellow to brown biotite metacrysts with poikilitic texture that contain fine-grained quartz as inclusions are both dimensionally aligned along the rock foliation or lie athwart of it. Kyanite occurs in long, foliation-aligned grains that are intergrown with or enclose fine-grained granoblastic quartz. Kyanite also occurs as wispy stretched and broken crystals. Euhedral pyrite cubes are abundant. Chlorite is also present and in places abuts pyrite. Mineral Quadrangle at lat 38°03′5″N and long 77°53′20″W.
P-78-6 —	Medium-grained greenschist gneiss. Composed of pleochroic green amphibole and cloudy clinozoisite. Sparse quartz, plagioclase and chlorite are intersertal; magnetite is accessory. May be saussuritized mafic metavolcanic rock. Mine Run Quadrangle at lat 38°21′09″N. and long 77°45′47″W.
P-78-7 —	Massive, aphanitic serpentinite. Composed of interlocking and interpenetrating antigorite. Intersertal, fine-grained serpentine and chlorite occur between the antigorite pseudomorphs. Mine Run Quadrangle at lat 38°20′50″N. and long 77°46′18″W.
P-78-22 —	Strongly foliated, fine-grained greenschist composed predominantly of aligned, pale-green pleochroic amphibole and epidote-zoisite grains that, in part or in whole, pseudomorph plagioclase. White mica is a common foliation constituent and also forms small masses. Fine-grained twinned and untwinned albitic plagioclase is a minor constituent. Mine Run Quadrangle at lat 38°18′40″N. and long 77°49′06″W.
P-78-29 —	Massive, aphanitic serpentinite. Composed of mesh-textured antigorite that pseudomorphously has replaced olivine(?); intersertal chlorite separates antigorite pseudomorphs; chromian magnetite is widely scattered throughout the rock. Mine Run Quadrangle at lat 38°17′53″N. and long 77°50′54″W.
P-78-52 —	Biotite-amphibole monzonite: strongly foliated (dimensional alignment of elongate grains), medium-grained, mesocratic rock. Feldspar laths of plagioclase and microcline are particularly well-aligned. Well-formed green amphibole, that is locally poikilitic, also encloses relict pyroxene. Greenish-brown biotite in places encloses apatite. Magnetite and titanite are minor accessories. Lahore Quadrangle at lat 38°12′19″N. and long 77°56′45″W.
P-78-53 —	Biotite-pyroxene monzonite: massive, fine-grained, mesocratic, hypidiomorphic-granular rock. Plagioclase of andesine to labradorite composition, that in places has clear rims, is the most abundant felsic mineral and is clouded to varying degrees by fine-grained white mica alteration. Microcline about half as abundant as plagioclase also is mostly finer grained than plagioclase. Abundant augite is unaltered except for minor local replacement by chlorite and generally occurs as twinned grains. Greenish brown biotite is as abundant as augite. Accessory minerals include magnetite (abundant) and apatite (less abundant). Myrmekite is rare. Lahore Quadrangle at lat 38°11′40″N. and long 77°56′58″W.
P-80-4 —	Biotite granodiorite: rudely foliated, leucocratic, medium-grained rock. Biotite locally bent or broken and along with subhedral epidote, forms discontinuous wavy folia. Framework quartz is granoblastic textured and encloses the major constituent, subhedral plagioclase, that commonly is clouded by fine-grained white mica alteration. Perthitic potassic feldspar is less abundant than quartz. Accessory minerals include euhedral titanite that locally encloses an earlier, dusty titanite. In places titanite is enclosed by epidote. Apatite is a minor accessory commonly enclosed within biotite. Mineral Quadrangle at lat 38°05′20″N. and long 77°54′29″W.

P-80-8 — Quartz monzonite: rudely foliated, coarsely porphyritic, leucocratic, medium-grained rock. Orthoclase phenocrysts up to 5 cm long are poikilitic and enclose biotite, quartz, and epidote, as well as small subhedral plagioclase grains that commonly have inclusion-free albitic(?) rims. Zoned plagioclase is a common groundmass constitutent. Quartz occurs both as single grains that are strained and in granoblastic aggregates. Greenish biotite is the characterizing accessory; epidote is minor and apatite is rare. Mineral Quadrangle at lat 38°06′59″N. and long 77°54′49″W.

P-80-14 — Biotite granodiorite: medium-grained, massive, leucocratic rock consists predominantly of plagioclase mostly clouded by fine grained white mica, and minor potassic feldspar, both set in a groundmass of granoblastic quartz. Myrmekite is developed at plagioclase-potassic feldspar contacts. Quartz also forms megacrystic strained grains. Greenish brown biotite is the characterizing accessory. Epidote occurs in large grains, commonly in clots with biotite. Locally epidote occurs in symplectic intergrowth with quartz. Subhedral titanite and apatite (commonly enclosed within biotite) are minor accessories. Mineral Quadrangle at lat 38°05′09″N. and long 77°56′28″W.

P-80-15 — Tonalite: massive, leucocratic medium-grained rock with subhedral to anhedral plagioclase enclosed in a finer grained granoblastic quartz framework. Greenish brown biotite is the characterizing accessory and commonly is intergrown with epidote. Epidote locally encloses metamict allanite. Apatite is a minor accessory, in places enclosed within biotite. Mineral Quadrangle at lat 38°05′04″N. and long 77°56′28″W.

P-80-19 — Biotite granodiorite: fine-grained, massive rock. Hypidiomorphic-granular textured, with zoned plagioclase and minor potassic feldspar set in granoblastic as well as strained quartz groundmass. Plagioclase is myrmekitic at contacts with potassic feldspar. Brownish-green biotite, the major accessory, is commonly intergrown with crystalline epidote. Apatite is a minor accessory, titanite is sparse, and allanite is rare. Mineral Quadrangle at lat 38°05′17″ N. and long 77°56′31″ W.

P-80-20 — Granodiorite: massive, leucocratic fine-grained and equigranular rock, with hypidiomorphic granular texture. Quartz occurs as large grains or as granoblastic intersertal grains; plagioclase is present in twinned or untwinned grains that locally are altered to granular epidote. Microcline is the dominant potassic feldspar and is locally perthitic. Greenish-brown biotite is the characterizing mica and accessory apatite occur as small euhedral grains. Mineral Quadrangle at lat 38°04′29″N. and long 77°58′09″W.

P-80-23 — Biotite granodiorite: Massive, coarse-grained porphyritic rock with an allotriomorphic-granular groundmass. Microcline, although less abundant than plagioclase, commonly forms large poikilitic megacrysts that enclose small grains of plagioclase that locally have clear albitic(?) rims as well as lesser amounts of quartz and biotite. Plagioclase phenocrysts commonly are zoned. Quartz occurs in large grains that, in places, poikilitically enclose plagioclase. Green biotite is the characterizing accessory mineral. Large, subhedral crystals of epidote enclose apatite, metamict allanite and locally, biotite. Some biotite and epidote form symplectic intergrowths with quartz. Titanite is a generally euhedral common accessory. Mineral Quadrangle at lat 38°05′47″N. and long 77°58′14″W.

P-80-32 — Biotite granodiorite: foliated, medium-grained leucocratic rock with foliation imparted by crystallographic and dimensional alignment of biotite and rude dimensional alignment of felsic grains. Quartz occurs as large single grain and as granoblastic aggregates. Some of the plagioclase is zoned. Epidote occurs in large grains many of which enclose zoned allanite and such epidote has developed radiating fractures that emanate from the border of the allanite grain. Augite is a minor accessory. Louisa Quadrangle at lat 38°02′07.5″N. and long 78°00′32.5″W.

P-80-36 — Biotite granodiorite: well-foliated (dimensional alignment of mineral grains), medium-grained porphyritic rock. Microcline phenocrysts up to 2 cm are poikilitic and enclose small grains of plagioclase and biotite. Groundmass plagioclase is locally zoned. Biotite is the characterizing accessory and small amounts of green amphibole and colorless pyroxene are also present. Subhedral epidote, that commonly encloses allanite occurs in association with biotite. Subhedral titanite crystals and apatite are minor accessories. Mineral Quadrangle at lat 38°03′07″N. and long 77°59′39″W.

P-80-39 — Biotite granodiorite: foliated, coarse-grained porphyritic leucocratic rock. Both plagioclase and microcline form phenocrysts. Microcline is generally poikilitic and encloses small plagioclase and biotite grains. Myrmekite within groundmass plagioclase is formed at contacts with microcline.

Quartz is granoblastic textured. Brownish-green biotite is the characterizing accessory and subhedral epidote that commonly encloses allanite and subhedral titanite is an important accessory. Green amphibole is a minor constituent. Lahore Quadrangle at lat 38°08′12″N. and long 77°56′59″W.

P-80-40 — Biotite granodiorite: rudely foliated to massive, coarse-grained, leucocratic hypidiomorphic-granular rock. Megacrysts of microcline are poikilitic and enclose small crystals and grains of plagioclase, biotite, and epidote. Groundmass quartz occurs in discrete non-granoblastic textured grains. Coarse-grained, brownish-green biotite is the characterizing accessory and in places, poikilitically encloses titanite and apatite. Epidote forms large grains and commonly encloses allanite which has developed radiating fractures in the enclosing epidote. Allanite also is enclosed in quartz that also has developed radiating fractures around the enclosed allanite. Green amphibole is a minor accessory. Lahore Quadrangle at lat 38°08′15″N. and long 77°56′57″W.

P-80-41 — Biotite granodiorite: strongly foliated (dimensional alignment of mineral grains) medium-grained, leucocratic rock. Plagioclase is zoned and in a few places it contains smaller, randomly oriented plagioclase crystals that suggest a late poikilitic crystallization phase. Microcline commonly forms poikilitic megacrysts that enclose small grains of myrmekite that locally have a clear albitic(?) rim. Quartz occurs as large, single grains in the groundmass. Brownish-green biotite is the characterizing accessory whereas subhedral epidote, some in contact with allanite, is a lesser accessory. Subhedral titanite crystals are a minor accessory and green amphibole is a rare constituent. Lahore Quadrangle at lat 38°08′57.5″N. and long 77°56′32″W.

P-80-42 — Granodiorite: foliated (dimensional alignment of grains) medium-grained leucratic rock. Brown biotite with dimensional orientation wraps around dimensionally aligned large felsic grains. Microcline is nonpoikilitic and quartz lacks granoblastic texture. Subhedral epidote commonly encloses rare allanite. Lahore Quadrangle at lat 38°09′10″N. and long 77°56′25″W.

P-80-46C — Greenschist granofels: fine-grained rock wtih predominantly pale-green pleocroic amphibole and lesser amounts of plagioclase, minor quartz and accessory epidote. Lahore Quadrangle at lat 38°12′13″N. and long 77°54′39″W.

P-80-48B — Greenstone granofels: Fine-grained massive rock composed primarily of pleochroic blue-green amphibole and sparser amounts of plagioclase and quartz. Lensoid quartz-filled veinlets are common. A very large ellipsoidal clot of epidote is present that is fine-grained at its margin and coarser grained in its interior. Lahore Quadrangle at lat 38°12′21″N. and long 77°54′34″W.

P-80-67 — Quartz-syenomonzonite: melanocratic, strongly foliated rock. Foliation imparted by dimensional alinement of elongate-tabular crystals of feldspar, that is predominantly poikilitic microcline and about twice as abundant as oligoclase-andesine plagioclase. Bulbous myrmekite embays into plagioclase at places where plagioclase and microcline are in contact locally. Well-crystallized, colorless augite occurs as grains with varying degrees of irregular alteration to green amphibole. Some subhedral pyroxene, however, is mantled in sharp contact by green amphibole; a feature that suggests a discontinuous-reaction series process wherein magmatic pyroxene crystallization changes to amphibole crystallization as the activity of H_2O increased. Euhedral and subhedral magnetite and apatite are common accessories and titanite and fine-grained epidote are also present. Quartz is minor. Lahore Quadrangle at lat 38°11′45″N. and long 77°57′22″W.

P-80-70 — Biotite-amphibole monzonite: strongly foliated (dimensional orientation of elongate grains) medium-grained mesocratic rock. Large tabular microcline commonly with ribbon perthite texture is the characterizing feldspar. Large green amphibole encloses relict pyroxene that is surrounded in places by a bleach zone within the amphibole. Plagioclase is generally altered to fine-grained white mica and granular epidote aggregates. Green biotite is commonly enclosed within amphibole. Accessory magnetite is commonly rimmed by titanite and titanite also occurs in the groundmass as individual grains and subhedral crystals. Groundmass epidote is a common accessory and fluorite(?) is locally present. Green chlorite may, in part, have formed from amphibole. Lahore Quadrangle at lat 38°11′22″N. and long 77°57′41″W.

P-80-76 — Amphibolite "hornfels": fine-grained, weakly foliated rock composed predominantly of green hornblende and essentially unaltered, both untwinned and twinned plagioclase (An_{38} by flat-stage measurements). Titanite and ilmenite(?) are accessory and in places, titanite is crystallized along the margin of ilmenite(?). Rock is very near the contact with the Ellisville pluton and may have been recrystallized from a more altered greenschist state through contact metamorphism. Lahore Quadrangle at lat 38°10′39″N. and long 77°56′24″W.

P-80-86 — Serpentineferous metapyroxenite: green, massive, medium-grained rock. Anhedral to subhedral diopside with intersertal mesh textured serpentine. Lahore quadrangle at lat 38°13′37″N. and long 77°56′55″W.

P-80-87 — Actinolite-diopside "metapyroxenite": green, massive, medium-grained rock. Diopside with irregular embayed shapes is mantled by colorless tremolitic amphibole that pseudomorphously has partly replaced the diopside. Amphibole also occurs as large laths, probably formed through replacement of diopside. Chlorite is rare. Lahore quadrangle at lat 38°13′32″N. and long 77°56′54″W.

P-81-10 — Pyroxene-biotite monzonite: massive, medium-grained, mesocratic rock. Pyroxene occurs as large poikilitic grains that enclose small grains of apatite, magnetite and biotite. Plagioclase is zoned and some has cores clouded with granular epidote alteration; the rims of such plagioclase are clear (albite?). Biotite is common and green amphibole locally replaces pyroxene. Opaque is magnetite. Lahore Quadrangle at lat 38°11′08″N. and long 77°56′31.5″W.

P-81-11 — Biotite-amphibole monzonite: strongly foliated, coarse-grained, mesocratic rock. Microcline is locally perthitic. Megacrysts of green poikilitic amphibole enclose fine-grained quartz and microcline. Plagioclase is untwinned and clouded by fine-grained, granular epidote alteration. Myrmekite occurs with microcline grains. Accessory brownish green biotite poikilitically encloses fine-grained titanite and apatite. Biotite generally occurs in clumps and in a few places is closely associated with subhedral epidote. Lahore Quadrangle at lat 38°10′09″N. and long 77°57′36″W.

P-81-12 — Biotite-amphibole monzonite: strongly foliated, medium-grained mesocratic rock. Microcline is the most strongly aligned mineral. Highly poikilitic, green amphibole is crowded with inclusions of fine-grained green amphibole, quartz, and apatite. Plagioclase is clouded with finely granular epidote-zoisite and white mica alteration. Zoned plagioclase commonly has clear rims. Accessory greenish-brown biotite commonly encloses fine-grained sphene, rutile and apatite. Titanite and apatite also occur as groundmass constituents. Magnetite is a common opaque accessory. Lahore Quadrangle at lat 38°09′29″N. and long 77°58′46″W.

P-81-14 — Amphibole-pyroxene monzonite: foliated, medium-grained, mesocratic rock. Microcline poikilitically encloses quartz and unaltered plagioclase. Groundmass plagioclase is almost completely altered to an aggregate of clinozoisite and white mica except in a few places where the plagioclase retains a clear rim. Unaltered pyroxene is common but in many places along its margin it is altered to green amphibole. Locally, amphibole is pseudomorphous after pyroxene. Brown biotite is accessory and locally encloses apatite, but apatite is also a groundmass constituent. Bulbous protrusions of myrmekite into plagioclase are common. Accessory magnetite is locally rimmed by titanite. Lahore Quadrangle at lat 38°12′15″N. and long 77°58′58″W.

P-81-15 — Amphibolitic quartz monzonite: strongly foliated (dimensional alinement of elongate minerals), medium-grained mesocratic rock. Microcline occurs in aligned, elongate, tabular, poikilitic and nonpoikilitic crystals. Small grains of quartz and albite(?)-rimmed plagioclase are common in poikilitic microcline. Groundmass quartz ranges in grain size from medium to fine. Locally, untwinned plagioclase is clouded by alteration. Green, poikilitic to nonpoikilitic amphibole is less aligned than the feldspars. Poikilitic amphibole encloses small grains of quartz, plagioclase, microcline, epidote, and biotite, as well as unaltered pyroxene: euhedral magnetite and apatite are also inclusions. Biotite occurs as a groundmass constituent. Lahore Quadrangle at lat 38°11′37″N. and long 77°57′37″W.

P-25 — Biotite granodiorite: massive, leucocratic, fine-grained rock. Groundmass quartz occurs in granoblastic habit indicating considerable post-magmatic recrystallization. Greenish-brown biotite is the characterizing accessory and subhedral epidote is common, whereas well-formed titanite with angular rhombic-sections is a rare accessory. From quarry in Mineral Quadrangle at lat 38°04′21″N. and long 77°55′37″W.

P-84-20 — Foliated greenschist composed of fine-grained, poikilitic green amphibole with intersertal granoblastic textured quartz. No plagioclase is present. Epidote is an abundant accessory. Mineral Quadrangle at lat 38°01′17″N. and long 77°53′13″W.

P-84-21 — Amphibole-quartz granofels. Composed of medium-grained poikilitic (quartz inclusions) pleochroic pale green to blue green amphibole with its long dimension randomly oriented. Set in a fine-grained granoblastic quartz and possibly untwinned plagioclase(?) groundmass containing fine-grained actinolite grains. Poikilitic ilmenite is accessory and is locally enclosed by the large amphibole grains. Mineral Quadrangle at lat 38°01′38″N. and long 77°52′35″W.

P-84-23 — Fine-grained greenstone with small anhedral actinolite embedded in a groundmass of fine-grained crystalline actinolite, plagioclase, and chlorite. Chlorite locally replaces amphibole. Magnetite is accessory. Pendleton Quadrangle (immediately south of Mineral Quadrangle) at lat 37°59′48″N. and long 77°56′40″W.

V-1810-D — Greenish black gneiss with thin lenticular leucocratic layers. The dark layers consist of coarse-grained, subhedral green biotite. Acicular sheaves of white mica which are composed of muscovite and margarite are commonly enclosed within biotite or intersertal mats of fine-grained muscovite. Pleochroic yellow subhedral to euhedral, poikilitic as well as nonpoikilitic, zincian staurolite is an abundant constituent. Fine-grained euhedral, green, pleochroic, weakly zoned tourmaline is locally present and randomly interspersed with biotite and within muscovitic mats. Euhedral metamictic allanite enclosed by clinozoisite rims (morphologically molded on the allanite) is a sparse constituent. Intersertal quartz is a minor constituent. Leucocratic laminae consist of fine-grained granoblastic textured quartz with interspersed coarser-grained green, poikilitic to nonpoikilitic biotite. Locally, bundles of fine-grained acicular white mica are present. Anhedral fine-grained staurolite is a sparse constituent. Pale green, euhedral and finer-grained euhedral chlorite that occurs in irregular patches is also present. Specimen is from the mine dump of the Sulfur deposit in the Mineral Quadrangle. See plate 2*B* for the location of the mine.

V-1883-D — Massive micaceous granofels. Green, anhedral to euhedral biotite and pleochroic yellow subhedral to anhedral zincian staurolite are the most abundant constituents. Coarse-grained pleochroic (colorless to pale green) polysynthetically twinned chlorite that locally has replaced biotite is a minor constituent; finer-grained euhedral chlorite forms local clots within which are embedded fine-grained euhedral biotite and subhedral staurolite. Intersertal, anhedral magnetite is abundant and locally occurs with euhedral to subhedral staurolite and biotite in a subtabular mass that contains abundant pleochroic green, unzoned tourmaline. Specimen is from the mine dump of the Sulfur deposit in the Mineral Quadrangle. See plate 2*B* for the location of the mine.

V-1884-D — Crudely layered magnetite-muscovite-biotite staurolite granofels. Muscovite forms fine-grained mats in layers containing fine grained biotite. However, biotite in the rest of the rock is typically a medium-grained, green, poikilitic and of anhedral to subhedral habit that commonly encloses subhedral to euhedral magnetite and staurolite. Anhedral and subhedral staurolite along with magnetite and chlorite in places occur within muscovitic mats. Green, unzoned, euhedral tourmaline is a minor constituent. Specimen is from the mine dump of the Sulfur deposit in the Mineral Quadrangle. See plate 2*B* for the location of the mine.

TABLE E-2. *Rocks from which electron microprobe analyses of minerals were made and tables in which they are listed*

Rock	Appendix tables	Rock	Appendix tables
P-76-122	D-5	P-80-42	C-7
P-77-86	D-6, D-7	P-80-46C	A-2, A-3
P-77-99	D-1, D-4, D-7	P-80-48B	A-3, A-5
P-78-6	A-2, A-4, A-5, A-7	P-80-67	B-6, B-8
P-78-7	A-1, A-4	P-80-70	B-5, B-6, B-9, B-10
P-78-22	A-3, A-4, A-6	P-80-76	B-10
P-78-25	A-4	P-80-86	A-1, B-1, B-2, B-3
P-78-29	A-1	P-80-87	B-1, B-3, B-4
P-78-52	B-5, B-6, B-10	P-81-10	B-5, B-6, B-7, B-8
P-78-53	B-5, B-6, B-7, B-8		B-9, B-10
P-80-4	C-3	P-81-11	D-2
P-80-8	C-1, C-2, C-3, C-4	P-81-12	B-10, D-1, D-2
P-80-15	C-3	P-81-14	D-1
P-80-19	C-2	P-81-15	B-7, B-10, D-1
P-80-20	C-1, C-2, C-3, C-4	P-25	C-1, D-1
P-80-23	C-1, C-3, C-4	P-84-20	D-8, D-9
P-80-32	C-1, C-2, C-3, C-4, D-1, D-2	P-84-21	D-9
P-80-36	D-1, D-2	P-84-23	D-9
P-80-39	C-1	V 1810 D	D-1, D-2, D-3, D-5
P-80-40	D-2	V 1883 D	D-1, D-5, D-7, D-10
P-80-41	C-1, C-6, C-7, D-1	V 1884 D	D-1, D-5

APPENDIX F: ANALYTICAL METHODS

TABLE F-1. *Electron microprobe analytical and mineral calculation methods*

Electron microprobe analyses were carried out on polished carbon-coated thin sections and are tabulated in Appendix tables A, B, C, and D. The analyses were done at the Electron Microprobe Laboratory of the U.S. Geological Survey at Reston, Virginia. Analyses were performed on an automated ARL-SEQM 9-channel electron microprobe at an operating voltage of 15 kV and a beam current at 0.1 microamps. Correction procedures of Bence and Albee (1968) and alpha-factor modification of Albee and Ray (1970) were used. Data collection procedures have been outlined by McGee (1983). Standards used for calibration were either natural or synthetic silicates and oxides. Known to unknown calibration used well analyzed standards (for example, Kakanui hornblende, Benson orthoclase, Lake County plagioclase and others).

Traverses of some of the minerals were done by visual estimates of distances. An energy-dispersive analyzer was used where deemed appropriate to qualitatively determine the presence of elements not specifically analyzed for by the microprobe such as chromium in magnetite within serpentinite. The computer programs used to obtain cations and normative calculations report values to 3 and 4 decimal places and these are so given in the appendix tables only for purposes of internal arithmetic consistency.

Electron microprobe analyses report total iron as ferrous iron (Fe^{2+}). Except for pyroxene and clinozoisite-epidote all cations have been calculated in tables A through D on the basis that all Fe is FeO. Pyroxene cation calculations have been made on the basis that all Fe is Feo as well as that the Fe is present as both Fe and Fe_2O_3 by using the computer program of Freeborn and others (1985). All amphiboles have their cations calculated on the basis that all the Fe is present as FeO. However, a large number of amphiboles from amphibole-bearing rocks were also calculated on the basis that Fe is present as both FeO and Fe_2O_3 (unpublished data) using the Recamp computer programs of Spear and Kimball (1984) as modified by J.S. Huebner of the U.S. Geological Survey. These FeO-Fe_2O_3 calculations indicate that the Lahore and Ellisville plutons have $Fe^{3+}>Al^{vi}$ whereas amphiboles from the mafic pluton of the Lahore Complex, the mafic exotic blocks or olistoliths from the Mine Run Complex and from metavolcanic rocks of the Chopawamsic Formation mostly have $Fe^{3}<Al^{1}$. These Fe^{3+}-Al^{vi} features were used in the classification diagrams of Rock and Leake (1984) shown in figure 3.

TABLE F-2. *$^{40}Ar/^{39}Ar$ Analytical Method*

Ultra-pure separates (>99.9 by visual examination) of amphibole, biotite, and potassic feldspar were made using classical magnetic and heavy-liquid mineral separation techniques. Grain sizes for all separates are between 100 and 250 um diameter. Approximately 1000 mg of amphibole and 100–250 mg of biotite and potassic feldspar were packaged in labelled aluminum capsules. Capsules containing the mineral samples to be analyzed were stacked in a measured geometry, together with capsules containing about 40 mg each of the $^{40}Ar/^{39}Ar$ standard mineral MMhb-1 (Alexander and others, 1978), in high-purity quartz vials. The vials were evacuated to about 10^{-2}-10^{-3} mm Hg and sealed under vacuum. The quartz vials were then loaded into an aluminum rack and the rack loaded into an aluminum tube that was cold welded and leak-checked. The leak-checked tube, containing the samples and standards, was then lowered into the Central Thimble facility of the US*GS-TR*IGA reactor (GSTR) at the Federal Center in Lakewood, Colorado. The entire package was irradiated with neutrons for about 30 mega-watt hours (MWH) or until the samples and standards had received a dose of about 10^{18} total neutrons. In the $^{40}Ar/^{39}Ar$ variant of K-Ar dating a small portion of the ^{39}K contained in the samples and standards is converted to ^{39}Ar via the nuclear reaction ^{39}K (n,p) $^{39}Ar_K$ a so-called np reaction whereby a ^{39}K nucleus is bombarded with a neutron (n) and causes a proton (p) to be emitted from the ^{39}K nucleus thus transforming it into a ^{39}Ar nucleus. The subscript K is attached to the designation to show that it is ^{39}Ar that is K-derived, since ^{39}Ar can also be produced by neutron bombardment of the ^{42}Ca nucleus. Because the ratio of ^{40}K to ^{39}K is a constant in all natural materials, the $^{39}Ar_K$ can be used as a "proxy" for the ^{40}K (the parent isotope in the K-Ar decay series) as long as the portion of ^{39}K converted to ^{39}Ar is known or can be measured. This converted portion of ^{39}K is determined by irradiating a standard mineral (sometimes called the monitor mineral or neutron flux monitor) in the same neutron fluence as the samples of unknown age, and then measuring the $^{40}Ar_R/^{39}Ar_K$ ratio in the standards of known age and solving the $^{40}Ar/^{39}Ar$ age equation for J.

$$J=\frac{e^{\lambda t_m}-1}{({}^{40}Ar_R/{}^{39}Ar_K)_m}\text{ ; where}$$

λ= decay constant for ^{40}K = 5.543 × 10^{-10}/year

t_m= known age of monitor mineral in years; 5.194 × 10^8 years for MMhb-1 (Alexander and others, 1978).

A J-value versus geometry curve can be constructed for the irradiation cannister and the J-values for the samples of unknown age can be assigned from the curve by their known geometry. Correction factors for interfering argon isotopes and decay rates for short-lived argon isotopes used in this study are those reported by Dalrymple and others (1981). The test for an "age plateau" in the age spectrum is that described by Snee and others (1988). The decay constant for ^{40}K and the isotopic composition of both K and Ar used in this study are those reported by Steiger and Jager (1977). Apparent K/Ca ratios for argon from individual temperature steps were calculated as follows:

$$K/Ca = 0.49\ (\text{moles } {}^{39}Ar_K/\text{moles } {}^{37}Ar_{Ca}).$$

At times minerals from plutonic and metamorphic rocks exhibit discordant age spectra that do not define age "plateaus." In some cases, especially for the amphibole family of minerals, it has been shown that this discordance is likely to result from the presence of a trapped (initial) argon component whose $^{40}Ar/^{36}Ar$ >295.5 (present-day atmosphere). This potential situation cannot be easily evaluated with an age spectrum diagram but can be evaluated with the aid of an isotope correlation (isochron) diagram. This is a plot of the $^{36}Ar/^{40}Ar$ (y-axis) vs $^{39}Ar/^{40}Ar$ (x-axis) for each temperature step of an incremental heating experiment for a mineral. If a linear correlation exists on this diagram for some or all of the heating steps, one possible explanation is that this portion of the mineral contains a simple mixture of only two components of argon, a trapped (initial) component and a radiogenic (from in situ decay of ^{40}K) component. If this is true, the isotopic composition of the trapped component is the Y-intercept and the age of the mineral is proportional to the X-intercept. Thus it is possible in some cases to extract geologically meaningful information from minerals that contain a non-atmospheric trapped component of argon. In this study we use the isotope correlation approach to help interpret the age of three amphibole samples (P-80-42, P-80-46C, and P-81-15) whose age spectra are slightly discordant and do not define age plateaus. The isotope correlation plots were made by the "least-squares" regression techniques described by McIntyre and others (1966), York (1966), and York (1969).

TABLE F-3. *U-Th-Pb Method*

Samples were crushed and sieved, and the zircons were concentrated using a Wilfley table, heavy liquids, and a magnetic separator. The zircon separates were acid washed with hot HNO and HCl to remove any surface contamination. The zircon separates of various sizes and magnetic susceptibilities were digested in teflon bombs with hydrofluoric acid as described by Krough (1973). All reagents were purified with a subboiling technique: water and HNO_3 in a quartz still, and HF and HCl in a teflon still (Mattinson, 1972). The samples were aliquoted into concentration and composition portions prior to spiking. The concentration split was spiked with a combined ^{235}U-^{230}Th-^{208}Pb enriched solution prepared and calibrated by M. Tatsumoto. Lead was extracted from the samples by ion-exchange columns and electrodeposition (Barnes and others, 1973). Lead blanks ranged from 0.3 to 1.9 ng. Contamination by airborne particulate matter was minimized by the use of laminar-flow hoods using an absolute prefiltered air supply.

Isotope abundance measurements of lead were made with the silica gel technique (Cameron and others, 1969). National Bureau of Standards common lead isotopic standard was used to measure fractionation. The lead isotopes were depleted in the heavy isotopes by less than 0.05 percent per mass unit. No correction factor was applied. Uranium and thorium solutions which passed through the first lead resin column were collected and isolated on a nitrate resin (Tatsumoto, 1966). Accuracy of the concentration determination is estimated at 1 to 2 percent. The following values for decay constants and atomic abundance were used: ^{238}U = 1.55125 × 10^{-10}/yr, ^{235}U = 9.8485 × 10^{-10}/yr, ^{232}Th = 4.9475 × 10^{-11}/yr, and $^{238}U/^{235}U$ = 137.88 (Steiger and Jager, 1977).

The isotopic compositions and the quantitative results for lead, uranium, and thorium as well as the calculated ages are given in table 5. They have a laboratory analytical error of about 2 percent at the 95 percent confidence level. Common lead is present in the samples, probably from inclusions and fractures. All age calculations were corrected using the following common lead: $^{206}Pb/^{204}Pb$ = 18.51, $^{207}Pb/^{204}Pb$ = 15.72, and $^{208}Pb/^{204}Pb$ = 38.44.

TABLE F-4. *Rb-Sr Isochron Method*

Strontium, rubidium, and $^{87}Sr/^{86}Sr$ were determined on whole-rock splits by isotope-dilution mass spectrometry using a partly automated 6-inch 60°-sector NBS-type mass spectrometer. Sample powders were produced from unweathered 3,000- to 5,000-g rock samples by crushing, grinding, mixing, and splitting to 200-mesh size. Rubidium and strontium spikes (99.9 percent ^{84}Sr and 98.0 percent ^{87}Rb) were added to a 300 to 500 mg split of each sample. The samples were dissolved in HF in teflon beakers. Rubidium and strontium were completely separated using 3N HCL and Dowex 50WX8, 100/200 mesh, cation-exchange resin on a 26 cm by 1 cm quartz column. Rubidium and strontium were loaded as chlorides onto a triple rhenium-filament assembly for mass analysis. No corrections for ^{87}Rb were required for the strontium-isotope measurement. Strontium-isotope ratios were corrected for fractionation on the basis of an $^{86}Sr/^{88}Sr$ ratio of 0.11940. Blank determinations were less than 2 ng for strontium and 0.2 ng for rubidium.

Accuracy of the strontium-isotope measurements is based on 14 analyses of NBS SRM 987, which give a mean $^{87}Sr/^{86}Sr$ value of 0.71016±0.00003 (67 percent confidence level) compared with 0.71015±0.00003 obtained at the National Bureau of Standards (I. Lynus Barnes, oral commun.). Precision of individual rock determinations, based on eight complete replicate whole-rock determinations, is 0.011 percent for $^{87}Sr/^{86}Sr$, 0.6 percent for rubidium, and 1.0 percent for strontium at the 67 percent confidence level.

The analytical data for rubidium and strontium are given in tables 5 and 6 and plotted on an isochron diagram (fig. 40). The size of individual data points reflects the 95 percent confidence level. The regression and uncertainty calculation method of York (1969) was used to determine ages and their uncertainty at the 67 percent confidence level.

The isotopic and decay constants used are those recommended by the IUGS Subcommission on Geochronology (Steiger and Jager, 1977). Ages quoted from the literature are recalculated to these constants.