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NOTE

This guidebook has been reformatted from the original *SOUTH CAROLINA GEOLOGY* publication.

Cover Photo:
Overview of the North Pit at Ridgeway Gold Mine (Kennecott-Ridgeway Mining Company).

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THE CAROLINA TERRANE IN NORTHEASTERN SOUTH CAROLINA: HISTORY OF AN EXOTIC VOLCANIC ARC

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ABSTRACT

The oldest rocks in the Ridgeway–Camden area are metaplutonic, metavolcanic, and metasedimentary rocks that were deposited and deformed in an Upper Proterozoic to Lower Cambrian subduction-related volcanic arc, here considered to be part of the exotic Carolina terrane. During the Late Proterozoic to Early Cambrian deformation, high-grade metaplutonic rocks, that had been deeply buried, were juxtaposed against shallow, low-grade metavolcanic and metasedimentary rocks along a major ductile shear zone that now comprises the boundary between high-grade rocks in the interior of the Carolina terrane and low-grade rocks along the southeastern side of the Carolina terrane. The penetrative deformation fabrics that formed in the Late Proterozoic to Early Cambrian were subsequently folded and cut by three major brittle faults: the north-striking Ridgeway fault, the west–northwest-striking Longtown fault, and the northeast-striking Camden fault. In the southeastern part of the Ridgeway–Camden area, the Camden fault separates the above Upper Proterozoic to Lower Cambrian deformed sequence on the northwest from a sequence of sericitic phyllonite and orthogneiss of unknown terrane affinity on the southeast. This southeastern phyllonite/orthogneiss sequence is interpreted to be a part of the Alleghanian Modoc shear zone, which extends southwestward for 380 km through western South Carolina and Georgia. During and/or following the Late Cretaceous, the Camden and Longtown faults were reactivated, producing up-on-the-north vertical separations of the basal Late Cretaceous unconformity of ~15 to 25 m.

INTRODUCTION

Our purpose here is to describe the geology of the Ridgeway–Camden area and discuss its significance for an understanding of the pre-, syn-, and post-accretionary history of the Carolina terrane in the southern Appalachian orogen. The Ridgeway–Camden area is an east-west tier of three $7^1/_2$' quadrangles: Rabon Crossroads, Longtown, and Ridgeway, located along the Fall Line northeast of Columbia, South Carolina (Fig. 1).

REGIONAL RELATIONSHIPS

The eastern Blue Ridge and Piedmont of the southern Appalachians contain an assemblage of terranes that were incorporated into the Appalachian orogen during the Paleozoic (Williams and Hatcher, 1983; Horton and others, 1989). At present, knowledge concerning the configuration and geologic history of the terranes is incomplete. Our interpretation of the terrane configuration of a part of the southeastern Piedmont is illustrated in Figure 2. The Carolina terrane (Secor and others, 1983) is a structurally complex assemblage of igneous, metaigneous, and metasedimentary rocks located in the southeastern part of the Appalachian Piedmont province and extending from south-central Virginia to west-central Georgia (Horton and others, 1991). The Carolina terrane is bounded by faults of Paleozoic and Mesozoic age (Horton, 1981; Dallmeyer and others, 1986; Secor and others, 1986a, 1986b; Hatcher, 1989; Butler and Secor, 1991; Maher and others, 1991; Stoddard and others, 1991; Dennis, 1995; West and others, 1995; Hibbard and others, 1998; West, 1998; Wortman and others, 1998). The west-central part of the Carolina terrane consists of predominantly plutonic and upper amphibolite-facies metaplutonic rocks. Sequences of greenschist and lower amphibolite-facies metasedimentary and metavolcanic rocks are found in the southeastern and locally in the northwestern parts of the Carolina terrane (Fig. 2). The Ridgeway–Camden area is located in the Carolina terrane in northeastern South Carolina and extends from the central high-grade sequence, across the southeastern low-grade sequence, to the Atlantic Coastal Plain (Fig. 2).

GEOLOGY OF THE RIDGEWAY-CAMDE AREA

Rock Units (Fig. 3)

Some of the rock units in the Ridgeway–Camden area are defined on the basis of primary or relict primary mineralogy, textures, and structures. Examples of primary or relict primary features include: ophitic texture in diabase, cross-bedding in Coastal Plain sedimentary rocks, relict granophyric texture in metagranite, relict gabbroic texture in metagab-

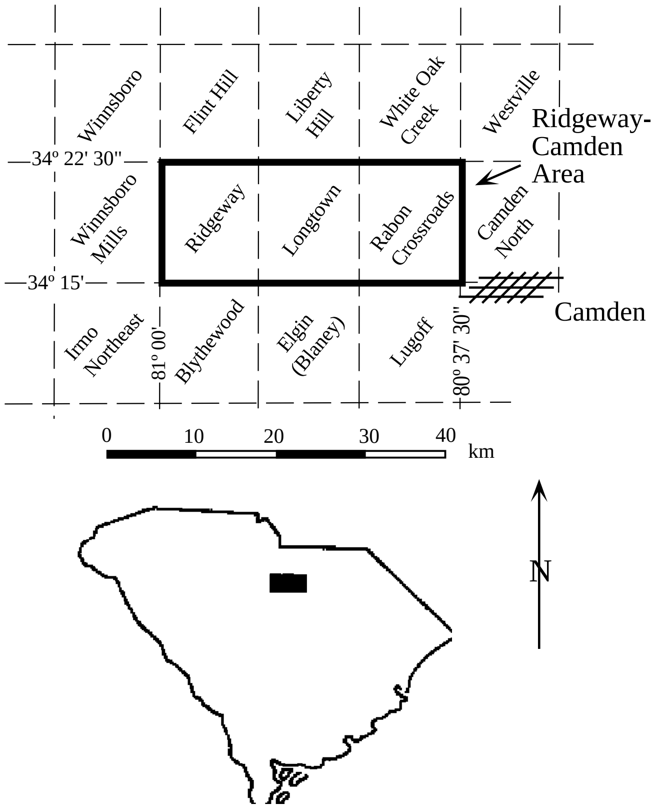

Figure 1. Position of the Ridgeway–Camden area relative to 1:24,000 scale topographic quadrangle maps in South Carolina near Columbia and Camden.

bro and amphibolite, relict lapilli in metavolcanic tuff, and relict bedding in metasedimentary rocks. Other rock units, such as phyllonite and mylonitic gneiss, are defined on the basis of secondary deformational fabrics, because primary textures and structures have been obliterated by penetrative deformation. The various rock units in the Ridgeway–Camden area, described below, are arranged according to our interpretation of their relative age, from oldest to youngest.

MigmatiticFelsic Gneiss and Metagabbro.

This unit is a compositionally heterogeneous sequence of biotite gneiss, amphibolite, hornblende gneiss, leucocratic gneiss, biotite schist, and pegmatite, in order of decreasing abundance, which crops out in the northwestern corner of the Ridgeway Quadrangle (pŒgn in Figure 3 on Maps CD). Relict igneous textures and mineralogy indicate derivation from an intrusive complex, heterogeneously deformed, and metamorphosed in the upper amphibolite-facies. This unit is continuous with an extensive area of plutonic and metaplutonic rocks in the interior part of the Carolina terrane, extending from central North Carolina to Georgia (Fig. 2). Geochronological studies of the migmatitic felsic gneiss and metagabbro unit have not been conducted in the Ridgeway–Camden area, although elsewhere in South Carolina geochronological studies suggest a Late Proterozoic to Cambrian age for the emplacement (Fullagar, 1971, 1981; Gilbert, 1982; McSween and others, 1984; Dallmeyer and others, 1986) and deformation (Dennis and Wright, 1997) of this intrusive complex.

Intermediate to Felsic Metatuff. This unit is a quartz-sericite phyllite, regionally metamorphosed to the greenschist-facies, and containing, in addition to quartz and sericite, variable amounts of albite, chlorite, epidote, and opaque oxides. Locally preserved relict primary textures indicate derivation from a sequence of intermediate to felsic crystal-lapilli tuffs, locally interlayered with greenstone, mudstone, siltstone, and wacke, and locally intruded by shallow-level mafic to felsic igneous plugs and sheets. The metatuff unit outcrops in the eastern, central, and southwestern parts of the Ridgeway–Camden area (pŒft in Figure 3, on Maps CD) and is continuous to the southwest with rocks included in the Persimmon Fork Formation (Secor and Wagener, 1968; Secor and Snoke, 1978; Secor and others, 1986a). The depositional lower contact of the metatuff unit has not been recognized. The upper contact with the metamudstone and metasiltstone unit (pŒms in Figure 3, on Maps CD) is gradational. The exposed stratigraphic thickness of the metatuff sequence is difficult to estimate because of penetrative deformation, but in the Ridgeway–Camden area the thickness probably exceeds 1 km. The metatuff unit is similar in age and stratigraphic position to both the Lincolnton metadacite in western South Carolina and eastern Georgia (Carpenter and others, 1982) and to the Uwharrie volcanic rocks in the Albemarle area of North Carolina (Wright and Seiders, 1980; Milton, 1984). The available geochronologic data suggest that the metatuff unit was erupted in the Late Proterozoic or Early Cambrian. In the Irmo Northeast Quadrangle, immediately southwest of the Ridgeway–Camden area (Fig. 1), Barker and others (1998) interpreted quartz-feldspar crystal-lapilli metatuff to have been erupted in the Late Proterozoic to Early Cambrian, based on a U-Pb zircon upper concordia intercept age of 557 ± 15 Ma, and a weighted mean $^{207}Pb/^{206}Pb$ age of 550.5 ± 5.9 Ma. In northeast South Carolina, Eades and others (1991) reported an Rb-Sr whole-rock age of 534 ± 20 Ma for eleven samples of metavolcanic rock, from the southeastern Carolina terrane, which they interpreted as a minimum eruption age. Along the Georgia-South Carolina border, Carpenter and others (1982) reported eruption ages for the Lincolnton metadacite of 554 ± 20 Ma (Rb-Sr whole rock) and 568 Ma (U-Pb zircon). The age and composition of metavolcanic rocks along the southeastern side of the Carolina terrane are similar to the age and composition of some metaplutonic rocks in the interior of the Carolina terrane, and some previous workers have suggested that the metatuffs are the eruptive equivalent of the metaplutonic rocks (Butler and Ragland, 1969a; Weisenfluh and Snoke, 1978; Secor and others, 1982).

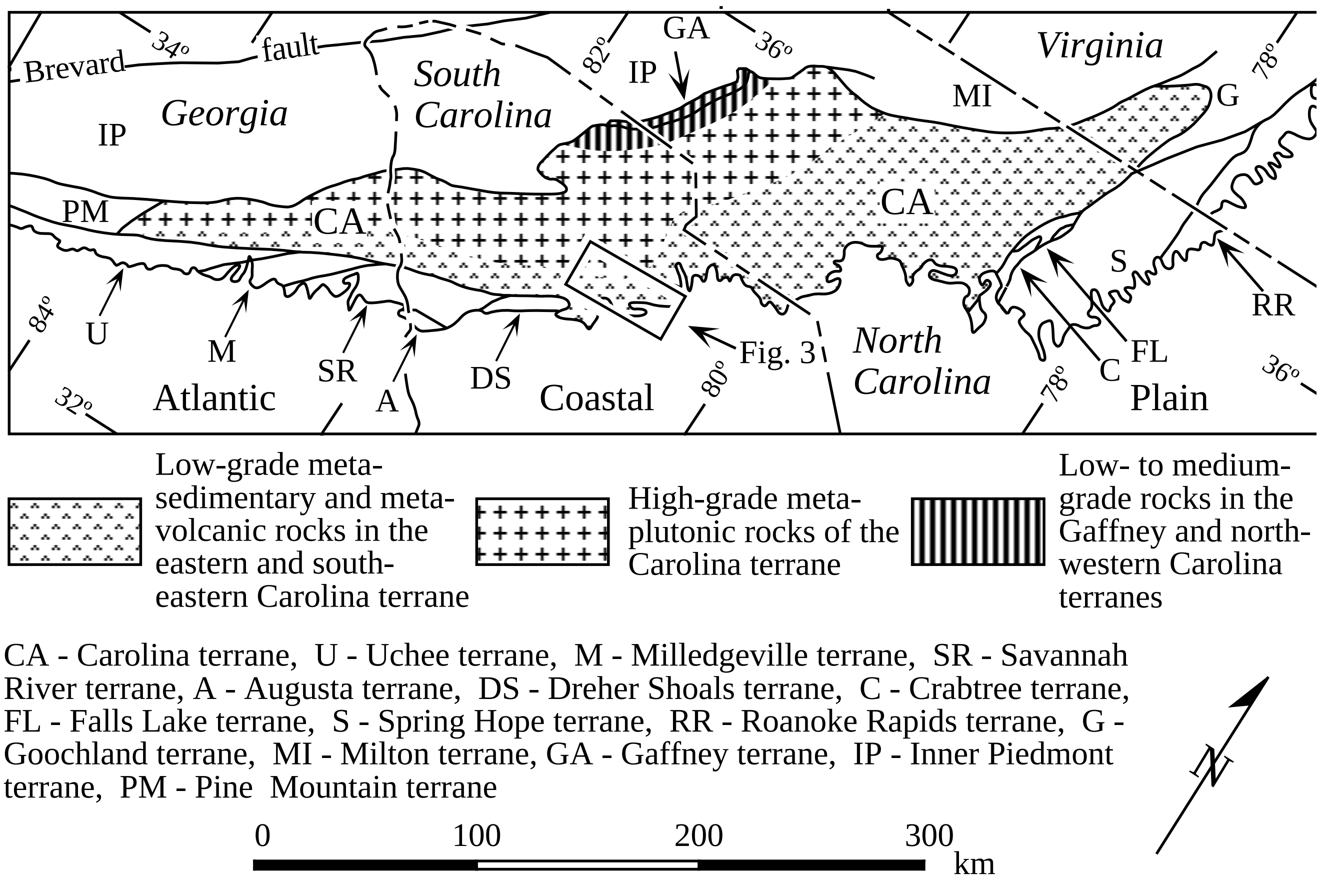

Figure 2. Provisional terrane map of a portion of the southeastern Piedmont province showing (in the patterned area) the distribution of the high-grade and low- to medium- grade parts of the Carolina terrane. The area of low- to medium- grade rocks along the northwestern side of the Carolina terrane includes the Gaffney terrane of Horton and others (1989, 1991). Modified in part from Goldsmith and others (1988), Hatcher and others (1990), Horton and others (1989, 1991), West and others (1995), and Barker and others (1998).

Bee Branch Metagranite.

This unit is a fine- to medium-grained quartzo-feldspathic gneiss that outcrops over a few square kilometers in the west-central part of the Rabon Crossroads Quadrangle (pŒbb in Figure 3, on *Maps CD*). It is interpreted as a metagranite because of its homogeneity and apparent lack of both compositional layering and relict volcanic textures. Our attempts to separate zircons from this unit for geochronological studies have been unsuccessful. The Bee Branch metagranite may represent a shallow-level intrusion genetically related to the adjacent intermediate to felsic metatuff unit.

Mafic Metatuffs and Metaflows.

In the southwestern part of the Ridgeway Quadrangle, two small areas are underlain by greenstone (pŒmt in Figure 3, on Maps CD) containing quartz, albite, epidote, chlorite, and opaque oxides. Relict primary features indicate derivation from a sequence of mafic tuffs and/or flow breccias. This unit may correlate with amphibolite and amygdaloidal greenstone mapped near the base of the metamudstone and metasiltstone unit (pŒms) to the southwest [i.e. the Richtex Formation of Secor and Wagener (1968) and Secor and others (1982)].

Metamudstone and Metasiltstone.

This unit, outcropping in the northeastern and south-central parts of the Ridgeway–Camden area, is quartz-albite-sericite slate and phyllite with accessory epidote and chlorite (pŒms in Figure 3, on Maps CD). It contains abundant relict primary stratification indicating derivation from a sequence of graded siltstone, mudstone, and wacke. Thin-bedded sequences containing numerous varve-like layers of graded silt/clay, a few millimeters to a few centimeters thick, are interlayered with graded wacke layers several centimeters to a few meters thick. Locally, these wacke layers contain relict lapilli and albite phenocrysts, indicating that nearby coeval volcanism was a source for at least some of the sediment in this unit. The metamudstone and metasiltstone unit also locally contains greenstone layers up to ~ 20 m thick. The depositional contact of the metamudstone and metasiltstone unit with the underlying intermediate to felsic metatuff unit is gradational, with interlayering of metasedimentary and metavolcanic rocks through a stratigraphic thickness of several tens of meters. The upper contact of this unit has not been recognized. The exposed stratigraphic thickness of metamudstone and metasiltstone in the Ridgeway–Camden area is difficult to estimate because of folding and penetrative deformation, but probably exceeds a few kilometers. This metasedimentary unit resembles rocks in the type area of the Richtex Formation several miles to the southwest of the Ridgeway Quadrangle (Secor and Wagener 1968), and Richtex-like sequences of metasedimentary rocks have been mapped in many areas in the Carolina terrane of western South Carolina and eastern Georgia (Secor and others, 1986a; Maher and Sacks, 1987). The age of the metamudstone and metasiltstone unit is interpreted to be Late Proterozoic to Early Cambrian, because it was deposited on Upper Proterozoic to Lower Cambrian volcanic rocks, and because (at the Ridgeway gold mine) it was mineralized at ~ 555 Ma (Stein and others, 1997). The metamudstone and metasiltstone unit resembles and may correlate with the Tillery Formation and the mudstone member of the Cid Formation in the lower part of the Albemarle Group in central North Carolina. However, this correlation is incompatible with the recently reported occurrence of euconodonts and fragments of gastropods and bryozoans that constrain the age of the Tillery Formation (in the lower part of the Albemarle Group) to be no older than early Middle Ordovician (Koeppen and others, 1995).

Feldspathic Phyllonite.

This unit (pŒfp in Figure 3, On Maps CD) is predominantly made up of quartz, albite, and sericite, locally with chlorite-rich layers. Map relationships in the central part of the Ridgeway–Camden area (Fig. 3) suggest that the feldspathic phyllonite occupies a shear zone, which formed during greenschist-facies regional metamorphism, and which is discordant to stratigraphic boundaries and structural fabrics in the Carolina terrane. These relationships indicate that the shear zone formed after the deposition and initial deformation of the Carolina terrane. The protolith of the feldspathic phyllonite is uncertain because of intense deformation. Rare locally preserved relict textures suggest derivation from felsite porphyry and/or felsic crystal-lapilli tuff. The feldspathic phyllonite unit locally occurs as predeformed enclaves and xenoliths in the Upper Proterozoic to Lower Cambrian Longtown metagranite (Barker and others, 1998). The above relationships indicate a Late Proterozoic to Early Cambrian age for the feldspathic phyllonite unit.

Mylonitic Gneiss.

The mylonitic gneiss unit (pŒmgn in Figure 3, on Maps CD) is predominantly mylonitic felsic gneiss, but in many places it contains mylonitic amphibolite layers up to several meters thick. This unit outcrops in the northwestern part of the Ridgeway–Camden area, and occupies a shear zone between the high-grade and low-grade parts of the Carolina terrane. Mineralogy and locally preserved relict textures indicate that this unit formed during amphibolite-facies regional metamorphism and was derived from migmatitic felsic gneiss and metagabbro (PŒgn) of the high-grade part of the Carolina terrane. Crosscutting relationships in the east-central Ridgeway Quadrangle (Fig. 3) indicate that the mylonitic gneiss is discordant to (and hence younger than) the feldspathic phyllonite unit. Some of the predeformed enclaves and xenoliths in the Upper Proterozoic to Lower Cambrian Longtown metagranite are interpreted to be derived from the mylonitic gneiss unit (Barker and others 1998). The above relationships suggest a Late Proterozoic to Early Cambrian age for the mylonitic gneiss unit.

Longtown Metagranite.

A large pluton of Longtown metagranite (pŒlg in Figure 3, on Maps CD) underlies northeastern Ridgeway and northwestern Longtown Quadrangles. In addition, two smaller plutons of the Longtown metagranite are located in the central and western parts of the Ridgeway Quadrangle. The Longtown metagranite is a heterogeneously deformed, fine- to medium-grained biotite metagranite. In thin section, it characteristically has well developed granophyric texture, suggesting shallow-level emplacement. The Longtown metagranite has a U-Pb zircon upper concordia intercept age of 549.1 ± 4.7 Ma and a weighted mean $^{207}Pb/^{206}Pb$ age of 551.2 ± 2.6 Ma (Barker and others, 1998), indicating Late Proterozoic to Early Cambrian emplacement. In most large exposures of Longtown metagranite, a system of anastomosing meso-to macroscale shear zones of strongly deformed to mylonitic metagranite enclose macroscale lenses of weakly deformed to undeformed metagranite. Along the southern and western edges of the large pluton, the Longtown metagranite intruded mylonitic gneiss, feldspathic phyllonite, and intermediate to felsic metatuff. Locally, in the south-central and eastern parts of the large pluton of Longtown metagranite, weakly deformed to undeformed metagranite encloses meso- and macroscale enclaves (Fig. 4) of strongly deformed mylonitic gneiss and feldspathic phyllonite. The above observations indicate that the enclaves acquired most of their deformational fabric prior to being intruded by the Longtown metagranite, but that the metagranite (as well as its enclaves) were variably overprinted by additional ductile deformation. The brittle Longtown fault forms the northeast boundary of the large Longtown pluton.

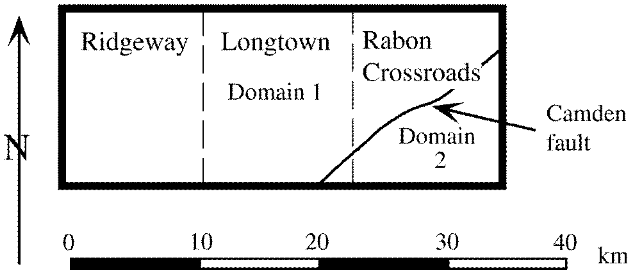

Figure 4. Location of the fabric domains in the Ridgeway-Camden area.

Miscellaneous Late- to Post-metamorphic intrusive rocks.

The above crystalline rocks are intruded by small, weakly deformed to undeformed, late- to post-metamorphic stocks, plugs, and dikes, some of which are not shown individually in Figure 3 (on Maps CD). Both metabasalt porphyry (mp) and felsic porphyry (fp) have been observed in outcrop to intrude the Longtown metagranite as well as some of the older crystalline rock units. Plugs of heterogeneously deformed metafelsite (mf) intrude both the Richtex Formation and the mylonitic gneiss unit in the northwestern part of the Longtown Quadrangle. Dikes and plugs of fine- to medium-grained biotite granite (gr) intrude the mylonitic gneiss unit and the metatuff unit. An elongate plug or sheet of megacrystic granite (grm) intrudes the migmatitic felsic gneiss and metagabbro unit in the northwestern part of the Ridgeway Quadrangle (Fig. 3). Our attempts to separate zircons from these miscellaneous late- to post-metamorphic intrusive rocks for geochronological studies have been unsuccessful.

Wateree Igneous Complex.

This unit outcrops in an irregular area, covering about 8 km^2, and is surrounded by the metamudstone and metasiltstone unit at the south end of Lake Wateree in the northeastern part of the Ridgeway–Camden area (pŒw in Figure 3, on Maps CD). The main rock type is quartz latite metaporphyry, containing conspicuous albite phenocrysts, up to 8 mm in diameter, embedded in a fine-grained matrix of plagioclase, alkali feldspar, quartz, and biotite (Mitchell, 1970). A variety of north-striking and steeply west-dipping metadikes, described as andesite, diorite, spessartite, and minette by Mitchell (1970), are also present in the complex. The complete absence of fragmental volcanic rocks, together with the porphyritic texture and fine-grained matrix, are interpreted to indicate a hypabyssal intrusive origin for the quartz latite. Incipient alteration to epidote and chlorite, together with the apparent absence of penetrative deformation fabrics, indicates that the Wateree igneous complex was intruded after the development of penetrative deformation fabrics in the Richtex Formation and during the waning stages of regional metamorphism.

Dutchmans Creek Gabbro.

Coarse-grained unmetamorphosed gabbro (the Dutchmans Creek gabbro of McSween, 1972) underlies much of the northwestern part of the Ridgeway–Camden area (Cgb in Figure 3, on Maps CD). A small gabbro plug in the central part of the Longtown Quadrangle may be an satellite body of the Dutchmans Creek gabbro. A detailed petrographic description of the gabbro is given in McSween and Nystro (1979). Surface mapping and geophysical surveys (Smith and Talwani, 1987) indicate that the gabbro is a barely exhumed downwardly concave sheet, less than 2 km thick. This shape is discordant to the shape of the Dutchmans Creek synform (Fig. 3), therefore the gabbro is interpreted to have been intruded following the development of the synform. The igneous crystallization age of the Dutchmans Creek gabbro has not been determined by radiometric dating. Mafic rocks, petrographically similar to the Dutchmans Creek gabbro, are abundant in the Siluro–Devonian Concord plutonic suite which intrudes the central part of the Carolina terrane (McSween and others, 1984; McSween and Harvey, 1997). Mafic rocks are also sparingly present in the suite of upper Paleozoic plutons which intrude the southeastern part of the Carolina terrane (Waskom and Butler, 1971; Speer and Hoff, 1997). The age of the Dutchmans Creek gabbro is here interpreted to be late Paleozoic, because it is located within this southeastern suite of upper Paleozoic plutons.

Sericite Phyllonite.

This unit outcrops over an extensive area in the southeastern corner of the Ridgeway–Camden area (Csp in Figure 3, on Maps CD), and is in part continuous, to the southwest in the Elgin (Blaney) Quadrangle, with the "laminated phyllite" unit of Ridgeway–and others (1966). West of the Wateree River, this unit is mostly a very mica-rich phyllonite although mesoscale lenses of quartzite, amphibolite, and mylonitic orthogneiss are locally present. East of the Wateree River, mesoscale lenses of mylonitic orthogneiss are an important secondary constituent of the sericite phyllonite unit. The protolith of the sericite phyllonite unit is uncertain. Rare locally preserved relict lapilli (?) and plagioclase crystals suggest an intermediate to felsic tuff protolith. Alternatively, it can be argued that the pelitic nature of the rock, as well as the rare locally preserved lenses of quartzite, indicate a shale or mudstone protolith with local interlayers of quartz sandstone. Perhaps the protolith for the sericite phyllonite unit was a stratigraphic section containing intermediate to felsic tuff interlayered with or adjacent to mudstone locally containing quartzite layers. Such a section is present along the boundary between the Persimmon Fork Formation and the Asbill Pond formation in the Carolina terrane of west-central South Carolina (Secor and others, 1986a). Our attempts to separate zircons from orthogneiss lenses in the sericite phyllonite, for geochronological studies, have been unsuccessful. $^{40}Ar/^{39}Ar$ age spectra for two whole-rock sericite phyllonite samples from the Rabon Crossroads Quadrangle south of the Camden fault both have plateau ages of ~265 Ma (R. D. Dallmeyer, personal communication, 1997). These are interpreted to indicate the time that the samples cooled through the ~350º C blocking temperature for white mica, which is the principal potassium-bearing constituent of the phyllonite. On the basis of these cooling ages, as well as based on regional geological and geophysical data and lithologic similarity, we interpret the sericite phyllonite unit to represent the northeastward continuation of the rocks of the Alleghanian Modoc shear zone, which coincides with the southeastern side of the exposed Carolina terrane in western South Carolina and Georgia (Secor and Snoke, 1978; Secor and others, 1986a; Maher and Sacks, 1987; West and others, 1995).

Mylonitic Orthogneiss.

This unit (Cogn in Figure 3, on Maps CD) is present in the east-central part of the Ridgeway–Camden area, and it is adjacent to the northwest side of the sericite phyllonite unit. There are no direct geochronological data bearing on the age of this unit. Because of its apparent association with the sericite phyllonite unit, however, it is interpreted to be a deformed upper Paleozoic granite in the northeastern continuation of the Modoc shear zone.

Mesozoic Diabase Dikes.

All of the previously described crystalline rocks are intruded by unmetamorphosed Mesozoic diabase dikes (Dooley and Smith, 1982; Bell, 1988; Ragland 1991). In the Longtown and Ridgeway Quadrangles, the average strike of diabase dikes is N 30W, and the normal thickness of individual dikes is 1-10 m. A prominent swarm of diabase dikes crosses the eastern and central parts of the Longtown Quadrangle (Fig. 3).

Kaolinitic Sand.

The above crystalline rocks are unconformably overlain by a southeastwardly thickening wedge of unconsolidated-to weakly consolidated cross-bedded kaolinitic sand containing sparsely distributed small quartz pebbles and kaolin pellets (Ks in Figure 3, on Maps CD). A 0-2 m-thick angular quartz lag gravel is found immediately above the unconformity that separates this unit from the underlying crystalline rocks. In the Ridgeway–Camden area, the unconformity at the base of the kaolinitic sand slopes gently southeastward at about 5-7 m/km. The thickest part of this unit is in the southeastern corner of the Ridgeway–Camden area where 30-35 m of strata are present. The kaolinitic sand unit is correlated with the Upper Cretaceous Middendorf Formation (Heron, 1958; Nystrom and others, 1991). On Cross Section B-B' of Colquhoun and others (1983), the kaolinitic sand unit is shown equivalent to strata bearing undifferentiated Coniacian-Turonian microfossils in the coastal area. Younger overlying Campanian and Maastrichtian aged strata of the Black Creek and Peedee are eroded in the subsurface. Generally, the Coniacian aged Cape Fear Formation underlies the Middendorf in more coastal areas, but the lithotype does not extend to the surface near the Fall Line.

Upland Gravels.

This unit is characterized by 1-3 m-thick layers and lenses of well-rounded quartz pebbles and cobbles interbedded with sand layers up to 5 m thick (Tg in Figure 3, on Maps CD). In most places the sands and gravels are stained reddish-brown, although buff to white sands and gravels are also locally present. This unit rests unconformably on both the pre-Mesozoic crystalline rocks and on the kaolinitic sands of the Middendorf Formation. The unconformity slopes gently southeastward at about 2-3 m/km. In the Ridgeway–Camden area, the upland gravels occur principally as erosional remnants capping hills adjacent to the Wateree River (Fig. 3).

The upland gravels are interpreted to represent the Citronelle Gravels of Doering (1960), as well as the informal “upland unit” of Nystrom and others (1991) and Colquhoun and others (1993). These gravels occur widely in the Upper Coastal Plain of central and western South Carolina, Georgia, and Alabama, north of the Georgia Trough. The upland gravels were interpreted to be Early Pleistocene by Doering (1960), Miocene by Nystrom and others (1991), and Oligocene by Colquhoun and others (1993). More recently, a regional comparison of dipping unconformity surfaces plotted against time indicate an Early Oligocene (Chattian, pre-Tejas B) age for the base of the “upland unit” (Colquhoun, 1995). Regional mapping and power augering in the “upland” and other units in the Upper, Middle, and Lower Coastal Plains have yielded lithologic and fossil data which indicate a Chattian (Early Oligocene) age for the Chandler Bridge lithologies (Katuna and others, 1997). The Chandler Bridge lithologies are interpreted either to be the downdip equivalent of the upland gravels or to have been derived from the upland gravels as a source. A Chattian or possibly even earlier Jacksonian Age is thus indicated for the upland gravels.

Alluvium.

This unit consists of thin patches of clay, sand, and gravel deposited on the modern stream floodplanes (Qal in Figure 3, on Maps CD). Locally, where resting unconformably on crystalline rock, the alluvium is cemented by iron and manganese oxides.

Ductile Deformation Fabric

The Ridgeway–Camden area has a protracted and complex deformational history. As indicated in the preceding section, many of the crystalline rock units contain ductile deformation fabrics, and there is also good evidence for macroscale folds and major brittle faults. Our data on the ductile deformation fabrics are divisible into two domains separated by the Camden fault, which is located in the southeastern part of the Ridgeway–Camden area (Fig. 4).

Domain 1.

In most places, the Longtown metagranite and older rock units (see explanation for Figure 3, on Maps CD) contain a foliation (**S**) and an associated elongation lineation (**L**) in the plane of **S**. **S** results from the alignment of platy minerals (such as sericite, biotite, and chlorite) as well as from the preferred orientation of dynamically recrystallized mineral aggregates, and, in metavolcanic rocks, from the preferred orientation of strained relict lapilli. **L** results from the preferred orientation of elongate minerals such as hornblende, as well as from the elongation of dynamically recrystallized mineral aggregates and lapilli. Stereoplots of **S-L** data from various rock units in domain 1 (Figs. 5a-5d) are similar to each other. The average orientations of **S** and **L**, are approximately N 75º W, 32 NE and 12º N 83º E, respectively. Poles to **S** are weakly dispersed along girdles having axes about parallel to the average orientation of **L**. Data from the northwestern part of the Ridgeway–Camden area (Figs. 3 and 5f) indicate that **S** has been folded into a synform (the Dutchmans Creek synform) plunging 35º N, 66º E, and the dispersion of **S** data from elsewhere in domain 1 may be, in part, a consequence of folding about northeast-plunging axes. The predominant northwest strike and northeast dip of **S** in Figures 5a-5d is interpreted to indicate that the **S** data is derived predominantly from stations on the south limbs of northeast-plunging synforms. In many places, **S** foliation planes contain low-amplitude crenulations resulting from the intersection of a weak crenulation cleavage with **S**. There is a weak preferred orientation of the crenulations at 10º N 75 E, about parallel to **L**, but there is substantial scatter to the data (Fig. 5e). Most of the crenulation data are from rock units older than the mylonitic gneiss unit, although crenulations were observed in a few places in the Longtown metagranite.

The intensity of development of the **S-L** fabric varies spatially in domain 1. Mylonitic and phyllonitic fabrics are most strongly developed in the mylonitic gneiss and feldspathic phyllonite units, respectively, and these units comprise shear zones between less strongly deformed rocks. The termination of the feldspathic phyllonite unit against the mylonitic gneiss unit in the west-central part of the map area (Fig. 3) indicates that the shear zone occupied by the feldspathic phyllonite is older than the shear zone occupied by the mylonitic gneiss. The apparent interlayering of mylonitic gneiss with felsic metatuff in the west-central part of the map area is interpreted to indicate ductile, synkinematic imbrication of slices of metatuff into the shear zone containing mylonitic gneiss. The general position of the mylonitic gneiss unit between the low- and high-grade parts of the Carolina terrane indicates that the two rock sequences have been juxtaposed by motion along the shear zone containing the mylonitic gneiss unit. The gently east-plunging elongation lineations in the sheared rocks (Figs. 5a-5d) indicate the predominant movement direction during shearing. Further interpretations of the kinematics of the above shear zones are difficult because the sheared rocks have been folded, and because consistent shear sense indicators have not been found in the mylonitic and phyllonitic rocks. Regionally, the high-grade metaplutonic rocks in the interior of the Carolina terrane (pŒgn unit in Figure 3, on Maps CD) are interpreted to underlie the low-grade metavolcanic and metasedimentary rocks to the southeast. The progressive northward reduction of the dip of **S** in the low-grade rocks of the Carolina terrane (see cross section A-A' in Figure 3, on Maps CD) is interpreted to be a consequence of drag adjacent to the shear zone containing the mylonitic gneiss unit. If the mylonitic gneiss unit juxtaposes the high- and low-grade sequences, and if **L** is taken to indicate the direction of shearing, then the sense of drag implies dextral motion (in plan view) for the shear zone containing the mylonitic gneiss unit (in its present orientation). The dispersion of **S** along girdles having gentle east-plunging axes (e.g. Fig. 5a) may, in part, be a consequence of the above drag.

As previously noted, undeformed or weakly deformed parts of the Longtown metagranite contain xenoliths and enclaves of mylonite gneiss and crenulated phyllonite. These observations indicate that the Longtown metagranite postdates the development of mylonitic and crenulated phyllonitic fabrics in the older rocks. Nevertheless, the Longtown metagranite itself carries a spatially heterogeneous **S-L** fabric, and the average orientations of **S** and **L** in the Longtown metagranite are similar to the average orientations of **S** and **L** in older rocks. The above data indicate that the Longtown metagranite was emplaced late synkinematically relative to the ductile deformation event that was responsible for the development of the **S-L** fabric.

The intermediate to felsic metatuff unit, which was erupted prior to the development of **S-L** fabric in the in the Ridgeway–Camden area, has a U-Pb zircon upper concordia intercept age of 557 ± 15 Ma, and a weighted mean $^{207}Pb/^{206}Pb$ age of 550.5 ± 5.9 Ma (Barker and others, 1998). The Longtown metagranite, which is late synkinematic relative to the development of **S-L** fabric, has a U-Pb zircon upper concordia intercept age of 549.1 ± 4.7 Ma and a weighted mean $^{207}Pb/^{206}Pb$ age of 551.2 ± 2.6 Ma (Barker and others, 1998). The above geochronological data indicate that the stratigraphic units in Domain 1 of the Carolina terrane in the

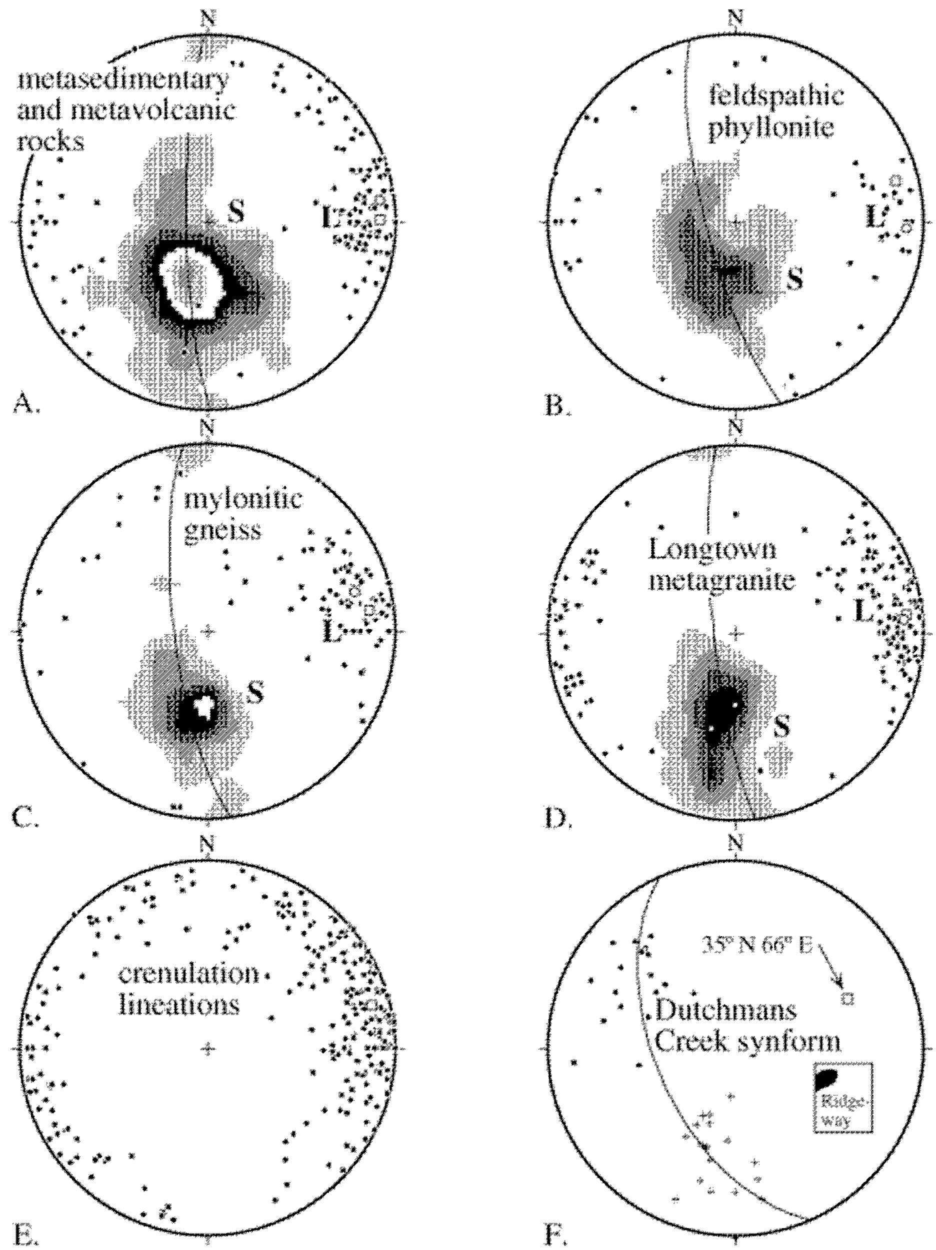

Figure 5. Lower-hemisphere, equal-area projections of structural data from the Ridgeway and Longtown Quadrangles in Domain 1. Contoured data are poles to foliation (S). Black dots are lineations measured in the foliation planes. Open squares indicate positions of poles to best-fit great circles passed through the poles to S, and open circles indicate mean lineation orientations. A: Poles to 599 S foliation planes (contour: 1% per 1% area) and scatter plot of 145 L elongation lineations from the felsic tuff (pŒft) and metasedimentary (pms) units. B: Poles to 149 S foliation planes (contours: 2% per 1% area) and scatter plot of 46 L elongation lineations from the feldspathic phyllonite unit (pŒfp). C: Poles to 229 S foliation planes (contours: 2% per 1% area) and scatter plot of 99 L elongation lineations from the mylonitic gneiss unit (pŒmgn). D: Poles to 279 S foliation planes (contours: 2% per 1% area) and scatter plot of 167 L elongation lineations from the Longtown metagranite (pŒlg). E: Scatter plot of 264 crenulation lineations from the felsic metatuff (pŒft), metasedimentary (pŒms), and feldspathic phyllonite (pŒsp) units. F: Structural data from the mylonitic gneiss unit (pŒmgn) in the flanks of the Dutchmans Creek synform. Dots indicate poles to 20 S foliation planes from the northwest flank and plus signs indicate poles to 20 S planes fro the southeast flank. Inset of the Ridgeway Quadrangle shows the location of the domain from which the data were taken.

Ridgeway–Camden area were rapidly deposited and deformed during the Late Proterozoic to Early Cambrian, because the boundary between the Precambrian and Paleozoic is now considered to be ~ 544 Ma (Bowring and others, 1993).

Domain 2.

All of the crystalline rocks southeast of the Camden fault contain a foliation (**S**), and locally an elongation lineation (**L**). **S** results from the parallel alignment of micas and chlorite and is most strongly developed in the sericite phyllonite unit. **L** results from the parallel alignment of recrystallized quartz ribbons and tails of feldspar porphyroclasts and is most evident in granitic orthogneiss. The average orientations of **S** and **L** are respectively N 62º E, 69º NW and 15º N 68º E, and the poles to **S** are weekly dispersed along a girdle having an axis oriented 9º N 56º E (Fig. 6). The orientations of fabric elements in Domain 2 (Fig. 6) differ substantially from the orientations of fabric elements in Domain 1 (Fig. 5), although domain 2 fabric orientations are very similar to fabric orientations described from rocks of the Modoc shear zone in central and western South Carolina (Secor and Snoke, 1978; Secor and others, 1986a; Dennis and Secor, 1987; Sacks and Dennis, 1987). The above data are compatible with our interpretation that the rocks in Domain 2 of the Ridgeway–Camden area represent a northeastward continuation of the Alleghanian Modoc shear zone.

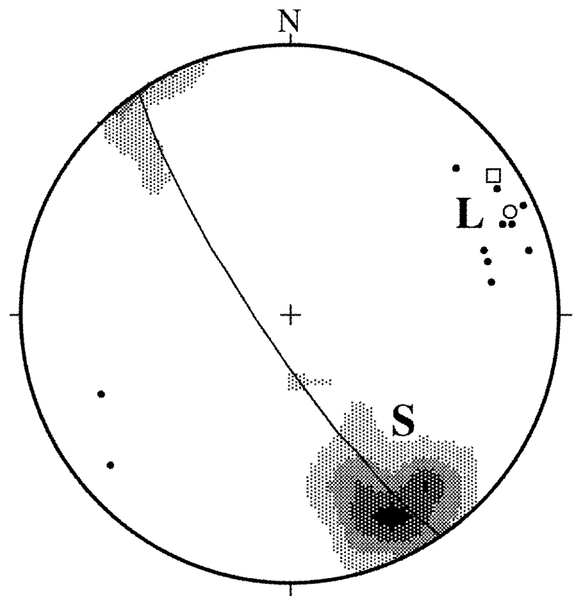

Figure 6. Lower-hemisphere, equal-area projection of Poles to 87 S foliation planes (contours: 3% per 1% area) and scatter plot of 11 L elongation lineations from Domain 2 of the Ridgeway–Camden area, South Carolina. Open square indicates positions of pole to great circle, and open circle indicates mean lineation orientation.

Brittle Faulting

The Ridgeway–Camden area contains three major brittle fault zones that were recognized because they interrupt the continuity of map units and are associated with extensive fracturing and brecciation of the crystalline rocks (the Ridgeway, Longtown, and Camden faults on Fig. 3). Several smaller unnamed faults, characterized by the presence of silicified breccia, are also present, but these do not seem to significantly interrupt map units.

RidgewayFault.

The Ridgeway fault was first recognized near the town of Blythewood in the Blythewood Quadrangle (Fig. 1), where it juxtaposes the intermediate to felsic metatuff unit on the west against the metamudstone and metasiltstone unit on the east (Paradeses and others, 1966). It can be traced to the north into the western part of the Ridgeway Quadrangle, to a point about 3 km north of the town of Ridgeway, where it apparently dies out. Neither the dip nor the amount and direction of net slip are known for the Ridgeway fault. Its age is loosely delimited by the fact that it cuts rocks that were deposited and acquired penetrative deformation fabric in the Late Proterozoic to Early Cambrian and apparently does not cut the Upper Cretaceous kaolinitic sand unit. The above characteristics of the Ridgeway fault are similar to those of the Wateree Creek fault, which is a steeply west-dipping, reverse fault located about 20 km to the west, near Chapin, South Carolina (Simpson, 1981; Secor and others, 1982).

Longtown Fault Zone.

The Longtown fault zone strikes west-northwest, diagonally across the Ridgeway–Camden area (Fig. 3). At its eastern end, the Longtown fault zone apparently terminates against the Camden fault. At its western end, it either dies out or is interrupted by the Dutchmans Creek gabbro in the northern part of the Ridgeway Quadrangle. The Longtown fault zone is associated with substantial fracturing and brecciation of the crystalline rocks. In some traverses across the fault zone, its position can be located by the presence of fragments of silicified breccia containing small open cavities lined with tiny quartz crystals. Apparently there are multiple surfaces of movement in the Longtown fault zone, as manifested by mapable splays that curve away from the main fault trace, and by the presence of macroscale slices of various crystalline rock units within the fault zone (Fig. 3). Although the dip and net slip of the Longtown fault zone are unknown, the amount of net slip is interpreted to be large, on the order of hundreds or thousands of meters, based on the apparent disruption of the Upper Proterozoic to Lower Cambrian crystalline rock units. The Longtown fault zone may locally coincide with the south contact of the Dutchmans

Creek gabbro, but it is not clear if the gabbro is significantly offset by the fault zone or if the fault zone was later intruded by the gabbro. In the northwestern part of the Longtown Quadrangle, the Upper Cretaceous kaolinitic sand unit is cut by strands of the Longtown fault zone (Fig. 3). Map relationships here indicate an apparent north-side-up vertical separation of the unconformity at the base of the kaolinitic sand unit in excess of 20 m. Based on the map relationships described above, the Longtown fault zone is interpreted to have had multiple episodes of motion, beginning in the Late Proterozoic or early Paleozoic, and continuing at least until the Late Cretaceous.

Camden Fault.

The northeast-striking Camden fault is located in the eastern part of the Ridgeway–Camden area (Fig. 3). Northwest of the Camden fault, the crystalline rock units clearly are part of the Carolina terrane and contain a penetrative **S-L** deformation fabric that formed in the Late Proterozoic to Early Cambrian (Figs. 4 and 5). Southeast of the Camden fault, the orientation of the penetrative **S-L** deformation fabric in the crystalline rocks is different from the orientation to the northwest (compare Figures 5 and 6), and the **S-L** fabric is interpreted either to have formed in the late Paleozoic or to have been strongly modified by additional deformation in the late Paleozoic. The crystalline rocks southeast of the Camden fault are interpreted to be part of the Alleghanian Modoc shear zone. It is uncertain if the crystalline rocks southeast of the Camden fault are part of the Carolina terrane, although lithologies southeast of the fault resemble lithologies in the Carolina terrane of western South Carolina (Secor and others, 1986a). The net slip of the Camden fault is uncertain, although it seems that the late Paleozoic and/or Mesozoic displacement would have to be on the order of kilometers to explain the apparent disruption of the crystalline rock units.

At two locations (one in the northeastern corner of the Rabon Crossroads Quadrangle, and the other in the southeastern corner of the Longtown Quadrangle) the Upper Cretaceous kaolinitic sand unit is cut by the Camden fault. Map relationships in the northeastern Rabon Crossroads Quadrangle (Fig. 3) suggest a northwest-side up vertical separation of the unconformity at the base of the sand unit of ~25 m. Map relationships at the southeastern corner of the Longtown Quadrangle (Fig. 3) suggest a northwest -side-up vertical separation of the unconformity of ~17 m.

An auger drilling program was undertaken in order to confine in time the apparent offsets of the Coniacian-Turonian kaolinitic sand unit. Auger drilling along a north-south profile following a county road near the eastern edge of the Rabon Crossroads Quadrangle, indicated that the unconformity at the base of the Upper Cretaceous sand unit is flexed into a gently southeast-dipping faulted monocline, with a northwest side-up stepwise offset of 20 m coinciding with the position of the Camden fault. To the west, an abrupt downstream widening of the Holocene floodplain of the Wateree River coincides with the location where the Camden fault crosses the river (Fig. 3). Southwestward projection of the apparent fault line to South Carolina state highway # 5 (in the southwestern part of the Rabon Crossroads Quadrangle) provided a second location for an auger drill-hole section across the fault trace. At this location, the northwestern edge of the Upper Cretaceous kaolinitic sand unit was truncated by the Camden fault and then overlain unconformably by the upland gravel unit. At this location, the vertical separation of the unconformity at the base of the Upper Cretaceous sand unit was in excess of 17 m, with the northwest side relatively up. If the upland gravel unit is displaced by the Camden fault (and this has not been observed to date), the vertical separation must be less than a meter, which is the best accuracy attainable by the methods employed in this investigation. The results of auger drilling indicate that the Camden fault dips steeply, but the direction and exact amount of dip are unknown. The trace of the fault has been located to within a few meters along South Carolina route #5.

The above observations suggest that the last motion along the Camden fault occurred after the Coniacian-Turonian Late Cretaceous but before Late Eocene Jacksonian and/or Oligocene Chattian. A Late Middle Eocene to Late Eocene tectonic distortion of unconformities, such as that reported in other locations by Colquhoun and others (1983; see cross-section E-E' and contour maps 6 and 7) and by Colquhoun (1995), may also be associated with the Camden fault.

DISCUSSION

Origin and Accretionary History of the Carolina Terrane

There are three lines of evidence indicating that the Carolina terrane is an exotic terrane incorporated into the Appalachian orogen. Secor and others (1983) and Samson and others (1990) described an assemblage of Middle Cambrian trilobites from the upper mudstone member of the Asbill Pond formation in the Carolina terrane of western South Carolina. The upper mudstone member is interpreted to rest with angular unconformity on older rocks in the Carolina terrane (Dennis and others, 1993). The trilobite assemblage is most similar to cool water faunas presently found in the peri-Gondwana terranes of eastern Europe, and is not like the warm water faunas that characterize Middle Cambrian rocks deposited on Laurentia. The above data indicate that the Carolina terrane was located far from Laurentia in the Middle Cambrian. Several petrological and geochemical studies have been conducted to determine the plate tectonic setting in which the metavolcanic rocks of the Carolina terrane were erupted (Butler and Ragland, 1969b; Whitney and others, 1978; Black, 1980; Bland and Blackburn, 1980; Feiss, 1982; Rogers, 1982; Shervais and others, 1996). All of these studies agree that the Carolina terrane represents a subduction-related volcanic arc. The studies of Samson and others (1995), Wortman and others (1995), and Fullagar and others (1997) indicate that the oldest part of the arc formed on oceanic crust at ~610 Ma, which is approximately 60 m.y. prior to the opening of Iapetus (Bond and others, 1984; Simpson and Eriksson, 1989). By the latest Proterozoic, the arc may have been situated over Mesoproterozoic crust (Muller and others, 1996). The results of recent high-precision U-Pb zircon dating of pre-tectonic, syn-tectonic, and post-tectonic plutonic and volcanic rocks (Hibbard and Samson, 1995; Wortman and others, 1995; Dennis and Wright, 1997; Barker and others, 1998) are interpreted to indicate that the Carolina terrane was pervasively deformed during 557-535 Ma, at a time when a passive continental margin was beginning to form at the southeastern margin of Laurentia. The above data indicate that the Carolina terrane is exotic relative to Laurentia and formed outside of Iapetus.

At present, there is substantial disagreement among various workers concerning the time of the initial accretion of the Carolina terrane to Laurentia. Historically, the penetrative deformation fabrics in most of the Carolina terrane were interpreted to have formed during a "Taconic" (Butler, 1972, 1991; Hatcher and Odom, 1980; Glover and others, 1983) or "Acadian" (Hatcher, 1989) accretion to Laurentia, and the scattered early and middle Paleozoic $^{40}Ar/^{39}Ar$ cooling ages in the Carolina terrane (Kish and others, 1979; Sutter and others, 1983; Dallmeyer and others, 1986; Noel and others, 1988; Offield and others, 1995) have been interpreted to indicate cooling during or following these orogenic events. Field and U-Pb zircon geochronological studies, however, indicate both that the penetrative deformation fabric within portions of the Carolina terrane is Late Proterozoic to Early Cambrian (Hibbard and Samson, 1995; Wortman and others, 1995; Dennis and Wright, 1997; Barker and others, 1998), and that the oldest documented faults at the boundary of the Carolina terrane are Alleghanian (Dallmeyer and others, 1986; Horton and others, 1987; Student and Sinha, 1992; West and others, 1995; Hibbard and others, 1998; West, 1998; Wortman and others, 1998). It seems possible that accretion to Laurentia did not occur until the Alleghanian, and that the early and middle Paleozoic $^{40}Ar/^{39}Ar$ cooling ages in the interior of the Carolina terrane indicate deformation and/or plutonism far from Laurentia.

Character of the Boundary between the High- and Low-grade Parts of the Carolina Terrane

Recently, it has been suggested that the boundary between the high-grade metaplutonic rocks in the interior of the Carolina terrane and the low-grade metavolcanic and metasedimentary rocks to the southeast is a major fault (Offield, 1995) or ductile shear zone (Doar and Lawrence, 1996; Barker and others, 1998; Lawrence and others, 1998). We suggest that the mylonitic gneiss unit, in the northwestern part of the Ridgeway–Camden area, is a manifestation of such a major shear zone separating the high-grade interior of the Carolina terrane from the low-grade southeast flank. Our reconnaissance, and reinterpretation of the mapping of Peck (1981), Simpson (1981), Pitcher (1982), Smith (1982), Halik (1983), and Kirk (1985) suggests that the mylonitic gneiss unit can be traced at least ~100 km to the west, to the southern part of the Silverstreet Quadrangle. The mapping and geochronological studies of Barker (1998) and Barker and others (1998) show that the protolith of the mylonitic gneiss unit is the migmatitic felsic gneiss and metagabbro unit in the interior of the Carolina terrane, and that the mylonitic deformation manifested in the gneiss unit is Late Proterozoic to Early Cambrian. The Upper Proterozoic to Lower Cambrian Longtown metagranite is a stitching pluton in the shear zone. These relationships indicate that the high- and low-grade parts of the Carolina terrane have been proximal to each other since the Late Proterozoic to Early Cambrian. The east-trending elongation lineation in the mylonitic gneis unit indicates the direction of the relative motion between the high- and low-grade parts of the Carolina terrane. As previously indicated, **S** foliation drag in the low-grade part of the Carolina terrane adjacent to the shear zone containing the mylonitic gneiss unit suggests that the sense of shear is dextral in plan view.

Controls on the Location of Late Cretaceous and Younger Faults in the Piedmont and Coastal Plain

The presence of Late Cretaceous and younger faults in the southeastern United States is of considerable practical importance, because the proximity of young faults to dams and nuclear facilities can affect the engineering design and ultimate safety of the structures. Late Cretaceous and younger faults are difficult to identify in the Piedmont because of the general absence of upper Mesozoic and Cenozoic stratigraphic units. The Late Cretaceous or younger motions of the Longtown and Camden faults were recognized because of the apparent vertical separation of the basal Late Cretaceous unconformity in the region. Examination of the geology of the crystalline rocks proximal to the Longtown and Camden faults suggests some general guides that aid in the recognition of places in the Piedmont where Cretaceous or Cenozoic faulting may have occurred. For example, it is clear that the pre-Late Cretaceous movement of the Longtown and Camden faults is much greater than the Late Cretaceous or younger motion. In essence, these faults experienced minor reactivation during or after the Late Cretaceous. It follows that major brittle fault zones in the crystalline rocks are locations where young fault motions should be suspected. If the presence of young faults is of critical importance at a particular facility, detailed investigations such as trenching, geochronological studies, and seismic profiling should be carried out across nearby brittle fault zones prior to construction. Most of the Late Cretaceous or younger faults identified in Georgia and the Carolinas strike northeast (Bramlett and others, 1982; Prowell and Obermeier, 1991; Aadland and others, 1995; Domoracki, 1995). Northwest-striking faults should not be ruled out as potentially hazardous, however, because in the present study the north–northwest-striking Longtown fault apparently records Late Cretaceous or younger motion.

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PRELIMINARY MESOZOIC-CENOZOIC BRITTLE-DEFORMATION HISTORY OF EOCAMBRIAN ROCKS (RIDGEWAY GOLD MINE, SOUTH CAROLINA), CAROLINA TERRANE

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ABSTRACT

Fracture sets characterizing the brittle deformation in the Ridgeway mine are divided into five age groups: Group I: Triassic (four sets); Group II: Jurassic (two sets); Group III: Cretaceous to Late Eocene (five sets); Group IV: Late Eocene to Oligocene (three sets); and Group V: Miocene to Quaternary (two sets). Group I Triassic fractures are generally coated with chlorite+pyrite (***ch+py***), but a few exhibit pink staining prior to ***ch+py*** mineralization, a characteristic of similarly oriented (E-W-trending and NE-SW-trending) fracture sets of Triassic age in Alleghanian granites near Columbia, South Carolina. As in Alleghanian granites, the Group I Triassic fracture sets indicate that ~N-S extension was followed by NW-SE extension, respectively inferred to be related to development of the South Georgia basin followed by development of NE-trending rift basins in North Carolina and Virginia. As indicated in Alleghanian granites, the N-S-trending Group II Jurassic fractures with ***ch+py*** mineralization predate NW-trending, generally nonmineralized (±***cal***), Jurassic fractures. This relationship suggests that N-trending diabase dikes preceded NW-trending diabase dikes.

Group III fracture sets reflect a progressive counterclockwise 90^o rotation of s_3 from N-S to E-W. Following Late Eocene deformation characterized by ~N-S compression, Group IV fracture sets reflect a progressive clockwise 50o rotation of s_3 from NE-SW to WNW-ESE. The older Group V fracture set supports that s_3 was ~N-S during most of the Neogene; whereas the younger Group V fracture set trends NE, reflecting a NW-trending s_3 consistent with the present-day stress field.

INTRODUCTION

The Ridgeway Mine provides a unique opportunity to examine fracture sets in Eocambrian rocks of the Carolina Terrane at depths sufficiently below weathering to preserve the original mineralogy of fracture coatings and small vein fillings. Fracture ornamentation, such as plumose markings, pinnate fractures, or slickenlines either beneath or on top of mineral coatings, is better preserved in fresh exposures. The orientation, size, ornamentation and/or mineralization of fracture sets in the lower levels of the mine can be associated with both their weathered counterparts in the upper levels of the mine and surface exposures of similar rocks in the region.

Many geologic features in the mine are involved in the pre-Mesozoic deformation of these rocks. These include large quartz veins (typically >5cm width and >2m in length or height), rock-unit contacts, mafic dikes, and a granitoid dike (e.g., Gillon and others, 1998, this volume). These features may have individual contact-surfaces that are favorably oriented (e.g., Sibson, 1990) for reactivation as brittle fractures during either Mesozoic rifting or younger deformation.

Of particular importance is the resolution of several questions.

1. How many brittle fracture sets are present in these rocks? What are their attitudes, characteristics, and relative ages?
2. Are brittle-fracture sets that predate initiation of Mesozoic rifting (i.e. unrelated to, and post-dating early ore mineralization and Eocambrian penetrative deformation/metamorphism) present in these Precambrian rocks? Such fracture sets can only be recognized if they are both older than, and have different attitudes and mineralization than sets associated with Mesozoic rifting.
3. Were any pre-Mesozoic or Mesozoic fracture sets reactivated during subsequent deformation?
4. Are the youngest fractures consistent with the present-day stress field?

The structural analysis presented here is based on >550 individual measurements, with >250 observations of age relationships, from two locations in the north pit (one crossing a granitoid dike) and two locations in the south pit. Thus our sample population is still relatively small and does not yet include either fluid inclusion data or data from the upper weathered levels of the mine. We regard the analysis therefore as preliminary. Nonetheless, the data are sufficient to establish a general sequence of fracture sets and to answer the questions posed above.

REGIONAL GEOLOGY

The regional geology of the Ridgeway-Camden area is discussed in Secor and others (1998, this volume) and the geology of the Ridgeway gold mine is discussed by Gillon and others (1998, this volume). These papers and their references review past and current ideas regarding evolution of the Carolina Terrane, its amalgamation to Laurentia, and the origin of gold mineralization at Ridgeway. As used in papers for this volume, the Precambrian-Cambrian boundary is considered to be ~544 Ma (Bowring and others, 1993). Important contributions of the papers for this volume that are relevant to our study are:

- The Carolina Terrane evolved as an Eocambrian volcanic arc that was exotic to Laurentia (e.g., Secor and others, 1983; Samson and others, 1990; Wortman and others, 1995) and was pervasively deformed during the transition from Precambrian to Cambrian (e.g., Dennis and Wright, 1997; Barker and others, 1998) prior to Alleghanian amalgamation to Laurentia (e.g., Hibbard and others, 1998; West, 1998; Wortman and others, 1998).
- The Longtown metagranite was emplaced (~550 Ma) near the end of the latest Precambrian deformation (Barker and others, 1998) and a relatively undeformed dike of Longtown metagranite cuts across the north pit of the mine (see map in Gillon and others, 1998, this volume).
- Syngenetic ore mineralization (Spence, 1980) and any major ore remobiliation at the mine was completed by the end of the Eocambrian deformation.
- Large quartz veins and siliceous zones in the mine are associated with ore mineralization and Eocambrian deformation. Younger brittle deformation was also noted in the mine.
- Fabric related to the Alleghanian Modoc shear zone is found in rocks southeast of the Camden fault in the Ridgeway-Camden area but is lacking near the mine area.
- NW-trending Jurassic diabase dikes cut across Carolina Terrane rocks in the Ridgeway-Camden area (see map in Secor and others, 1998, this volume). The average trend of these dikes is N30^{o}W.
- Three faults characterized by brittle deformation and siliceous breccia are mapped in this area (see map in Secor and others, 1998, this volume). These faults are: 1) the ~N-trending Ridgeway fault; 2) the WNW-trending Longtown fault zone; and 3) the NE-trending Camden fault, which displaced Upper Cretaceous sediments.

PREVIOUS WORK AND METHODS

Recent fracture work has focused on fracture sets within the Alleghanian granites (~300 Ma) of the Piedmont of South Carolina and Georgia (e.g., Bartholomew and others, 1997a; Evans and Bartholomew, 1997; Heath and Bartholomew, 1997) because all fracture sets therein must necessarily be late or post-Alleghanian. Fracture sets within the Alleghanian granites thus provide a Mesozoic to Cenozoic sequence for correlation with the sequence of fracture sets within Coastal Plain strata (e.g., Brodie and Bartholomew, 1997; Bartholomew and others, 1997b) to establish the Mesozoic to Cenozoic deformational history of this region (Bartholomew, 1998). This sequence can then be compared with fracture data from drill core beneath the U.S. D.O.E. Savannah River Site (e.g., Dennis and others, 1997; Huner and others, 1997) as well as with previous work on brittle-fault zones with siliceous cataclasitic rocks in the Piedmont of northwestern South Carolina (e.g., Garihan and Ranson, 1992) and adjacent North Carolina (Garihan and others, 1993).

The preliminary fracture sequence presented below is based on the following types of observations:

- intersecting joint relationships;
- crosscutting fault or vein relationships;
- indicators of fault-slip directions (e.g., Petit, 1987);
- the sequence of mineral coatings on individual fractures or on intersecting fractures;
- the relationships of slickenlines to mineral coatings and to joints subsequently reactivated as faults.

Measurements, diagrams, and discussion of fracture attitudes all follow the right-hand convention with strikes fro 001^{o} to 360^{o} measured clockwise from north with the surface dipping to the right, dips from 000^{o} to 090^{o}, and pitches from 001^{o} to 180^{o} measured from the strike direction.

We compared fracture sets and age relationships within the relatively undeformed Eocambrian Longtown granitoid dike (~550 Ma) that is offset by a brittle fault (see map in Gillon and others, 1998, this volume) with those in the surrounding Precambrian country rocks. If the country rocks contained fracture sets that were older than the earliest set in the dike then that relationship would constitute evidence of Precambrian brittle deformation. The dike, however, contains the same fracture sets as the country rocks.

FRACTURE SEQUENCE

Our sequence for the Ridgeway mine (Table 1) is in good agreement with the regional sequence developed for the Alleghanian granites (e.g., Bartholomew and others, 1997a; Heath and Bartholomew, 1997; Bartholomew, 1998). The Ridgeway fracture sequence consists of four sets interpreted to have formed during the Triassic (Group I), followed by two sets interpreted to have formed during the Jurassic (Group II), followed by three sets which are interpreted to have preceded Late Eocene ~N-S compression (Group III), followed by five sets (Groups IV and V), the youngest of which is oriented ~045° ±25° consistent with the modern stress field.

Table 1: Fracture Sets at the Ridgeway Gold Mine

Group	Age	Set	JT Trend	Mineralization	s_3
I	Triassic	TR1	285	(PS); ch+py	195
I	Triassic	TR2	065	PS; ch+py	155
I	Triassic	TR3	205	PS; ch+py; cal	115
I	Triassic	TR4	045	(PS); ch+py; cal	135
II	Jurassic	JR1	185	(PS); ch+py or py; cal	275
II	Jurassic	JR2	325	NM; (cal)	235
III	Cretaceous	K1	270	cal	360
III	Cretaceous	K2	245	NM	335
III	Paleocene	P1	215	NM	305
III	Eocene	E1	355	NM	265
III	Eocene	ERF		NM	~270
IV	Eocene	E3a	135; 155	NM	~235
IV	Eocene	E4	170	NM	260
IV	Oligocene	O1	195	NM	285
V	Miocene	M1	275; 085	NM	~360
V	Quaternary	Q1	045	NM	315

FRACTURE COATINGS

The principal types of mineral coatings observed on fractures are: PS-pink staining (26 fractures); ch-chlorite (123); py-pyrite (115); cal-calcite (79); and lim-limonite (31). Populations of ep-epidote (3); hem-hematite (6); mn-manganese oxides (11); and cpy-chalcopyrite (7) coated fractures are also present but not yet encountered often enough for meaningful analysis. Many fractures (116) are nonmineralized (NM). Where fractures could not be determined to be either nonmineralized or coated, they were labeled as unknown. We did not attempt to distinguish among various quartz veins without fluid inclusion data. Although some small quartz veins may be related to early Mesozoic extension as was observed in the Alleghanian granites, the fluid inclusion data for quartz and calcite are essential for determining which are post-Eocambrian mineralization /metamorphism.

Pink Staining (PS)

Although PS fractures only constitute a small population here, their orientations are consistent with PS fractures in the Alleghanian granites (e.g., Heath and Bartholomew, 1997; Bartholomew and others, 1997a). PS is present on both N-S- to NE-SW-trending and ~E-W-trending fractures (Figure 1A) with a dominant trend of 205° ±5°. As in the granites, PS precedes other mineral coatings (e.g., ep, ch, py, or cal). Mauldin and others (1997) attribute the PS to hydrothermal alteration of calcic feldspar by potassic fluids moving along fractures, which is also consistent with observations in the Alleghanian granites.

Chlorite (ch)

Ch-coated fractures (Figure 1B) are the most common type of mineralized fractures at the mine and exhibit a variety of trends, but are dominated by a NE-trend (045° ±25°) with a secondary S-trend (185° ±15°). Ch post-dates PS where both are present. Ch is generally associated with py on most fractures here.

Ch is part of a greenschist-facies mineral assemblage (qtz+ch+ep+py) that coats E-W-trending fractures associated with the earliest phase of Mesozoic rifting in the Alleghanian granites (e.g., Bartholomew, 1998). However, ch is generally not present as a major mineral along fractures associated with later opening of the NE-trending Triassic basins or with intrusion of Jurassic N-trending diabase dikes in the granites. Extensive PS followed by hem typically characterizes these fractures in granites near Columbia, South Carolina. However, one granite quarry north of Columbia is like the mine in that ch does coat similarly oriented fractures to TR_3 and TR_4 that generally lack hem and exhibit only minor PS.

These observations suggest that the **ch** coatings along fractures at Ridgeway are Mesozoic and that the presence of **ch** versus **hem** is controlled by oxygen fugacity (e.g., Spear, 1995). Thus, the hydrothermal fluids that caused early ubiquitous **PS** along fractures in the granites probably are responsible for subsequent **hem** mineralization at higher fO_2 along those same fractures. With higher temperature, lower fO_2 and/or lower Fe content, **ch** formed instead of **hem**.

Pyrite (py)

Py-coated fractures are also quite common at the mine (Figure 1C) and are also dominated by a NE-trend (045° ±25°) with a secondary S-trend (185° ±15°). Py post-dates PS where both are present. It typically is associated with ch although py does occur on some fractures that lack ch. The presence of extensive py at the mine versus extensive hem in most of the Alleghanian granites is probably controlled by abundant sulfur in the rocks at the mine and a lower fO_2 (e.g., Spear, 1995) here than that associated with extensive

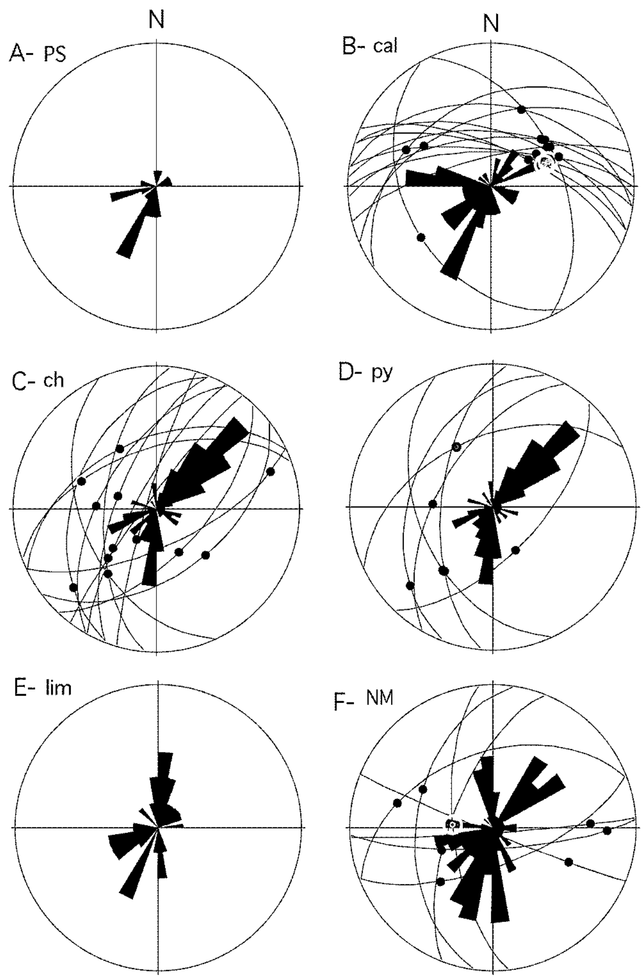

Figure 1. Fracture coatings at the Ridgeway mine. Joints ar shown as rose diagrams and faults are shown on equal-area lower hemisphere stereographic projections on Figures 1-6 with North (N) at the top of each diagram and strikes (follow a right-hand convention) go clockwise from 1^{o} to 360^{o} on all diagrams. The circle for each diagram is given as a percentage of the joint (in parentheses). A- 26 PS joints (35%); B- 66 cal joints (15% & 13 cal faults; C- 110 ch joints (15%) & 13 ch faults; D- 109 py joints (15%) & 6 py faults; E- 31 lim joints (18%; 1 faul included); F- 108 NM joints (11%) & 8 NM faults.

PS and hem-mineralization in the granites.,

Calcite (cal)

Cal is also common as a fracture coating at the Ridgeway mine. Cal-coated fractures are dominated by different trends (Figure 1D) than ch and py. It occurs as thin microcrystalline coatings, coarse spar, and thin veins. Cal post-dates PS, ch, and py and represents at least two separate events, which is consistent with fluid inclusion data and field observations in the Alleghanian granites (e.g., Evans and Bartholomew, 1997). The dominant trends of cal-coated fractures at the mine are $205^{o} \pm 15^{o}$ and 275o $\pm 15^{o}$ with secondary trends at $065^{o} \pm 5^{o}$ and $230^{o} \pm 10^{o}$. There is a set of oblique normal faults that strike ~270o -290o and a pair of NW-SE-striking normal faults that post-date cal-mineralization.

Limonite (lim)

Lim is not a common coating in the lower part of the mine and generally occurs in the more weathered zones. Li fractures have dominant trends of 205 o ±5 o, 005 o ±15 o, and 245 o ±15 o (Figure 1E). The 205 o trend is the same as that for both PS, cal, and several of the rare hem fractures. The other two trends overlap principal trends of the other mineralized fractures (Figure 1E c.f. Figure 1A, B, C, & D). Both the 205 o and 005 o trends are common PS-hem-cal trends in the Alleghanian granites, hence, lim probably represents alteration of a very thin veneer of hem at the Ridgeway mine.

Nonmineralized (NM)

NM fractures have a variety of prominent trends (Figure 1F), notably at $195^{o} \pm 15^{o}$, $175^{o} \pm 5^{o}$, $355^{o} \pm 15^{o}$, $035^{o} \pm 15^{o}$, and $055^{o} \pm 15^{o}$. Field observations and fluid inclusion data from the Alleghanian granites suggest that the last inclusion-forming event (at ~90^{o}C; Evans and Bartholomew, 1997) in calcite was probably coincident with, or slightly younger than emplacement of the NW-trending Jurassic dike swarm. Subsequent exhumation left Alleghanian granites (at least those near the Fall Line) and the Ridgeway mine area very near or exposed at the surface by the time that Cretaceous sediments were being deposited near the Fall Line. Thus **NM** fracture sets, which are consistently younger than the mineralized sets, represent the deformational history from the Cretaceous through the Cenozoic.

FRACTURE SETS

Group I Fracture Sets (TR1, TR2, TR3, and TR4)

The orientations of large quartz veins (Figure 2A), that probably formed during the Cambrian deformation and metamorphism of the Carolina Terrane (e.g., Secor and others, this volume), control development of the two initial fracture sets (TR_1-Figure 2B) and (***TR2***-Figure 2C). TR_1 and TR_2 in Alleghanian granites are related to ~N-S extension during the first Triassic phase of Mesozoic rifting (e.g., Bartholomew, 1998). A few age relationships suggest that the $285^{o} \pm 15^{o}$ (TR_1) may have preceded the $065^{o} \pm 15^{o}$ (TR_2). Both clearly pre-date all other sets and developed partially along contacts of and/or subparallel to major pre-existing quartz veins which also trend at 285^{o} and 065^{o} -245^{o}. As with the early ~E-W-trending fractures in the Alleghanian

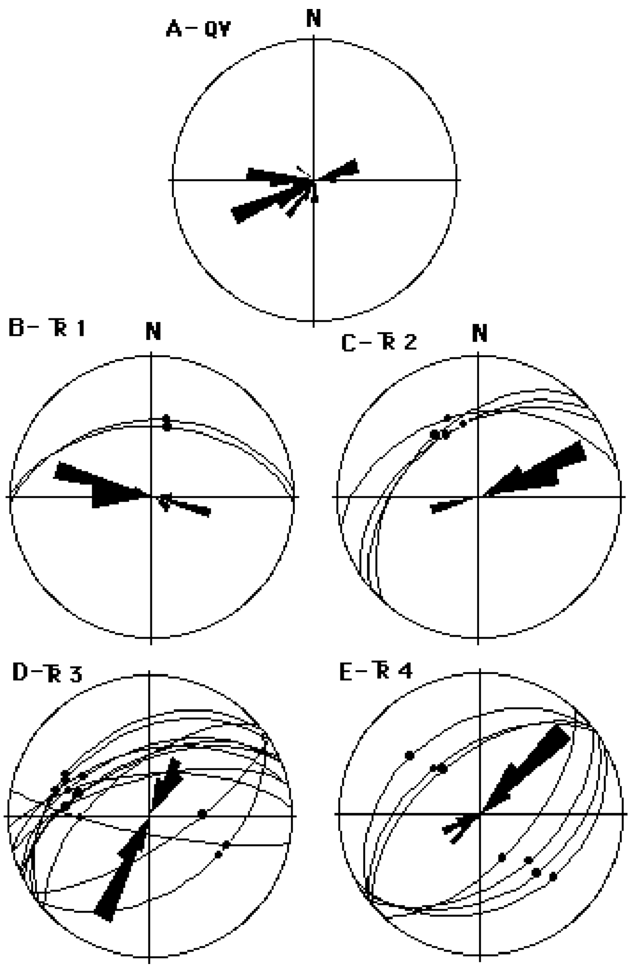

Figure 2. Group I fracture sets. A- 25 large quartz veins (QV 25%); B- 20 TR_1 joints (35%) & 2 TR_1 faults; C- 19 TR_2 joints (45%) & 4 TR_2 faults; D- 28 TR_3 joints (40%) & 11 TR_3 faults; E- 42 TR_4 joints (40%) & TR_4 faults.

granites, **PS** preceded **ch**±py and locally **ep** is also present. Many of these~E-W-trending fractures, both within Alleghan-ian granites and along big quartz veins at Ridgeway, are deeply weathered. **TR_1** and **TR_2** are associated (by orientation, mineralization, and/or relative age) with dip-slip normal faults (Figure 2B,C). **TR_3** (Figure 2D) with a dominant trend of 205^o ±15^o and **TR_4** (Figure 2E) with a dominant trend of 045^o ±15^o have attitudes consistent with their formation during development of the typical NE-trending Triassic basins. Like similarly oriented fractures in Alleghanian granites, **TR_3** and **TR_4** predate fracture sets related to Jurassic diabase dike emplacement. As with the earlier fractures, **PS** on **TR_3** and **TR_4** preceded **ch+py** mineralization. **TR_4** is the most common **ch+py** fracture set at the mine (Figure 2E). **TR_3** is associated with oblique-slip normal faults whereas **TR_4** is associated with dip-slip normal faults (Figure 2D,E). One steeply dipping **TR_1** joint and one **TR_2** joint were reactivated as oblique-slip **TR_3** faults (Figure 2D).

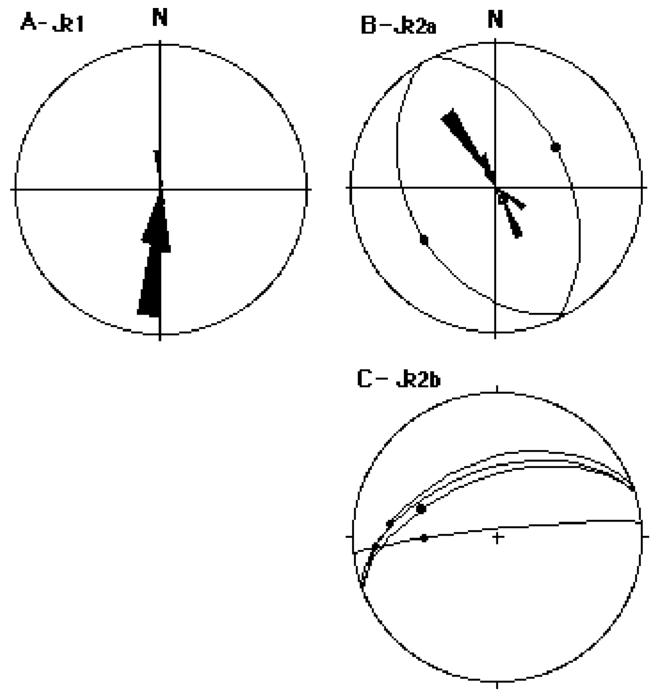

Figure 3. Group II fracture sets. A- 40 JR_1 joints (45%); B- 16 JR_2 joints (50%) & JR_2 normal faults; C- 4 JR_2 dextral strike-slip faults.

Group II Fracture Sets (JR1 and JR2)

Sets **JR_1** (Figure 3A) and **JR_2** (Figure 3B & C) are interpreted to be Jurassic. In a granite quarry at Columbia, South Carolina, diabase dikes cut an Alleghanian granite and fracture sets both within and related to diabase dikes can be correlated with those in the enveloping granite (Heath and Bartholomew, 1997). As in the Alleghanian granite N-S-trending, mineralized (**ch+py; py; cal**) fractures at Ridgeway pre-date NW-trending, generally **NM** fractures, suggesting that N-S-trending diabase dikes preceded NW-trending diabase dikes. **JR_1** has a dominant trend of 185^o ±15^o and is mineralized by **PS** followed by either **ch+py** or just **py**. **JR_2** has a dominant trend of 325^o ±15^o and is associated with dextral strike-slip movement on reactivated **TR_2** fractures. A few NW-SE-trending, **cal**-coated, dip-slip normal faults also appear to be part of this set. In the Alleghanian granites, strike-slip movement on reactivated **TR_3** fractures commonly accompanied **JR_1** whereas strike-slip movement on reactivated **JR_1** fractures commonly accompanied **JR_2**. Neither fault set has been identified yet in the mine.

Group III Fracture Sets (K_1, K_2, P_1, E_1, E_{RF})

Fracture sets **K_1** and **K_2** (Figure 4A & B) appear to correlate with the oldest fracture sets recognized in Cretaceous sediments (Brodie and Bartholomew, 1997), which correlate

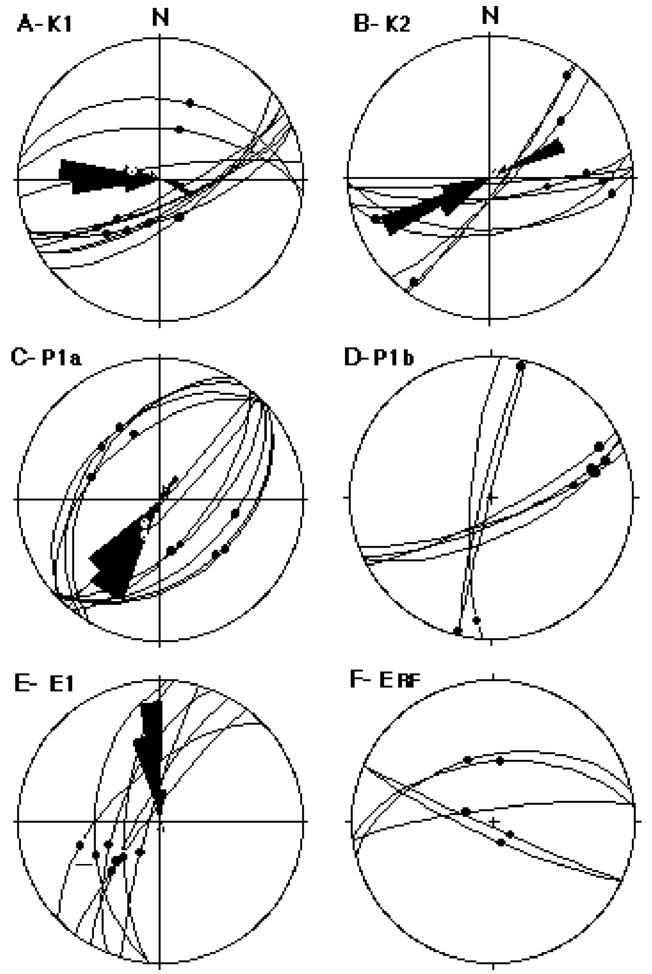

Figure 4. Group III fracture sets. A- 28 K_1 joints (40%) & K_1 faults; B- 36 K_2 joints (40%) & 8 K_2 faults; C- 30 P_{1a} joints (35%) & 11 P_{1a} faults; D- 8 P_{1b} strike-slip faults; E- 26 E_1 joints (50%) & 7 E_1 oblique-normal faults; F- 5 E_{RF} reverse faults.

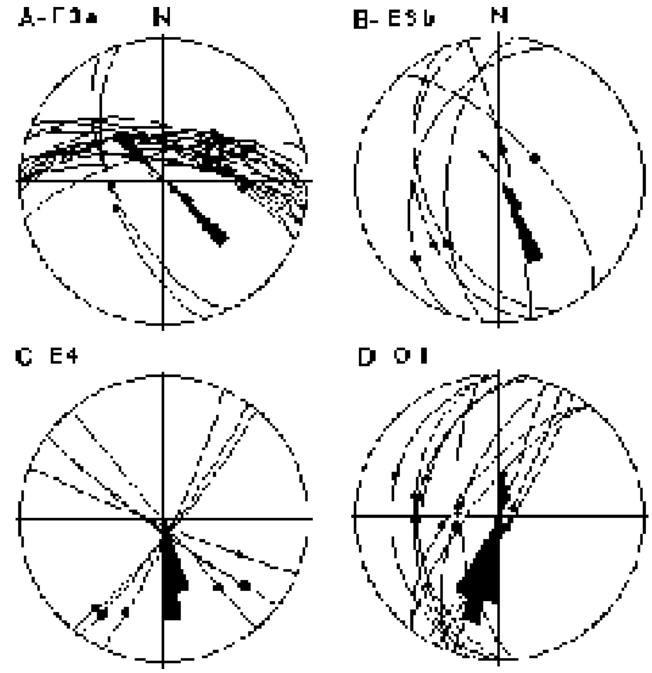

Figure 5. Group IV fracture sets. A- 14 E_{3a} joints (60%) & E_{3a} oblique-normal faults; B- 10 E_{3b} joints (80%) & 6 E_{3b} oblique-normal faults; C- 9 E_4 joints (80%) and 6 E_4 strike-slip faults; D- 52 O_1 joints (35%) & 11 O_1 normal faults.

with **NM** fractures in the, Alleghanian granites (Heath and Bartholomew, 1997). However, at Ridgeway, K_1 includes a significant number of **cal**-coated joints. Hence, K_1 fractures may have been forming for a substantial period of time before exhumation exposed these rocks in Late Cretaceous time. K_1 appears to be associated with oblique dip-slip normal movement on reactivated TR_1 and TR_4 fractures (Figure 4A). K_2 is associated with strike-slip movement on reactivated TR_2 and TR_3 fractures (Figure 4D). P_{1a} joints (Figure 4C) have a dominant trend of 215^o ±15^o and are associated with dip-slip normal faults that include some reactivated TR_4 fractures. P_{1b} also appears to be associated with strike-slip movement on reactivated TR_2 and JR_1 fractures (Figure 4D). E_1 joints (Figure 4E) have a dominant trend of 355 ^{o} ±15^o and correlate with the regionally oldest set of fractures found in Eocene sediments (Brodie and Bartholomew, 1997). At Ridgeway,

E_1 is associated with oblique-dextral normal movement on reactivated TR_3 and JR_1 faults (Figure 4E). E_1 may also be related to steeply dipping, dip-slip reverse faults (E_{RF}) along reactivated TR_1 and TR_2 fractures (Figure 4F). Similar ~N-S reverse movement on reactivated early Triassic normal faults is common in the Alleghanian granites.

Group IV Fracture Sets (E3, E_4, O_1)

E_{3a} and E_{3b} have overlapping attitudes and are distinguished from one another only on the basis of joint trends (135^o ±15^o and 155^o ±15^o, respectively) and corresponding slip directions on associated faults (Figure 5A & B). Both subsets clearly post-date E_1 and predate E_4 but we have not yet verified their age relationship to one another. E_{3a} faults have oblique-normal movement whereas E_{3b} faults have dip-slip normal movement. E_4 faults (Figure 5C) have strike-slip movement on reactivated TR_1 & TR_2 and TR_3 & TR_4 fractures. E_4 joints trend 170^o ±10^o. O_1 joints trend 195 ^{o} ±15 ^{o} and are associated with dip-slip normal faults which include some reactivated TR_3 and P_1 fractures.

Group V Fracture Sets (M1 and Q1

M_1 joints (Figure 6A)may include two overlapping sets with dominant trends of 275 ^{o} ±15^o and 085^o ±15^o, which appear to be associated with oblique-normal and dip-slip normal faults, respectively. They correlate with fractures found in Miocene sediments (Bartholomew and others,

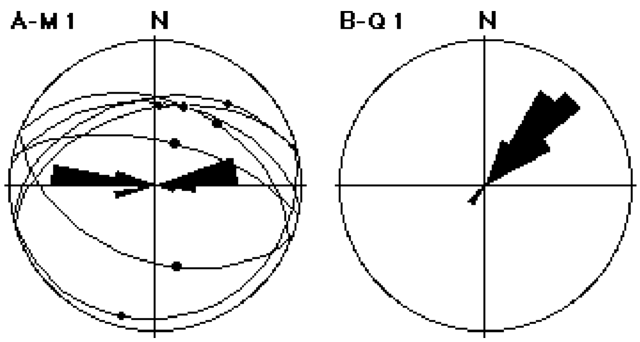

Figure 6. Group V fracture sets. A- 20 M_1 joints (35%) & 7 M_1 normal faults; B- 34 Q_1 joints (35%).

1997b; Hill and others, 1998). The youngest fractures (**Q_1**) observed at Ridgeway trend 045° ±20° (Figure 6B). They overlap the ranges of the youngest joints found in Miocene and Pliocene strata northeast of Charleston, South Carolina and in Miocene strata in southeastern Georgia near the Savannah River (Bartholomew and others, 1997b; Hill and others, 1998).

SUMMARY

The earliest two fracture sets (**TR_1** & **TR_2**), that postdate both mineralization and Eocambrian metamorphism, trend ~E-W and partially utilized pre-existing quartz veins. We interpret these two sets as Triassic for the following reasons:

- They trend consistently with the earliest fracture sets found in the Alleghanian granites near Columbia, South Carolina and are followed by the next younger fracture sets (**TR_3** & **TR_4**) that also trend consistent with their respective counterparts in these granites.
- The sequence of mineralization (**PS** then **ch+py** then **cal**) with **ep** present on a few surfaces is similar to the sequence on similarly oriented fractures in the granites (**PS** then **ep** then **hem** then **cal**) if fO_2 and sulfur content are considered to influence which minerals formed.

If **TR_1** and **TR_2** are related to early Mesozoic ~N-S extension recorded in Alleghanian granites for >150 km west of Columbia, South Carolina, then it appears that fractures sets that are representative of most of the Paleozoic (~230 my period) are not recognized here. Perhaps fluid inclusions in some of the quartz veins may record part of the Alleghanian or earlier Paleozoic history.

Group III fracture sets (**K_1**, **K_2**, **P_1**, & **E_1**), that represent the Cretaceous to pre-Late Eocene (when s_1 was ~N-S) time interval, suggest a 90° counterclockwise rotation of s_3 during that time. In contrast, Group IV fracture sets (**E_{3a}**, **E_{3b}**, **E_4**, & **O_1**) that represent the Late Eocene to pre-Miocene time interval, suggest a clockwise rotation of s_3. Group V fracture sets (**M_1** and **Q_1**) have orientations that are similar to those observed in Miocene and Pliocene Coastal Plain strata (Bartholomew and others, 1997b; Hill and others, 1998). Talwani and Rajendran (1991) show a N60°E orientation for SH_{MAX} for focal mechanism solutions near Charleston, South Carolina. Thus, regionally, the youngest joints (045° ±20°) are compatible with the present-day stress field.

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The Ridgeway Gold Deposits: A Window to the Evolution of a Neoproterozoic Intra-Arc Basin in the Carolina terrane, South Carolina

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ABSTRACT

The Ridgeway gold deposits formed from hydrothermal processes that operated throughout the depositional and tectonic evolution of a Neoproterozoic intra-arc basin of the Carolina terrane. Open pit mining of these deposits was initiated by Kennecott-Ridgeway Mining Company in December 1988. Production to date exceeds 1,300,000 and 820,000 troy ounces of gold and silver, respectively, making Ridgeway the largest gold mine to have ever operated in the United States east of the Mississippi River. Mine operations are scheduled to close in 1999, and a comprehensive environmental closure plan will be implemented in the several years following pouring of the last dore'. The deposits occupy the northern edge of the Ridgeway intra-arc basin. This basin records the transition from pyroclastic felsic volcanism of the Persimmon Fork Formation to submarine mafic-dominant volcanism and turbidite clastic sedimentation of the Richtex Formation. The syngenetic, exhalative gold mineralization was controlled by faulting, hydrothermal activity, and sedimentation associated with the opening of the Ridgeway basin. Subsequent tectonic evolution of the basin was fast-paced, with basin closure, transpressional deformation, and associated basal greenschist metamorphism also occurring during the Neoproterozoic. The Ridgeway gold deposits were subjected to a syntectonic, epithermal phase of mineralization also Neoproterozoic in age. The deformation rotated the basin homoclinally towards the south to produce a south-younging, S2-slaty cleaved and locally complexly deformed sequence. Textural and chemical data indicate magmatic fluids were accessible during this syntectonic hydrothermal event, which may have driven much of the pressure-solution transposition associated with higher grades of gold in the deposits. Subsequent tectonis and intrusions associated with the Alleghanian orogeny warped and sheared the deposits. A final phase of block faulting and dike intrusion occurred during the Mesozoic.

INTRODUCTION

In this paper, we expand on the ideas presented in a 1995 Society of Economic Geology Guidebook paper (Gillon and others, 1995b), which established a geologic framework for gold mineralization in the Ridgeway region. That paper, however, stopped short of integrating models for their genesis with recent concepts of the tectonic evolution of the southern Appalachian orogen. Here we present the thesis that the Ridgeway gold deposits formed in the previously unrecognized Ridgeway intra-arc basin, and that this synvolcanic, hydrothermal activity persisted through Neoproterozoic deformation of the Carolina terrane.

THE STATUS OF GOLD MINING IN SOUTH CAROLINA

The dramatic rise of world gold prices in the late 1970s spurred exploration efforts in the southern Appalachians. As a result, four gold mines in the South Carolina portion of the Carolina terrane were brought into production (Figure 1). Three of these mines occur in districts, which were active in the 1800s, and include Haile, Brewer, and Barite Hill. The fourth, Ridgeway, is a recent discovery. According to Feiss and others (1993), total gold production plus reserves from Barite Hill and Brewer are 55,400 and 150,480 ounces, respectively (all troy ounces).

The Haile and Ridgeway mines contained premine reserves that exceeded one million ounces of gold. During its operational period, which ranged from 1827 to 1991, the Haile produced an estimated 360,000 ounces of gold (Maddry and Speer, 1992; Maddry and Kilbey, 1995). A newly defined reserve of nearly one million ounces of gold still remains at the currently inactive mine.

RIDGEWAY MINE OPERATIONS

The Ridgeway gold mine is located in Fairfield County, South Carolina, approximately 5miles north of Columbia (Figure 2). The mine is owned and operated by Kennecott-Ridgeway Mining Company, a subsidiary of US-based Kennecott Minerals, whose parent is London/Perth-based Rio Tinto. Discussions of the discovery and development of Ridgeway are found in Spence and others (1986), Evans (1988), Gillon and others (1995b), and Lapoint (1995). Kennecott has produced over 1,300,000 ounces of gold and 820,000 ounces of silver from the operation since startup in 1988. This qualifies Ridgeway as the largest gold mine ever operated in the United States east of the Mississippi River. Ultimate production by year 2000 is expected to reach 1,500,000 ounces of gold and 980,000 ounces of silver produced from 59,000,000 tons of ore with an average grade of 0.031 ounces per ton gold.

The mine operates 24 hours per day, and initial production came from the South Pit, which was mined out in September 1997. Current production is from the approximately 360-feet deep, 90 acre North Pit, located 1 mile north of the South Pit. Sulfide facies ore in the North Pit is blasted, hauled in 85-ton trucks to a central mill complex, and crushed. Low grade oxide facies ore stockpiled near the mill is blended with the hard, sulfide ore to maintain mill feed, which has averaged 15,000 tons per day over the life of the mine. The crushed ore is conveyed to a circuit comprised of a semi-autogenous mill and two ball mills, where it is pulverized to 85 percent passing 200 mesh.

The resulting slurry is mixed with sodium cyanide and lime which is pumped into the first of 10 tanks, measuring 52 feet in height and 54 feet in diameter. The first three tanks are leach only, and the remaining seven are Carbon-In Leach (CIL) tanks. The gold-silver-cyanide ionic solution created from this leaching is progressively adsorbed onto particulate carbon (ground coconut-shell charcoal) circulated through the CIL tanks. The pregnant charcoal is subsequently separated from the ground ore in the tanks by screening, and the gold-silver-cyanide solution liberated from the carbon in a high pressure, heated tank. The precious metal-cyanide solution is next circulated through an electrowinning circuit, resulting in a gold/silver precipitate onto stainless steel plates. Scrapings from the plates are fired in a furnace and poured into dore bars averaging 60 percent gold and 40 percent silver.

RIDGEWAY MINE CLOSURE PLAN

The Ridgeway gold mine has been operated throughout its lifetime as a state and federally permitted mining facility. Extensive measures have been taken to maintain the quality of ambient groundwater, surface water, air, and wildlife habitat. As the mine moves towards closure, a reclamation plan has been developed by Kennecott Minerals. The plan proposes to:

- Contour the pit walls from the rim to ten feet below the ultimate water level with a slope of three to one. Both pits will become freshwater lakes by allowing them to fill with groundwater and surface waters.
- Construct an engineered drainage channel and wetlands area between the two pits designed to enhance biodiversity and wildlife habitat
- Cap the tailings pond with a positive-drainage soil cap and establish a grass cover
- Decommission and remove all crusher and mill facilities
- Contour and vegetate all disturbed areas on the property
- Maintain administrative and maintenance shop facilities until it is determined feasible to attract light industry for the purpose of replacing the mine’s tax base contribution to Fairfield County

Modifications to the above closure plan may be implemented if more effective approaches are developed.

REGIONAL GEOLOGIC SETTING

The Barite Hill, Brewer, Haile, and Ridgeway gold mines (Figure 1) are located in the South Carolina portion of the Carolina terrane (Secor and others, 1983). Major tectonostratigraphic elements of the southern Appalachians (Hatcher, 1989; Horton and others, 1989) have been recently grouped into tectonostratigraphic zones that share global scale affinities with the rest of the orogen (Hibbard and Samson, 1995: Figure 1). Proterozoic to early Paleozoic age rocks native to the North American continent (Laurentia) are grouped into the Cumberland zone. The Blue Ridge and Piedmont tectonic provinces, with their non-Laurentian mix-

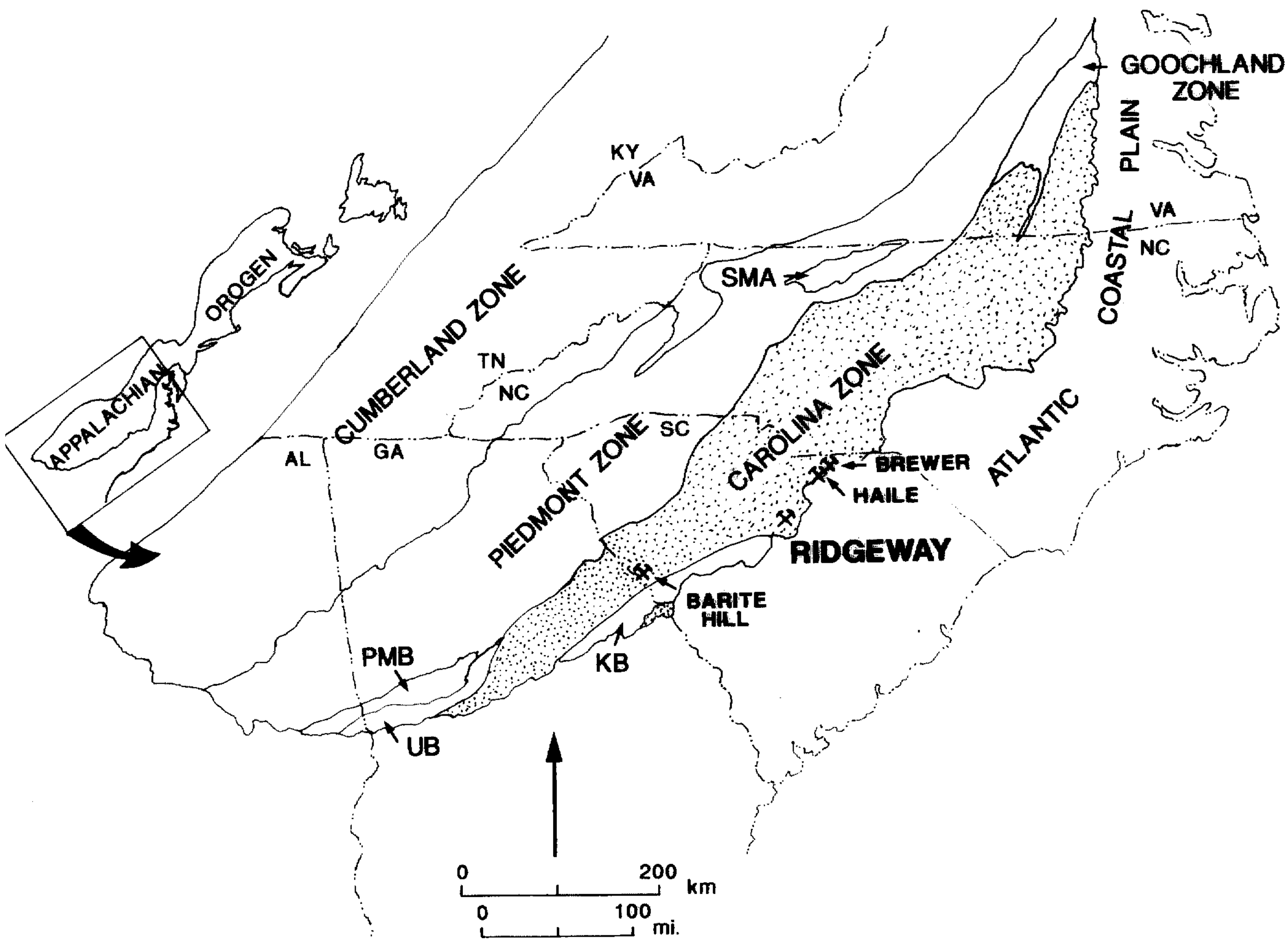

Figure 1. Tectonostratigraphic zonal map of the Southern Appalachian orogen (after Hibbard and Samson, 1995). Locations of the four gold mines active in South Carolina during the late twentieth century are posted on the map. The mines are located within the Carolina zone, whose largest subunit is the Carolina terrane subduction volcanic arc.

ture of complexly deformed and metamorphosed sediments and volcanics, are grouped in the Piedmont zone. Further southeast, the dominantly volcanic Carolina terrane is the largest element comprising the Carolina zone.

Recent paleontological, geochemical, geochronological and paleomagnetic data indicate that the Carolina terrane formed as one or more, subduction-related arcs of Late Proterozoic to Cambrian age. The arc, which evolved at high latitudes either on an older arc or on thinned continental crust, was in original proximity to Gondowana rather than Laurentia (Secor and others, 1983; Dalziel and others, 1994; Shervais and others, 1996; Barker and others,1998). The amalgamation of the Carolina terrane to the southeast, outboard portion of the southern Appalachian orogen is believed to have spanned several, successive orogenic pulses, including Virgilina (Late Proterozoic to Cambrian); Taconic (Middle Ordovician), Acadian (Devonian), and Alleghanies (Late Paleozoic): Dalziel and others (1994); Hibbard and Samson (1995).

Lithologically, the Carolina terrane is a complex of metaplutonic, metavolcanic, and metasedimentary rocks of lower greenschist to upper amphibolite facies metamorphis (Butler and Secor, 1991). The higher grade, western portion of the terrane (formerly Charlotte Belt) consists of variable amounts of mafic gneisses, amphibolites, metagabbros, and metavolcanic rocks, with lesser amounts of biotite gneiss, granitic gneiss, mica schist, quartzite, and ultramafic rocks.

The eastern portion of the Carolina terrane (formerly Carolina Slate Belt) is dominated by greenschist facies metamorphosed volcanics and sediments intruded by a variety of plutons (Butler and Secor, 1991). the oldest unit recognized in the west central piedmont of South Carolina is the domi-

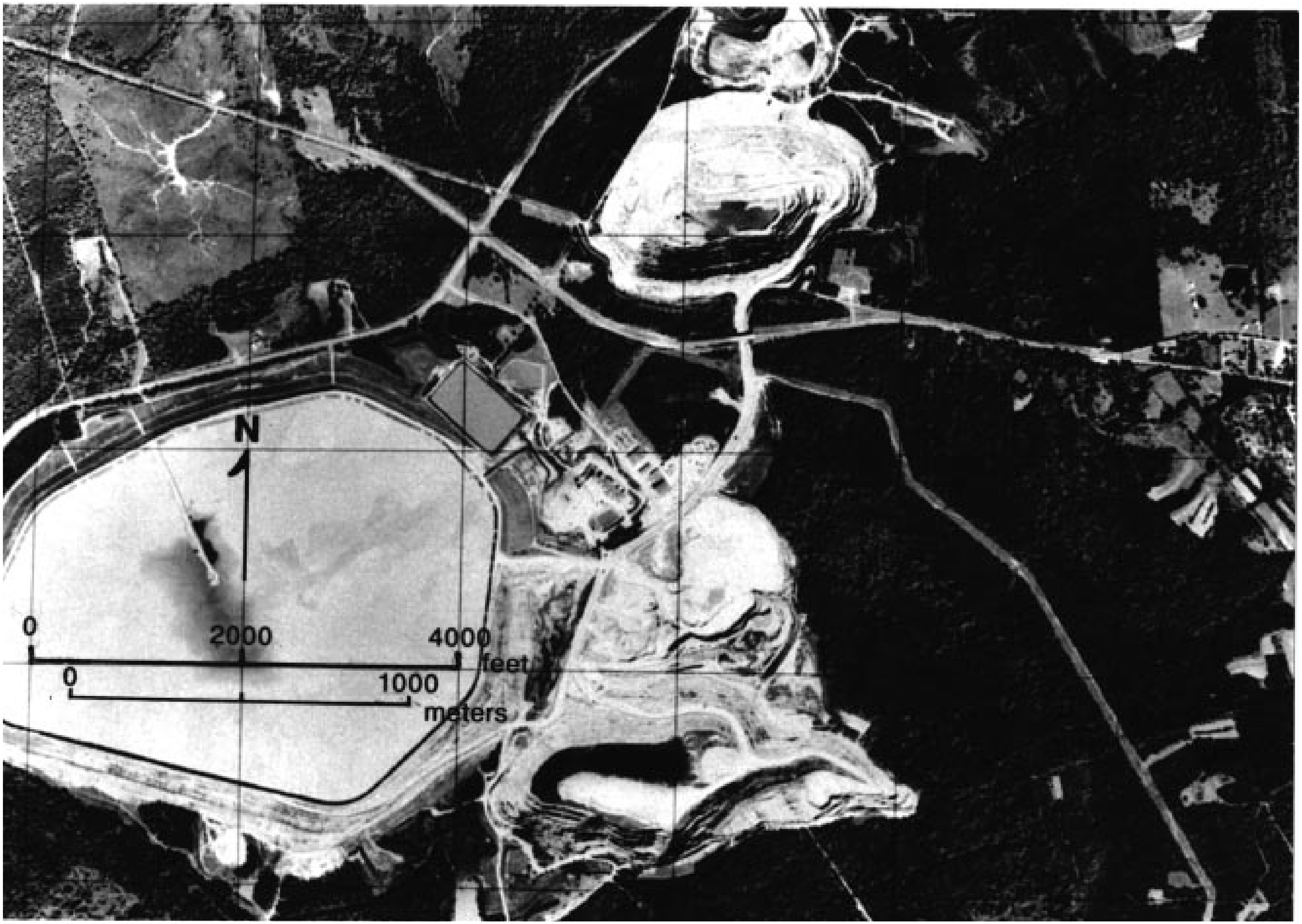

Figure 2. Aerial photograph of the Kennecott-Ridgeway gold mine from flyover conducted October 2, 1997.

nantly felsic pyroclastic Persimmon Fork Formation. Recent work by Barker and others (1998) in the Ridgeway region indicates the Persimmon Fork Formation to be late Proterozoic (550 Ma) in age.

Overlying the Persimmon Fork volcanics are turbiditic metagreywacke and metamudstone of the Richtex Formation (Secor and Wagner, 1968; Secor, 1988). Mafic flows, tuffs, and mafic igneous rocks are concentrated along the base of the Richtex Formation. Syngenetic hydrothermal alteration of these lithologies produced the Ridgeway gold deposits (Figures 3 and 4), which also contain abundant molybdenite. Recent rhenium/osmium isotopic age dating of molybdenite from the Ridgeway mine (Stein, and others, 1997; personal communications, 1998) indicates crystallization ages of 540 Ma (North deposit) and 550Ma (South deposit). Thus, these dates indicate that the ore-hosting Richtex Formation must have been deposited during the Neoproterozoic as well.

A third unit within the southwest portion of the Carolina terrane is the Asbill Pond formation (informal usage, Secor and others, 1986). This formation lies stratigraphically above the Persimmon Fork Formation but has not been observed in contact with the Richtex. The Asbill Pond is a sequence of metamudstone and quartzofeldspathic metasandstone, and contains Middle Cambrian trilobites of Atlantic Province. The contact between the upper, fossiliferous mudstone and lower clastics has recently been interpreted as an angular unconformity by Dennis and others (1993) and Dennis (1995).

In the following section, evidence for intra-arc rifting during formation of the Carolina terrane is presented. This presentation is followed by arguments favoring the existence of four basins in the central portion of South Carolina. This discussion leads up to a brief presentation on the depositional, structural, and hydrothermal history of the Ridgeway intra-arc basin with its associated gold mineralization. Unless required for clarity, the prefix “meta” is dropped from usage in the following discussions on geology of the Ridgeway region since most lithologies are metamorphosed to only lower greenschist facies metamorphism (Gillon and Duckett, 1988; Barnett, 1992a, 1992b; Gillon and others, 1995b).

Several field lithologic terms used in this paper require definition. Felsic rocks, including volcanics and associated intrusives, are those lithologies that are dacitic to rhyolitic in composition, typically light colored, and dominated modally by feldspar, quartz, and fine grained potassium-or sodium-dominant white micas (i.e., potassic- or sodic-phengite). Mafic rocks, including volcanics and intrusive dikes/sills, are characterized by their dark colors and dominated by chlorite or biotite with other accessory mafic minerals. The term turbidite in this paper refers to a depositional facies comprised of cyclical, bedded impure sandstone (greywacke) and mudstone units that exhibit evidence of deposition as submarine density flows (i.e., Bouma cycles: Walker, 1988). Criteria for recognizing turbidite facies were applied rigorously and successfully in field exploration efforts by Amselco-Kennecott geologists.

EVIDENCE FOR RIFT BASIN DEVELOPMENT WITHIN THE CAROLINA TERRANE

The rifted arc concept is not new, as many previous workers in the Carolina terrane have recognized that rifting played an important role in the evolution of this subduction arc. Several of these ideas are summarized below.

Amselco’s southeastern United States exploration efforts in the early 1980’s focused on the search for base and precious metal mineralization at the margins of extensional basins. The volcanic and turbidite stratigraphy established by Amselco geologists for the Ridgeway area led Bill Spence to propose that it was a rift basin.

In North Carolina, Harris and Glover (1985, 1988) proposed that the unconformity between the Neoproterozoic Virgilina arc sequence and younger, late Proterozoic Uwharrie-Abermarle sequence represents development of a new arc, transform, or pull-apart basin. Further developing this idea, Moye (1987) showed that the geology, structure, and geophysics of the Abermarle basin have strong similarities to pull-apart basins studied elsewhere in the world.

Feiss and Others (1993) utilized oxygen isotopic data to develop the model that volcanogenic mineral deposits of the Carolina terrane formed in a large, rift system (the Uwharrie-Abermarle sequence) that developed after the calc-alkaline arc (Virgilina sequence) construction was complete. These workers proposed that hydrothermal activity associated with initial rifting produced subaerial to shallow epithermal (<1 km depth) disseminated gold-pyrite deposits at the volcanic-sediment contact, as exemplified by the Brewer, Ridgeway and Haile mines. Continued evolution of the basin or in basins where sedimentation was rapid, produced submarine deposition of Kuroko-type volcanogenic massive sulfide deposits that include the Gold Hill and Cid districts in North Carolina, and the McCormick district in South Carolina. These workers proposed that the adjacent high grade (Charlotte belt) and Inner Piedmont terrane might represent the highlands that bounded the rift. In addition, the Neoproterozoic to Middle Cambrian age range of the Carolina terrane might have resulted from segmentation of the rift system into a series of basins of different ages and rates of extension and subsidence. Finally, these Neoproterozoic to Cambrian graben-bounding faults might partially explain the enigmatic boundary between the Charlotte and Slate Belt portions of the terrane.

The western edge of the Carolina terrane in northwest South Carolina has recently been established as a subduction-related volcanic arc (Dennis and Shervais, 1991; Dennis and Wright 1997). Geologic relationships, geochemistry, and geochronology in this area indicate that the greenschist to

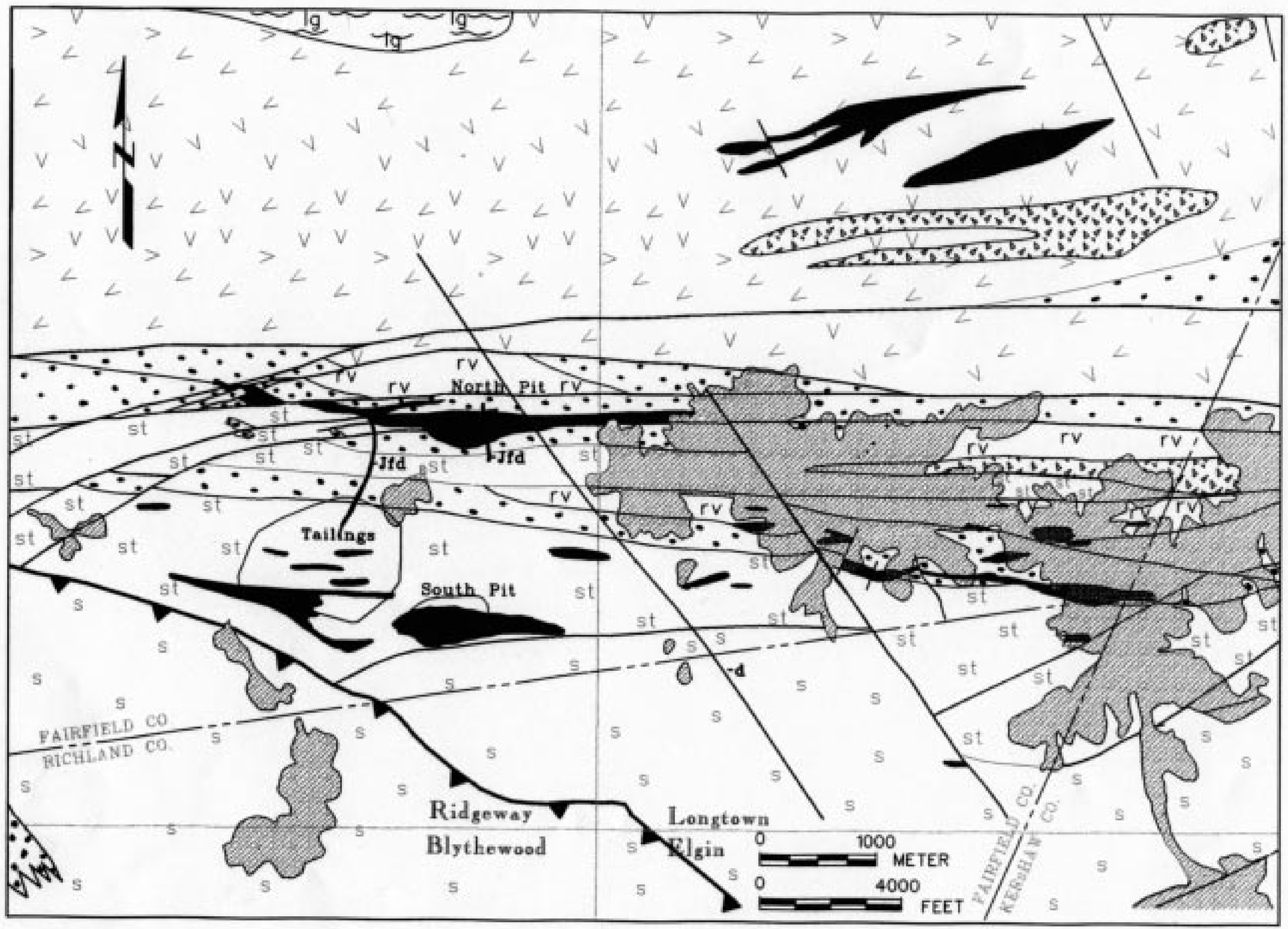

Figure 3. Geologic map of the Ridgeway mine region compiled from mapping of Kennecott geologists during the period 1982-1992, supplemented by data from the 1983 student field mapping program conducted at the University of South Carolina Geology Department under the supervision of R. D. Hatcher.

MESOZOIC

CRETACEOUS SEDIMENTS

-Jfd FELSIC DIKE

-d DIABASE DIKE

NEOPROTEROZOIC

lg Tg SYNKINEMATIC LONGTOWN METAGRANITE

s s UPPER RICHTEX SILTSTONE/MUDSTONE

st st RICHTEX FORMATION
TURBIDITIC GREYWACKE AND SILTSTONE

ZONES OF SYNGENETIC HYDROTHERMAL
ALTERATION

rv rv RICHTEX FORMATION FELSIC VOLCANICS

RICHTEX FORMATION MAFIC VOLCANICS
AND SEDIMENTS

FELSIC PORPHYRIES (FELDSPAR AND QUARTZ-EYE)

v v PERSIMMON FORK FELSIC VOLCANICS

FAULT

CONTACT

BEAR CREEK THRUST

RIDGEWAY	LONGTOWN
BLYTHWOOD	ELGIN

7.S - MINUTE TOPOGRAPHIC
QUADRANGLE BOUNDARIES

lower amphibolite metamorphosed mafic volcanics and subordinate felsic volcanics are intruded by a suite of spatially and genetically related ultramafic to mafic plutons. These workers also suggest that unconformities in the eastern portion of the Carolina terrane between felsic volcanics and overlying turbidites and mafic volcanics might be explained by the rifted arc hypothesis.

In a recent study of the geochemistry of the Carolina terrane in west central South Carolina, Shervais and others (1996) concluded that the Persimmon Fork Formation represents a mature, volcanic arc of transitional tholeiitic to calc-alkaline affinity. The arc was deposited on a substrate of older, orogenic volcanic rocks, or, less likely, on a basement of thinned continental crust. The younger Richtex Formation, with its basal, tholeiitic mafic volcanics and thick, overlying turbidite sequences, represents intra-arc rift basins that developed within the Persimmon Fork arc volcanics. The tholeiitic volcanics associated with the overlying Richtex Formation are recognized by these workers to be the inverse of a normal arc terrane, which progresses with time from mafic to felsic composition.

Proposed Intra-arc Basins in the CarolinaTerrane of Central South Carolina

Four intra-arc rift basins are proposed to exist in the Chapin to Dekalb region of South Carolina, and include the Chapin, Ridgeway, Lamar, and Dekalb basins (Figure 5). Volcanic-sedimentary sequences in each of these areas have characteristics suggestive of an origin as intra-arc basins. Supporting arguments for their existence are presented below.

The Richtex formation near Chapin, South Carolina has been reported by Maher and others (1991) to be in fault contact with the adjacent Persimmon Fork formation. Further northeast along the strike of the mapped formation, Richtex sediments narrow adjacent to a steeply dipping zone in the Irmo Northeast quadrangle that contains interlayered mafic and felsic volcanics, and sediments including greywackes (Bourland and Farrar, 1980; compilation of Lapoint, 1995). Zones of hydrothermal alteration and gold mineralization are also focused along this trend (Gillon and others, 1995b; Lapoint, 1995). Intense flattening of lithologies occurs along this trend, which was labeled the Cedar Creek fault zone (Bourland and Farrar, 1980). The trace of the Cedar Creek fault zone projects northeast into the proposed Ridgeway basin. Our interpretation here is that the Cedar Creek fault zone is part of a reactivated basin margin fault developed along the south side of the Chapin basin in the transitional zone between Richtex and Persimmon Fork formations, that was accompanied by hydrothermal alteration.

Northeast of the proposed Chapin basin, and east of the Ridgeway fault of Barker and others (1998) and Secor and others (this volume), Richtex mafic and felsic volcanics, turbidites and overlying mudstones define the Ridgeway basin (Figures 3 and 5). Details on the geometry and depositional history of this basin are discussed in a separate section below.

East of the Ridgeway basin, a narrow, northwest-striking rectangular-shaped area of turbidites and mudstones is nested between the Wateree igneous complex-hosted Lamar gold prospect and the northwest-striking Longtown fault of Barker and others (1998) and Secor and others (this volume; Figure 3). On the south side of the proposed basin is the Bee Creek metagranite interpreted by Secor and others (this volume) to be a possible epizonal intrusive related to adjacent felsic volcanics. Lapoint (1995) also reported several small porphyry intrusives and gold mineralization in the vicinity of the Bee Creek metagranite. The hypabyssal felsic intrusives, associated gold mineralization, and fault bounded contact with sediments supports the concept of the Lamar intra-arc basin. An additional, supporting piece of data is evidenced in the boulders dug from the tailrace and used as ballast for the Lake Wateree dam. The boulders reveal an impressive variety of heterolithic fragments in a turbidite greywacke matrix. Angular to rounded clasts of up to 0.3 meters in size consist of sediments, volcanics, and possible hydrothermal chert. Since the tailrace lies along the mapped contact between the Wateree igneous complex and sediments to the south, these proximal turbidites are interpreted to reflect rapid deposition along a developing basin margin fault associated with development of the Lamar basin.

Northeast of Lake Wateree, generally shallow to moderate, east-dipping turbidites and mudstones overlie a large area of felsic volcanics as compiled by Lapoint (1995). Further east and bounded by sediments above and below, is the Dekalb gold prospect (Gillon and others, 1995b). The Dekalb prospect is interpreted to represent a resurgent, subaerial to submarine, felsic volcanic center which built on top of basinal sediments. Evidence for subaerial volcanis includes concentric, rain-drop(?) lapilli tuffs, a topographically high area of coarse vent(?) breccias, and hematitic staining of the volcanics. The conformable, overlying Richtex(?) turbidites indicate basinal deepening either coincident or shortly after the eruptive event, which continued as a submarine phase of activity as evidenced in the overlying turbidites by as several thin tuff horizons. The interpretation here is that resurgent volcanism and sedimentation in the Dekalb area represents a second-order basin produced by an older, reactivated basin margin fault or a newer fault associated with continued spreading of a larger, as yet unspecified basin.

Stratigraphic Development of the Ridgeway Basin

The Ridgeway intra-arc basin, as proposed in this paper (Figure 5), is a triangular, apex-to-the-south shaped area whose northern boundary is approximately 17 km (11 miles)

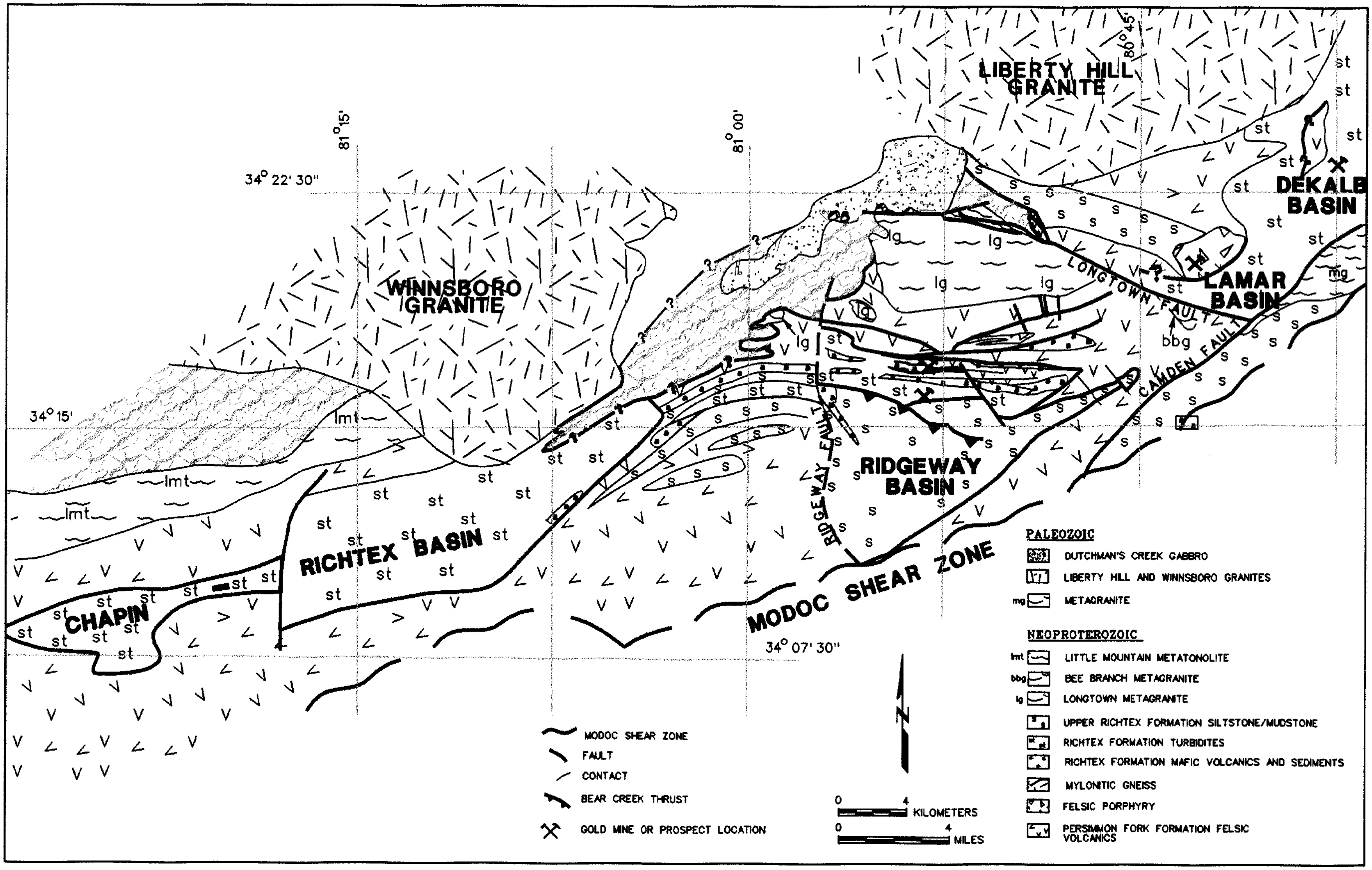

Figure 5. Compilation of Carolina terrane geology for the west-central portion of South Carolina showing four proposed intra-arc basins. These are labeled informally as the Chapin-Richtex, Ridgeway, Lamar, and Dekalb. Map sources include Lapoint (1995; and personal communications, 1998), Maher and others (1991); Barker and others (1998); Gillon and others (1995b); Paradeses (1966); Ridgeway (1966); and unpublished exploration data by Amselco-Kennecott geologists during the period 1982 through 1992.

in length. The southern apex of the basin is concealed by coastal plain cover, but aeromagnetics of the region (Gillon and others, 1995b) suggests a southeast boundary 19 km (12 miles) in length. The north-south trending western boundary (interpreted to be the reactivated Ridgeway fault of Barker and others, 1998) is an approximately 15 km (9 miles) in length.

Stratigraphy along the northern half of the basin strikes east-west and is generally steeply to moderately dipping to the north and south. This is in contrast to the southern portion of the basin south of a west-northwest trending thrust(?) informally referred to here as the Bear Creek thrust, where bedding is shallow to moderate dipping to the east and northwest. Stratigraphy along the western edge of the basin strikes north-northwest, dips shallow to moderate to the east, and youngs in that direction as well. Lithologies here consist of mudstone and minor greywackes interlayered with a unit of mafic and minor felsic volcanics that project southeast into the basin at a low angle to the faulted west boundary (Figure 5). Stratigraphy along the southeast boundary of the basin is poorly exposed, but where observed consists primarily of north-younging mudstones with a minor greywacke component.

Recent studies of the Ridgeway mine area (Gillon and others, 1995a, 1995b) indicate that a basin model might best explain the gross stratigraphy, structure, and geophysical signature of the mine region. That idea has been solidified by recent mapping of the North pit, reexamination and compilation of surrounding historical map data, and considering these data in light of recent literature on the evolution of the Carolina terrane (see above discussions on rift basins in the Carolina terrane. The resulting stratigraphy proposed for the northern portion of the mine area is one that records sequential development of an intra-arc basin.

The interpreted stratigraphic succession for the Ridgeway basin, as is shown in plan and cross section as Figures 6, 7, 8, and 9, requires a stratigraphy that homoclinally youngs to the south and is not repeated by a bedding parallel, pre-S2 slaty cleavage, isoclinal folding event. The following discussion presents the evidence gathered to date to support this argument.

A foliation subparallel to bedding is present in Ridgeway Basin lithologies at outcrop and microscopic scale. The S1 fabric is a slaty cleavage as defined by preferably oriented micas in thin sections. Mine studies have not recognized any meso- or megascopic folding associated with this S1 fabric, though early exploration mapping by Kennecott geologists attributed bedding dip reversals as D1 fold axes. Because of the potential for folding of gold bearing zones, Kennecott's detailed mapping of thousands of feet of trenches and diamond drillcore included a search for stratigraphy repeated by folding. In numerous trenches mapped across the strike of the Ridgeway Basin at a scale of one-inch equals five feet, observations were made where bedding dips of opposite direction were juxtaposed with each other. Facing criteria in graded turbidite greywacke and siltstone sequences mapped at these locations (Figure 10) were carefully inspected to see if early D1 isoclines were present, and none were observed.

The continuity in dip of S2 cleavage across the bedding reversals also suggests that early faulting subparallel to bedding was likely responsible for observed dip reversals. These faults are believed to represent reactivated basin margin faults.

The northern boundary of the Ridgeway basin is interpreted to be a fault zone rather than one single plane of slip (Figures 3 and 5). The east-trending quartz-veined and/or mafic-dike hosted shear zones mapped in this area by Gillon and others (1995b); Barker and others (1998); Secor and others (this volume), could reflect reactivations along the evolving basin margin. This trend is roughly along the trace of Sawneys Creek, as well as parallel to the trace of a series of regionally extensive aeromagnetic lineaments (Gillon and others 1995b).

Stratigraphic Units of the Ridgeway Basin

The abundance of volcanics stratigraphically beneath, within, and above the North gold deposit (Figures 11, 12) indicates this was a felsic and mafic volcanic center that was active during initial formation of the Ridgeway basin. The current level of detailed mapping (Figures 6, 7, 8, and 9) indicates that the felsic volcanic units are thicker and relatively monotonous in comparison to mafic volcanic units, which are typically volcaniclastic in character and interbedded with sediments. Massive to amygdaloidal mafic volcanic horizons have been mapped in the region, particularly at Ratttlesnake. Amygdular mafic units have also been observed in the Richtex Formation 1km east of the pit and 3km to the west. Otherwise, mafic volcanic units have been dominated by lithic lapilli tuffs. Shervais and others (1996) indicated that the transition from calc-alkaline arc volcanis to tholeiitic volcanism occurs synchronous with initial phases of submarine deposition in the developing intra-arc basin. The continued, though minor felsic volcanis observed out in the basin, as evidenced in the Ridgeway South gold deposit (Figures 5, 6, 7, 8, and 9), is consistent with the metallogenic evolution of other gold districts studied in the Carolina terrane (Worthington and Kiff, 1970; Feiss and others, 1993).

Twelve stratigraphic units are defined in this paper for that portion of the Ridgeway basin that encompasses the North and South deposits (Figures 6, 7, 8, and 9). In a north to south traverse from Sawneys Creek to Bear Creek and beyond, each of these units are described beginning with what is interpreted to be the oldest to youngest. The basin development begins with the first pulse of tholeiitic mafic volcanics and sediments, and thus, any felsic volcanics south of this line are labeled as part of the Richtex Formation. Apparent thicknesses of each unit are also stated, though some unit boundary faults are likely based on bedding dip reversals. In addition, several east -west to northeast trending quartz-veined shear zones displace units in a consistently dextral manner, though the amount of displacement does not appear to be large. Assuming that early isoclinal folding or faulting have not duplicated strata, units 1 through 11 comprise 14, 000 feet (4200 meters) of Neoproterozoic sedimentation in the Ridgeway basin. The stratigraphic position of unit 12, located south of the Bear Creek thrust, is uncertain with respect to the rest of the basin. Each unit is discussed below.

Unit 1, located adjacent to the south side of Sawneys Creek, has an apparent thickness of 1,0 00feet (300 meters). It is comprised of interbedded felsic and locally amygdaloidal mafic flows/tuffs, thin horizons of sediments, as well as rare chert and quartz-sericite-pyrite alteration.

Unit 2, with an apparent thickness of 700 feet (200 meters), is comprised of dominantly feldspar crystal felsic tuffs with vent breccias (Figure 12a).

Unit 3, with an apparent thickness of 300 feet (90 meters), and a strike length of at least 10,000 feet (3040 meters). It consists of interbedded mafic tuffs and sediments with locally intense quartz-sericite-pyrite alteration.

Unit 4, with an apparent thickness of 700 feet (200 meters), consists of well foliated feldspar and locally quartz crystal tuffs and flows (?). Exposures of this unit crop out on the northern edge of the North pit in proximity to vent breccias in unit 5. Portions of this unit are pyritic and quartz veined.

Unit 5 is comprised of approximately 300 feet (90 meters) of mafic lapilli tuffs, chert, siltstone, and minor felsic tuffs. The lapilli-sized fragments consist of chlorite and sericite, and feldspar crystals are common both in the lapilli and rock matrix (Figure 11b). The cherts are massive to foliated, fine grained quartz layers that in places appear to be interbedded or replacements of lapilli. Most recently, vent breccias comprised of angular to flattened felsic volcanics were discovered along the north rim of the North pit (Figure 13, with location marked with black triangle on Figure 9). Unit 5 has been traced over 5000 feet (1520 meters) west of the North pit; its exact trace to the east has not been mapped in detail.

Unit 6, the stratigraphic host of the Ridgeway North gold deposit, has an apparent thickness of 1200 feet (360 meters). It is dominated by thinly bedded turbidites and chert. Minor to rare felsic ash flow tuffs, mafic tuffs, vent breccias, and hydrothermal breccias are also present (Gillon and others, 1995b). Bedding in less altered as well as highly altered portions of the deposit is mostly vertical, steep, or moderate south dipping (Figure 14), though later deformation associated with cross-cutting shear zones has produced east-west trending synforms and antiforms (Figure 15). Chert and widespread quartz-sericite-pyrite hydrothermal alteration occurs in these sediments over a known strike length of 10,000 feet (3040 meters), culminating in the molybdenite-bearing, highly silicified and potassically altered Ridgeway North deposit (Figure 16). A turbidite-fragmental tuff unit mapped along the east face of the pit youngs to the south, and may extend across the entire strike length of the deposit (Figure 17 and thin section in 12b). A similar horizon was also identified in surface trenches 50 0meters west of the east pit wall prior to mining. If the unit were traceable across the entire deposit both from surface to depth, it would be a significant indication that the North deposit stratigraphy has simply been rotated on its side to produce the steeply dipping bedding currently observed.

Unit 7 has an apparent thickness of 200 feet (60 meters) and is comprised of interbedded mafic volcanics and thin siltstone horizons. The mafic volcanic lithologies include lapilli tuffs, fine-grained mafic ash beds (Figure 18), and to the east of the North pit, possible altered amygdaloidal flows. The unit is well exposed in the south wall of the North Pit, where it serves as the moderately north-dipping structural footwall of the North ore body (Figure 18). Unit 7 is chert poor, but is variably altered along its northern, sheared boundary with the North orebody.

Unit 8 has an apparent thickness of 1100 feet (330 meters), and is comprised of turbidites that appear to be barren of any hydrothermal alteration. A north-facing graded bed locality in this unit along SC Hwy 34 is the only north-facing criteria seen in the basin between the two deposits to suggest an early isoclinal folding event, but its significance might be discounted by its proximity to several quartz-veined shear zones in the area.

Unit 9 has an apparent thickness of 700 feet (200 meters), and is comprised of interbedded mafic volcanics, turbidites and with minor felsic tuffs and chert. The unit has been traced at leas t 3km west of the mine area. It has been mapped over 8 km to the east of the mine in association with numerous zones of quartz-sericite-pyrite alteration. Though consisting primarily of mafic tuffs, flows, and interbedded sediments, felsic feldspar tuff and porphyry are also present in the unit. The widespread hydrothermal alteration and gold mineralization along this trend was called the Rattlesnake trend, named for the large canebrake rattlesnake agitated by Amselco geologist Ron McDaniel.

Unit 10 has an apparent thickness of 3600 feet (1090 meters). It is comprised of turbidite greywacke and siltstone and contains numerous, thin horizons of quartz-sericite-pyrite and molybdenite altered greywacke and chert. The upper contact of Unit 10 is interpreted to be a fault separating older Richtex Formation turbidites to the north fro younger Richtex Foormation mudstone and siltstone to the south. On the north side of this contact is a 10,000-foot (3040 meters) long zone of hydrothermal alteration, whose widest portion hosts the 1,000-foot (300 meter) thick Ridge-

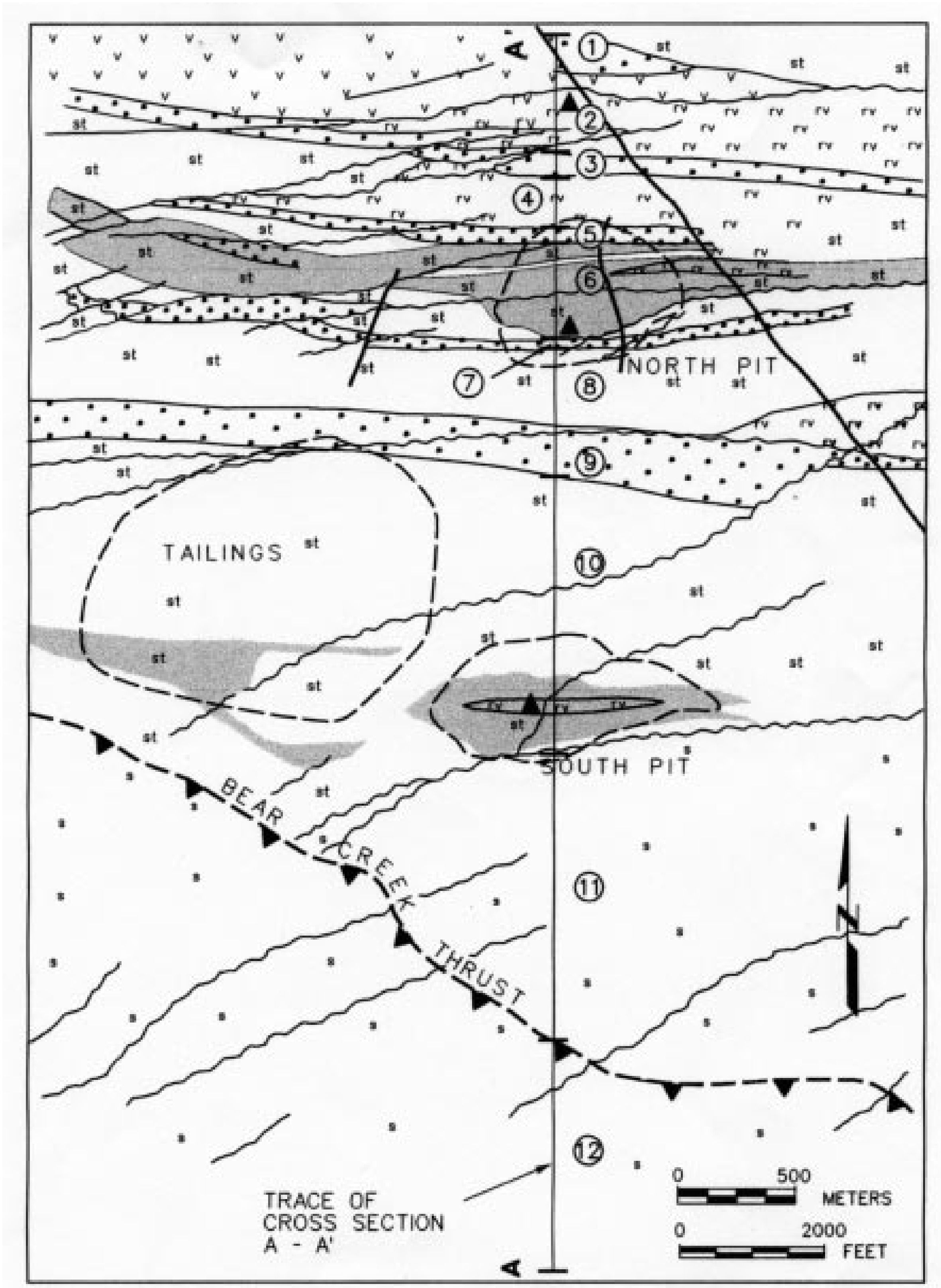

Figure 6. Revised geologic map of the Ridgeway mine, with legend included as Figure 7. Cross section along line A-A ' included as Figure 9. Stratigraphic units numbered on cross section trace are discussed in text. Sources of data include unpublished exploration data and geophysics by Amselco-Kennecott geologists during the period 1982-1992, Gillon and others (1995a; 1995b), 1996-1998 North pit mapping by S. R. Dinkowitz, and 1998 mapping by K. A. Gillon.

MESOZOIC

CRETACEOUS SEDIMENTS

-Jfd JURASSIC FELSIC DIKE

-d TRIASSIC DIABASE DIKE

NEOPROTEROZOIC

s s UPPER RICHTEX FORMATION SILTSTONE/MUDSTONE

st st RICHTEX FORMATION
TURBIDITIC GREYWACKE AND SILTSTONE

ZONES OF SYNGENETIC HYDROTHERMAL ALTERATION

RICHTEX FORMATION MAFIC VOLCANICS AND SEDIMENTS

rv rv RICHTEX FORMATION FELSIC VOLCANICS

V V V PERSIMMON FORK FELSIC VOLCANICS

FELSIC VENT BRECCIAS

FAULT

LITHOLOGIC CONTACT

BEAR CREEK THRUST FAULT

BEDDING VERTICAL

70 BEDDING, WITH DIP DIRECTION AND DEGREES, AS NOTED

LOCATION AND DIRECTION OF STRATIGRAPHIC FACING CRITERIA

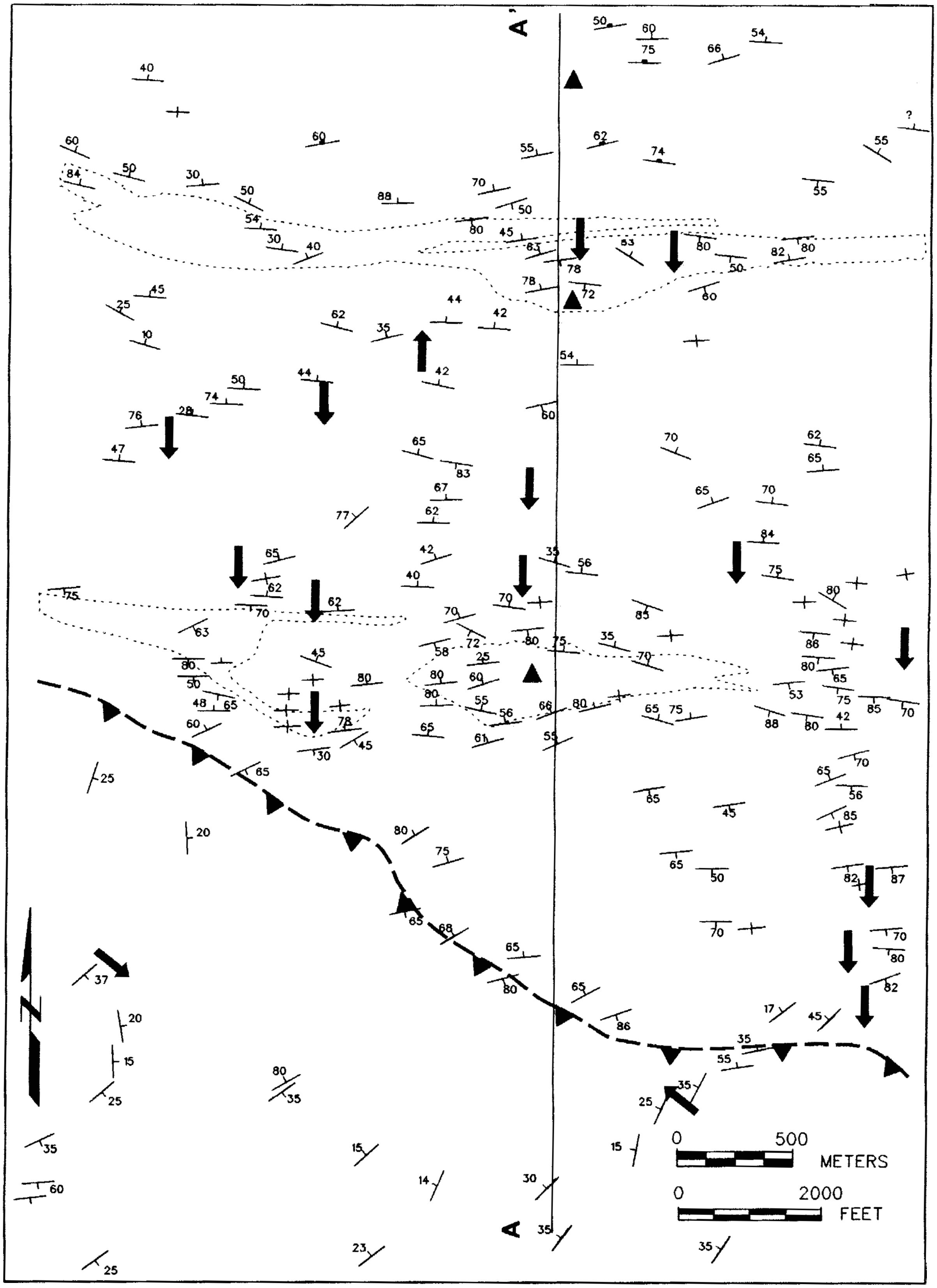

Figure 8. 1998 map of the Ridgeway mine area showing strike and dip of bedding and locations where stratigraphic facing directions were determined. Data were compiled from unpublished mapping of Amselco-Kennecott geologists during the period 1982-1992. The trace of cross section A-A' (Figure 9) is also noted.

way south gold deposit. The south deposit contains numerous zones of fragmental textured and hydrothermally altered silty to phyllitic clasts. Also present is a heterolithic fragmental unit which traced across the entire pit (black triangle in volcanic unit noted in south pit on Figures 6, 7, 8, and 9). This unit contains clasts of sediments, feldspar porphyry, and sulfides that are interpreted to represent an altered felsic volcanic debris flow or hydrothermal vent breccia (Gillon and others, 1995b).

Unit 11 has an apparent thickness of 4000 feet (1200 meters) and is comprised of generally thin, even-bedded mudstone, siltstone, and rare, sandstone/greywacke layers. Its northern contact with Richtex turbidites of unit 10 is a fault, though sense of displacement is not known.

Unit 12, located south of the Bear Creek thrust fault, is comprised the same thin bedded siltstone and mudstone that make up unit 11. The stratigraphic thickness of unit 12 has not been determined.

GEOLOGY OF THE NORTH DEPOSIT

Recent field mapping of the Ridgeway North pit have been compiled onto four pit maps that show deposit stratigraphy, structure, and hydrothermal alteration patterns (Figures 20, 21, 22, and 23). To facilitate discussion, each map includes as a graphically shaded backdrop that includes pit topography and the trace of major dikes, sills, and faults shown on Figure 20.

North Pit Stratigraphy

Figure 21 shows the trace of major, east-west striking depositional units as they crop out along the North pit floor and walls. Submarine mafic volcanics, chert, and siltstone deposition of Unit 5 followed the proximal felsic volcanis indicated by massive felsic volcanics of unit 4. Following unit 5 deposition, the basin appears to have been relatively starved of proximal felsic or mafic volcanism, as evidenced by the predominance of thin bedded siltstones that today comprise the northern half of the pit walls and the cherts prevalent in the south half.

The felsic fragmental volcanic ash flow tuff and associated turbidite cropping out along the east wall of the pit (Figure 17) is also shown with its south-facing younging criteria. The western limits of the unit in the pit wall and floor has yet to be found, but its possible continuation found at the original ground surface prior to mining is noted in plan and section on Figures 21 and 23, respectively.

Deposition of voluminous amounts of fine-grained silica occurred above the thin turbidites mapped along the northern half of the North pit. The silicification was likely coeval with continued deposition of mostly fine grained clastics and minor tuffs, as evidenced by mostly laminated bedding features preserved in the cherty unit. This exhalative/replacement (?) event is interpreted to be the primary gold-depositing event during formation of the North deposit, but was overprinted both structurally and hydrothermally by a later event interpreted in this paper to be epithermal mineralization. Relicts of the cherty unit can still be recognized as residual horizons cropping out on pit walls or in the botto of the current operating pit (Figures16 and 21).

The stratigraphic succession of lithologies above the cherty unit is not clear from current North pit exposures. Past exploration efforts at the ground surface and in drillcore

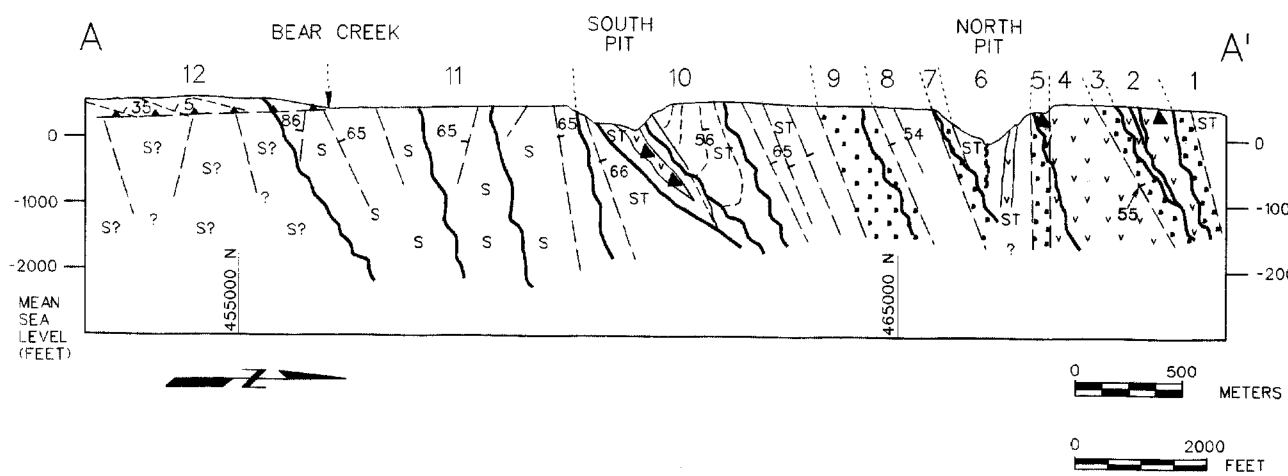

Figure 9. North-south oriented geologic cross section A-A' constructed across the Ridgeway mine. Trace of cross section is shown on Figures 6 and 8. Refer to text for discussion of stratigraphic units numbered above the line of section.

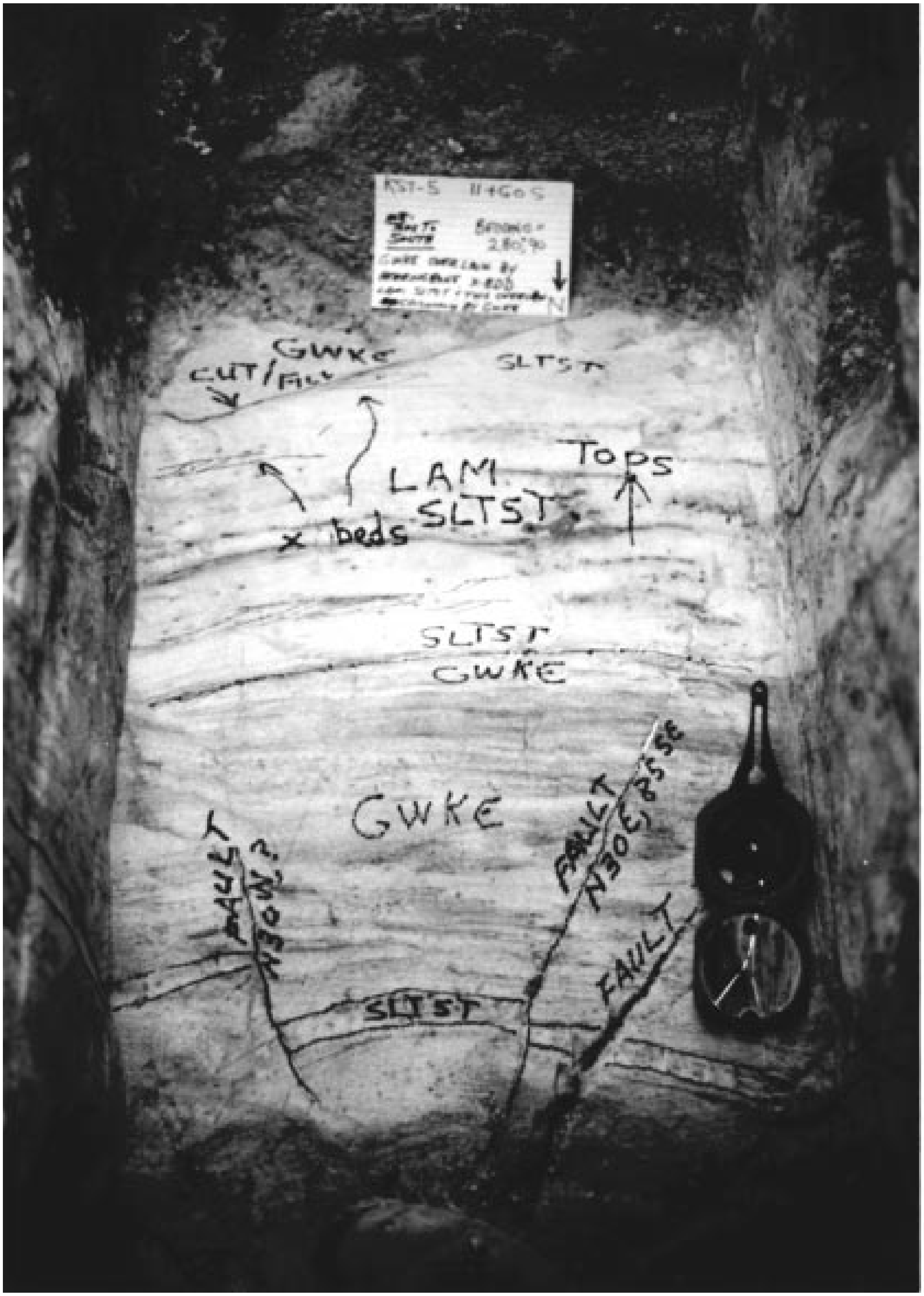

Figure 10. Photograph of 1984 trench exposing east-west striking, vertically dipping, and south-facing turbidite greywacke and siltstone of the Richtex Formation. Location is approximately 3000 feet (1 km) west of South pit. The depositional sequence preserved here is interpreted to be part of a Bouma cycle, as is follows: massive, poorly bedded greywacke at the bottom of the photograph grades upwards into faintly cross-bedded siltstone, followed by massive, fine-grained siltstone, and ending in mudstone. This mudstone is eroded by an overlying, new Bouma cycle basal greywacke. Brunton compass measures 23 cm.

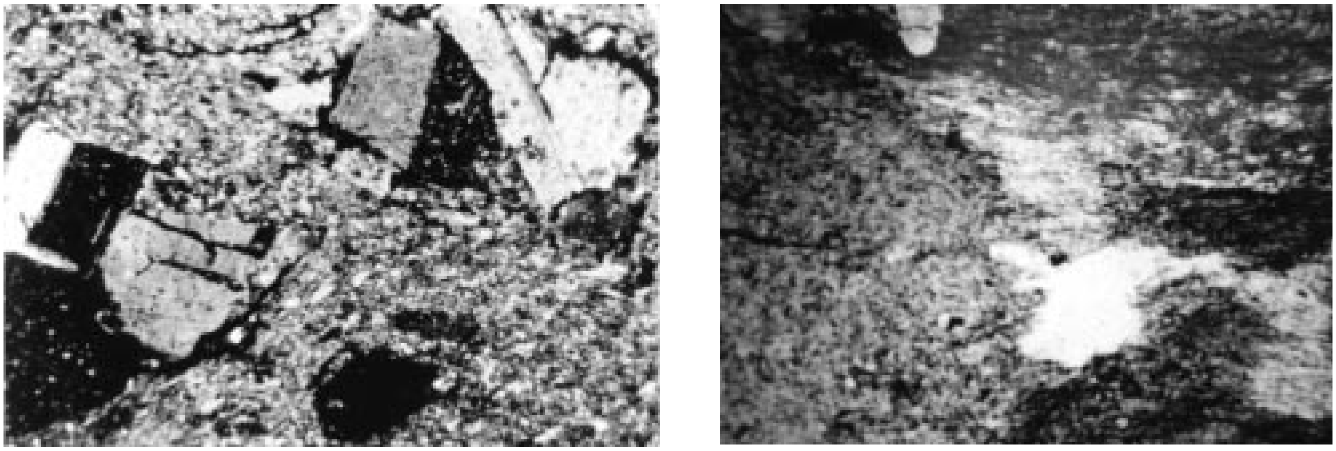

Figure 11. Photomicrographs of felsic and mafic volcanics in the Ridgeway area. A) Porphyritic albite (?)-quartz-sericite-feldspar porphyry from outcrop of large porphyry body located 2 miles (3.5 km) northeast of the North pit, as is shown in Figure 3. B) Mafic feldspar crystal lithic lapilli tuff from outcrop of Richtex Formation, stratigraphic unit 5, located approximately 1000 feet (300 m) west of the North pit. Large, rounded and light-colored sericitic lapilli fragment on left of sample is slightly flattened and surrounded by a matrix of dark colored chlorite, sericite, and euhedral albite (?). Width of view in both photomicrographs is approximately 8 mm.

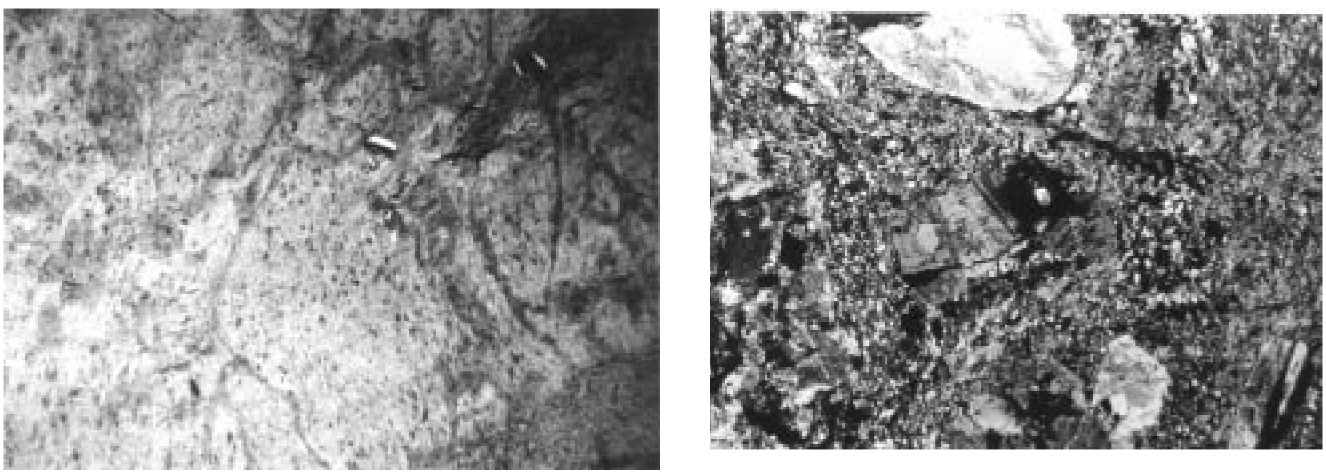

Figure 12. Photographs of Richtex Formation proximal felsic volcanics. A) Saprolite roadcut exposure of vent breccias located on Fairfield County Road 46, approximately 1500 feet (460 m) north of the North pit. Location is marked as black triangle in stratigraphic unit 2 (Figures 6, 8, 9). Breccia consists of angular to rounded dacite or rhyodacite fragments with darker chloritic reaction rims. Largest fragment measures approximately 18cm in length. B) Photomicrograph of porphyritic albite white mica-quartz felsic tuff or porphyry from drillhole KND-1, 472 feet (144 meters) depth. Drillhole is located approximately 1000 feet (300 meters) east of the North Pit. This volcanic unit appears to strike west into the North Pit, daylighting as a felsic fragmental ash flow(?) tuff and turbidite couplet with tops to the south. Field of view in photomicrograph is approximately 8 mm.

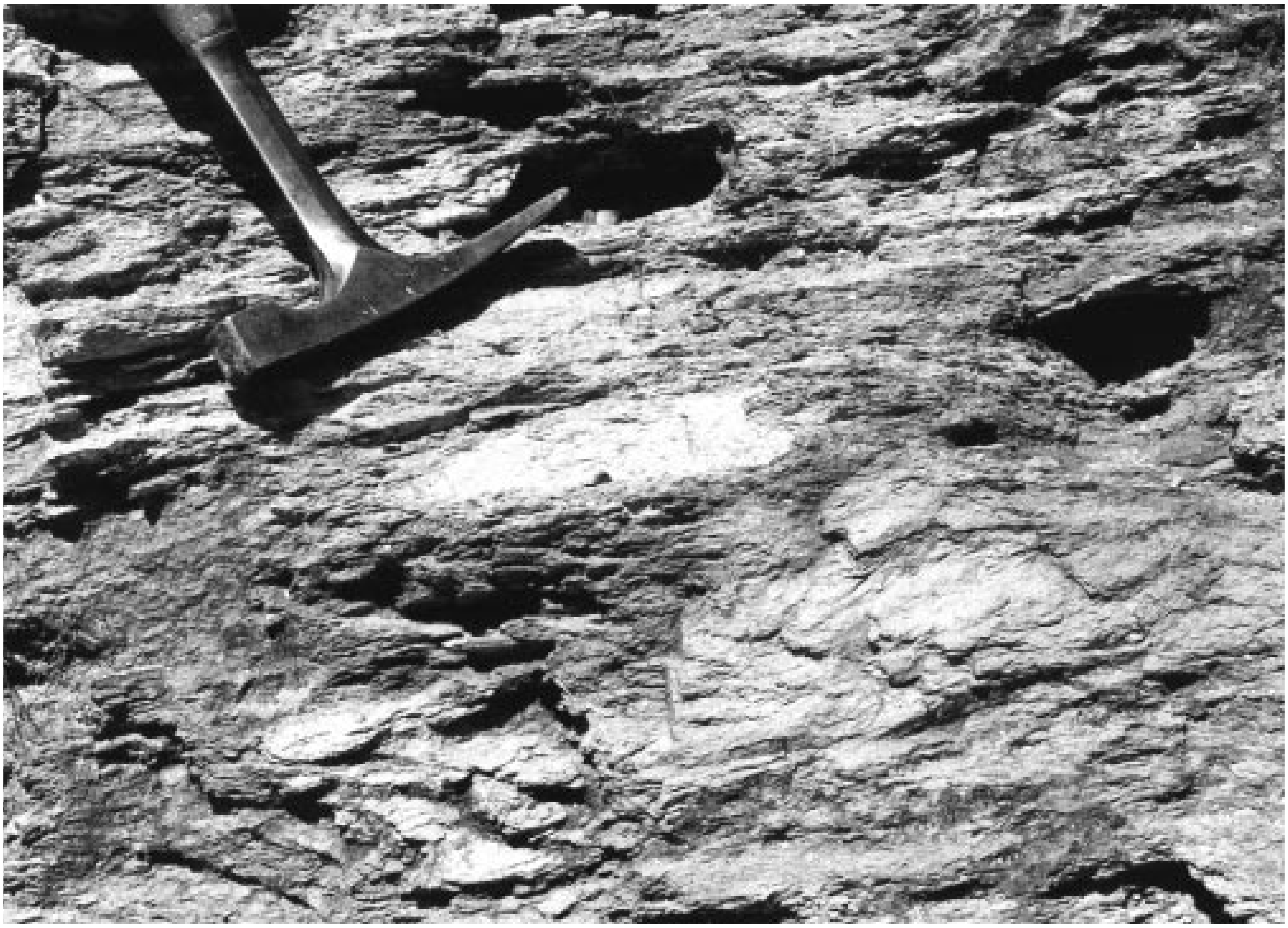

Figure 13. Photograph of Richtex Formation felsic vent breccia fragments in weak phyllic-altered mafic lapilli tuff of stratigraphic unit 5 (Figure 9, black triangle). Outcrop is exposed at the 420-foot elevation level along the north side of the pit. Dacitic or rhyodacitic felsic tuff fragments up to 30 cm are present in the bench face exposures here, and many of the fragments are angular with little indication of tectonic flattening. End of hammer measures 20 cm.

indicated that a felsic vent or hydrothermal breccia was present approximately where the current south overlook has been established (black triangle at south end of North pit noted in Figures 6 and 8). Additionally, tracing of the North deposit geology along strike to the west indicates alteration and mineralization gradually fade out into the surrounding stratigraphy. This picture, however, is highly complicated by the observed transposition and structural-disruption of lithologies along the S2 cleavage.

The south contact (structural footwall) of the deposit with mafic volcanics and sediments of unit 9 is a shear zone. The zone exhibits an early phase of ductile reverse movement followed by more recent brittle, normal slip. Hydrothermally altered portions of the footwall mafic volcanics and interbedded sediments of unit 9 suggest fault offset from their depositional contact with the North deposit may not have been significant since they were imprinted by a portion of the same thermally-driven alteration system.

STRUCTURAL DEVELOPMENT OF THE NORTH DEPOSIT

Numerous structural features have been recognized in the Ridgeway mine region during exploration activities. This section attempts to relate the observed fabrics in the mine area to regional events reported elsewhere in the Carolina terrane. The Ridgeway Basin appears to have experienced at least five deformational events following deposition.

D1 - Bedding Parallel Cleavage (S_1) — a Non-fold Event?

The recognition of primary depositional features and an early D1 isoclinal folding event within the Ridgeway region is discussed above in the section on stratigraphic development of the Ridgeway basin. Secor (1987) has reported regional deformation associated with an early isoclinal event

Figure 14. Photograph of northwest wall of North Pit from the 300-foot elevation bench taken during the winter of 1995. Pit depth is 160 feet (48 m). Moderate to steeply south-dipping ledges are comprised of laminated siltstones that are interpreted to occupy the stratigraphic foot wall of the Ridgeway North gold deposit. The S_2 cleavage here dips south at a shallower angle than bedding, contributing to the large scarps that also correspond to a prominent joint set in the pit.

for the Carolina terrane southwest of the mine. Termed the Delmar D1 deformation, this event produced major synclines and anticlines, and was accompanied by penetrative strain, tight to isoclinal folding, and greenschist facies metamorphism. It was also interpreted to be at least middle Cambrian in age, as it affected Asbill Pond formation lithologies.

The $S_{0/1}$ fabric of this paper precedes development of S2 slaty cleavage, as is discussed in the section below. The S2 fabric is interpreted to be the same deformational fabric in the Ridgeway and Longtown quadrangles that Barker and others (1998) and Secor and others (this volume) interpret to be Neoproterozoic in age. Since the S1, bedding parallel foliation identified in Ridgeway mine area predates S2, it, and S2 must have formed in a deformational event that was also pre-Delmar (pre- middle Cambrian).

D2 - Slaty Cleavage (S2) and Folding

A penetrative (S2) slaty cleavage is present throughout the mine region, being expressed in thin section as preferably oriented micas that overprint the S1 fabric and are associated with basal greenschist facies metamorphism in the mine area. The orientation of S2 strikes generally east west and dips moderate to shallow to the north where unaffected by later deformation (Figure 22). S2 is accompanied by flattening of markers such as lapilli in volcanics and intraclasts in turbidite beds, and the intersection lineation of S2 with S0/1 is typically shallow plunging in an easterly or westerly direction depending on the effects of later deformation.

Mesoscopic D2 folds associated with S2 development are believed to have developed in structural zones, which experienced relatively higher strain rates during deformation. This conclusion is drawn from observations in both North and South pits. In the South pit, south-verging D2 iso-

Figure 15. Photographs of grey-green, propylitic-altered siltstones from the 400-foot elevation bench in the northeast corner of the North Pit. A) Thin bedded to laminated, and shallow north-dipping bedding has been deformed into a D4 synform along a nearby quartz-veined shear zone. B) The thinly layered to laminated bedding contains finely disseminated pyrite and a few 1 cm pyrite porphyroblasts with pressure solution fringes oriented parallel to the crosscutting S_2 slaty cleavage. Knife measures 10cm.

Figure 16. Photographs of mine operations in the North Pit as of June 1998. A) View of pit from northeast rim. Mine operations at this time were at the 140-foot elevation, with a proposed, ultimate pit floor at the minus 100-foot elevation. B) View of highly silicified, shallow S2-cleaved cherty ore from center of the pit at the 140-foot elevation.

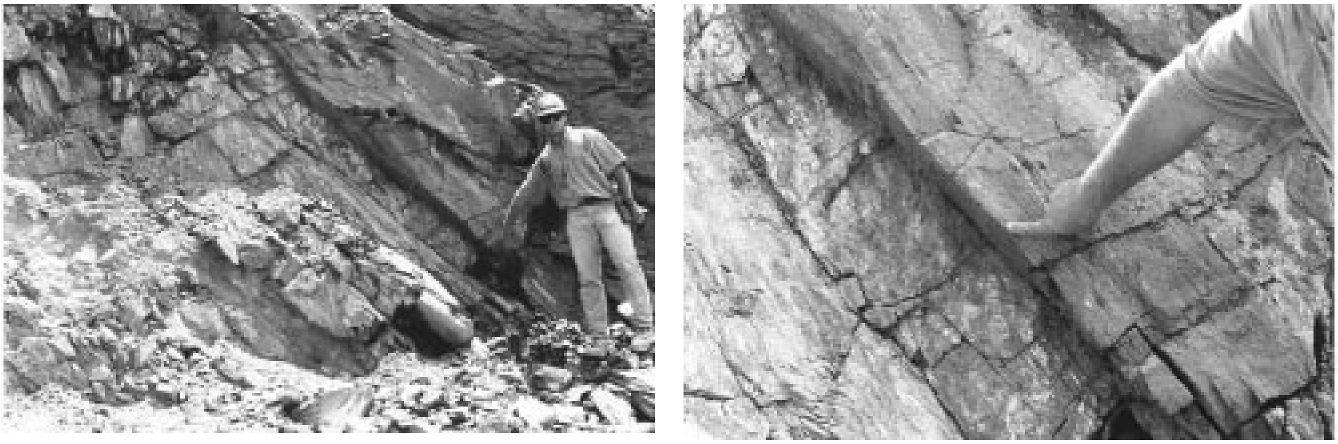

Figure 17. Photographs of quartz-phyllic altered and molybdenite-altered turbidites along the 340-foot elevation, east wall of North Pit. A) Bench face exposes several Bouma cycles with tops to the south, comprised of 1-2 meter thick greywacke layers (above Langdon Mitchell's hand), interbedded with thicker units of laminated siltstone. B) Closeup photograph shows a basal greywacke (finger points to contact) which fines upwards. Dark grey-mottling of laminated siltstones below greywacke is partially due to ine grained molybdenite mineralization. The concentration of molybdenite in the finer grained laminated units begs the question: was molybdenite deposited syngenetic with deposition, or was it introduced during a later replacement event?

Figure 18. Photographs of Richtex Formation stratigraphy along southwest rim of North pit. A) Southwest-directed view of propylitic, phyllic, to locally quartz-phillic altered Richtex mafic volcanics of stratigraphic unit 7 that are reverse faulted against thin-bedded footwall turbidite siltstones. The contact between these lithologies is interpreted to be the footwall shear zone of the North deposit. B) View of steeply north-dipping and overturned, thinly laminated turbidites of stratigraphic unit 6, located in the western corner of the pit rim. Sediments are propylitic-altered, with purplish iron and manganese staining. S2 cleavage dips shallow to the north-northeast.

clinal folds with sheared out limbs are observed. In these areas of the deposit, S2 is viewed as being of major importance as a fabric along which gold mineralization was concentrated (Gillon and Duckett, 1988; Duckett and others, 1988; Gillon and others, 1995a, 1995b).

In the North Pit, D2 folds have been refolded by a later east-west trending fold event. Along the south half of the North Pit, where S2 dips north, the few folds observed in the highly silicified ore verge south. South-verging D2 folds are also observed along the north side of the pit. Mapping of nearly two miles of mine bench face indicate that the S2 fabric is either an anastomosing fabric or is a composite of several strain events of similar orientation but with slightly different timing. Offsets of different mineralization zones by thin shear zones at a slightly different planar orientation to S2 have long been recognized in drill core from the deposit and generally corresponded to gold grade boundaries.

On a megascopic scale D2 folding is interpreted to be related to a large scale folding event which rotated Ridgeway Basin lithologies into their present, steeply homoclinal, south-younging orientation. Such an interpretation argues that the northern portion of the Ridgeway basin occupies the

Figure 19. Photograph of quartz-phyllic altered Richtex Formation turbidites(?) with shallow north-dipping S2-transposition of bedding. This exposure is mapped as the structural footwall shear zone between the North Pit deposit and mafic volcanics of unit 7. Knife measures 10 cm

hinge zone of a D2 fold.

The anastomosing orientation of S2 fabric in the North and South pits is consistent with the variable orientation of a regional S-fabric mapped by Barker and others (1998) and Secor and others (this volume). The S-fabric of these workers developed during a deformational event which spanned very short geologic time frame (after 550Ma volcanism and no later than synkinematic deformation of the Longtown metagranite, also 550 Ma). A hypothesis is presented in the below section on genesis of the Ridgeway deposits that links rapid evolution of the Ridgeway basin with deformation and hydrothermal activity.

D3 (S3) Flexural Folding, Faulting, and Igneous Intrusion

The third deformation event recognized in the mine region is the large-scale east-west trending synformal warping implied by S2 fabrics along the center of the North pit (Figure 22), and suggested in the cross section included as Figure 23. Upright, east-west trending crenulations parallel the axis of this folding. Pit face exposures show only mild warping of the silicified S2 fabric to hint of larger scale warping. Synchronous with D3 warping and possibly responsible for its existence are east-west striking, steeply south dipping faults into which mafic dikes have intruded. Flexural drag folds are associated with these faults, which indicate normal slip. The axis of the North Pit synform corresponds roughly to the strike of the main, east-west trending dike (Figure21), which dips 80 degrees to the south.

Other east-west striking, steeply south dipping dikes are also present in the north wall of the pit. These may have contributed to produce the synformal structure of the North deposit. The main east-west trending mafic dike shows no indications of movement after intrusion. The emplacement of shallow-dipping mafic sills along weaknesses subparallel to S2 cleavage may have corresponded with D3 warping.

D3 warping in the North deposit has some structural similarities to the D3-Kiokee antiformal deformation observed southwest of the mine region by Maher (1987); and suggested to be of 268 to 315 Ma in age. As described by Maher, this deformational event is characterized as large-scale crustal folds associated with thin-skinned crustal shortening recorded elsewhere in the southern Appalachians and

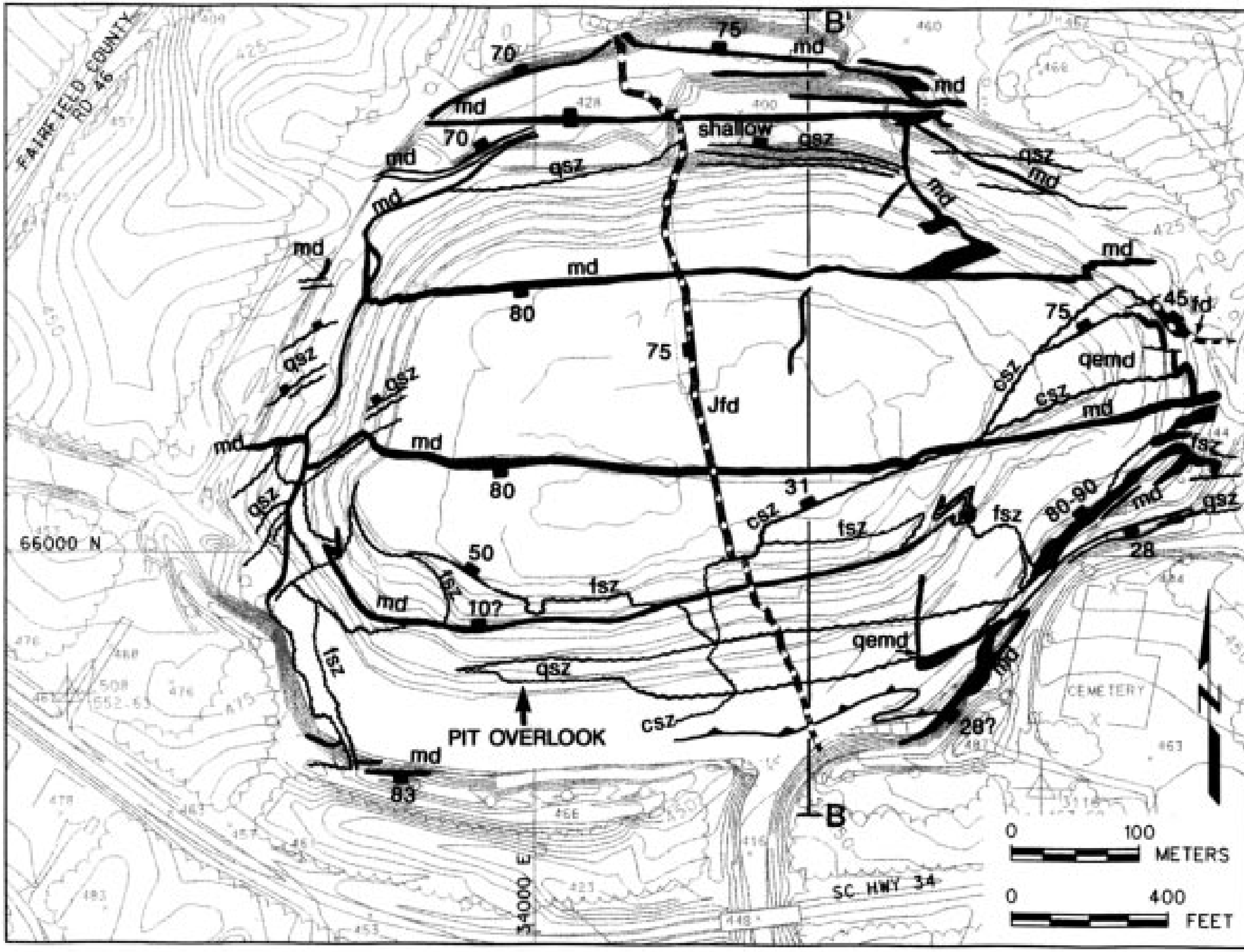

Figure 20. Map showing major structural features of the North pit as of June 1998. Dominant features include mafic (md) and felsic (Jfd; fd) dikes, central (csz) and footwall (fsz) shear zones, and quartz-veined shear zones (qsz). Strike and dip of structures/intrusives are posted where measured. Also shown is the trace of cross section B-B' (Figure 23). Location of North Pit overlook is also noted.

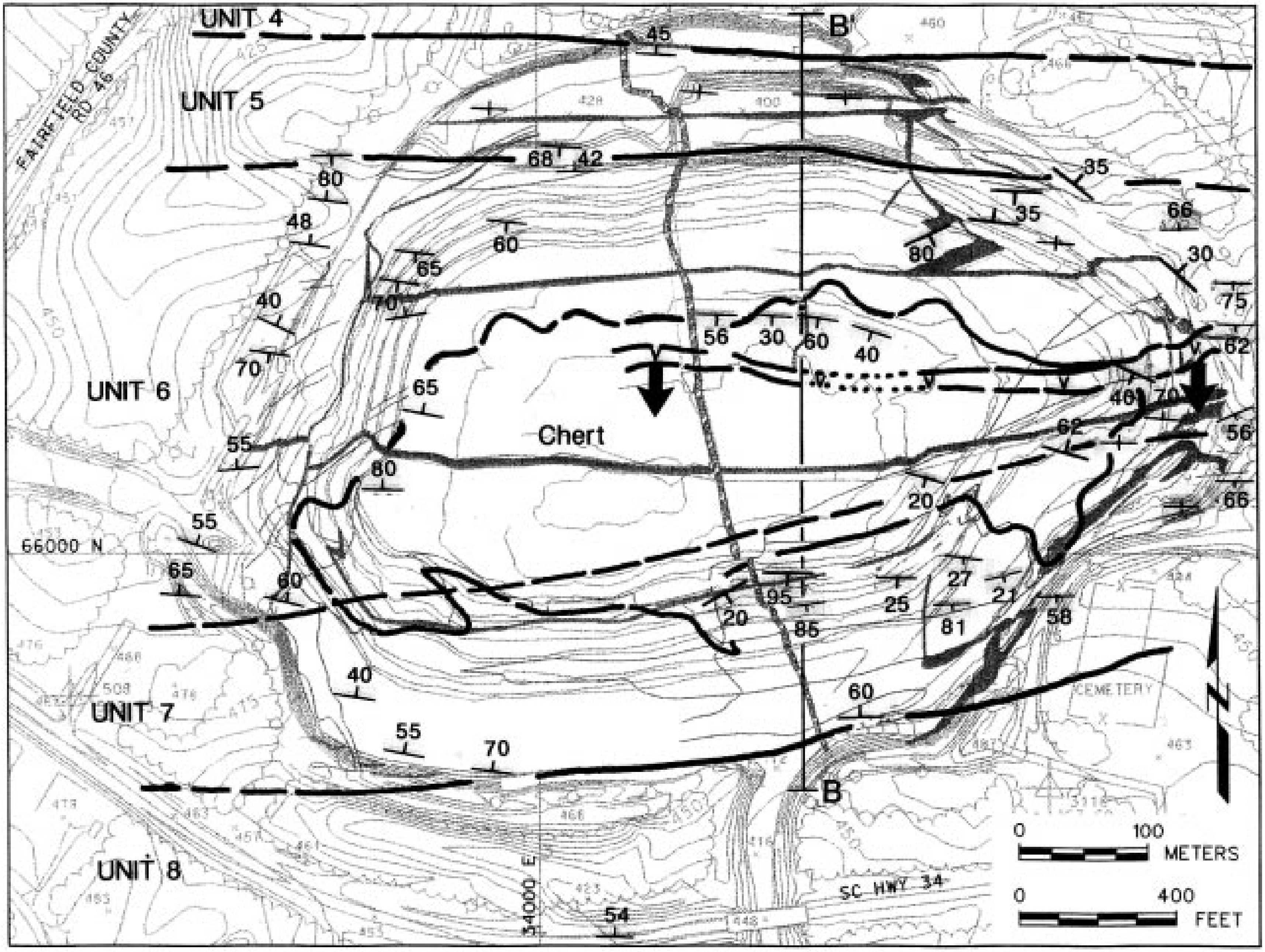

Figure 21. Geologic map of North pit showing mapped stratigraphic units and strike and dip of bedding. The approximate limits of gold-bearing chert are shown, as is the thin ash flow tuff/turbidite couplet recently mapped in the east wall of the pit. Its westward projection into the pit is based on premine trenching that exposed a similar turbidite that also exhibited criteria for stratigraphic tops to the south (note arrows on this figure as well as on Figure 8. Figure 20 structures are included as a backdrop for comparison.

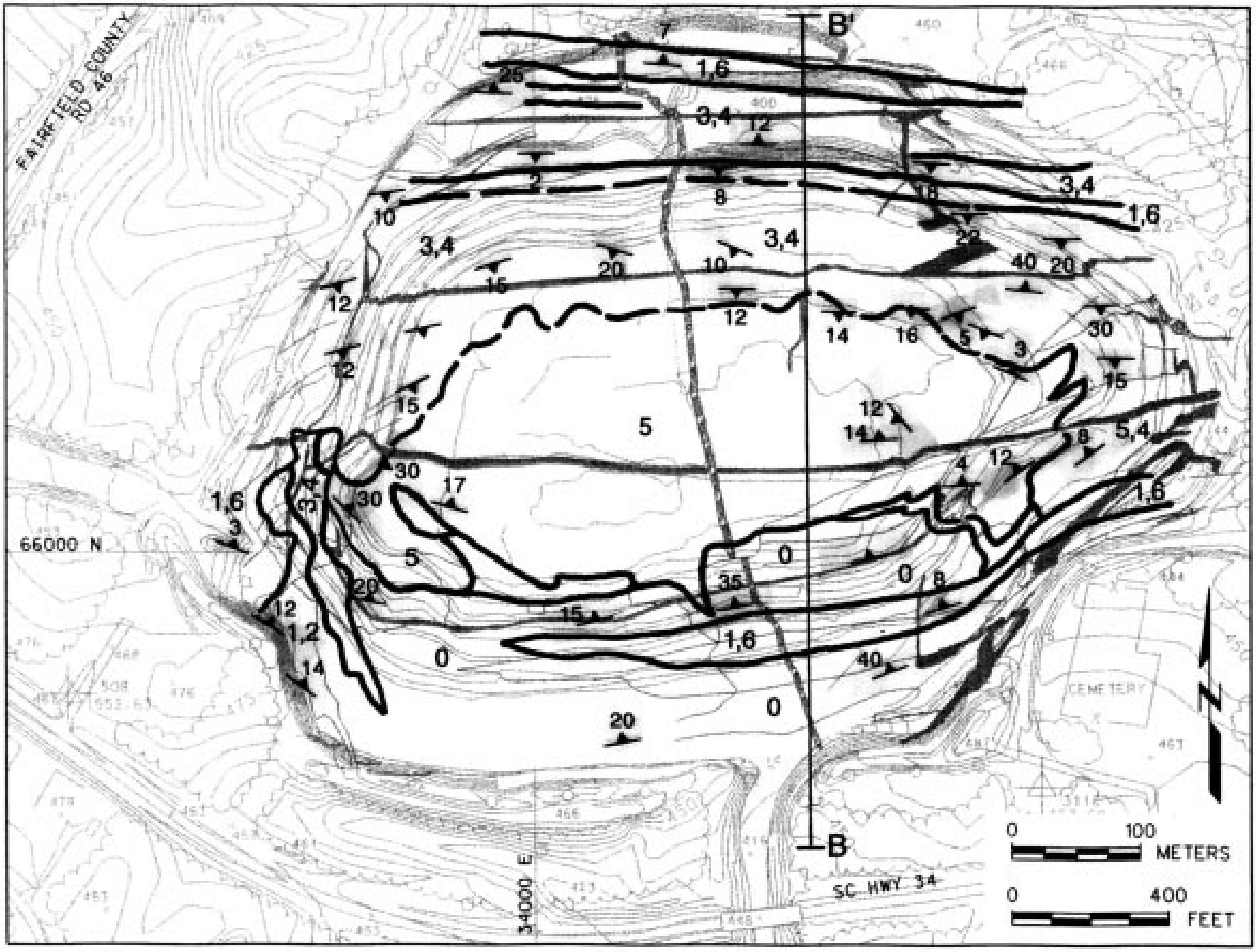

Figure 22. Map of North pit showing mapped boundaries of hydrothermal alteration zones and S2 cleavage. The center of the pit is warped about an east-west trending, upright D4 synform that roughly follows the trace of the east west dike in the center of the pit, shown as a backdrop from Figure 20. Six zones of increasing alteration intensity characterize the deposit, and are discussed in the text. In this figure they are labeled as follows: oxide (0), propylitic (1, 6), phyllic (2), quartz-phyllic (3), potassic (4), and silicic (5). Trace of cross section B-B' (Figure 23) is also shown.

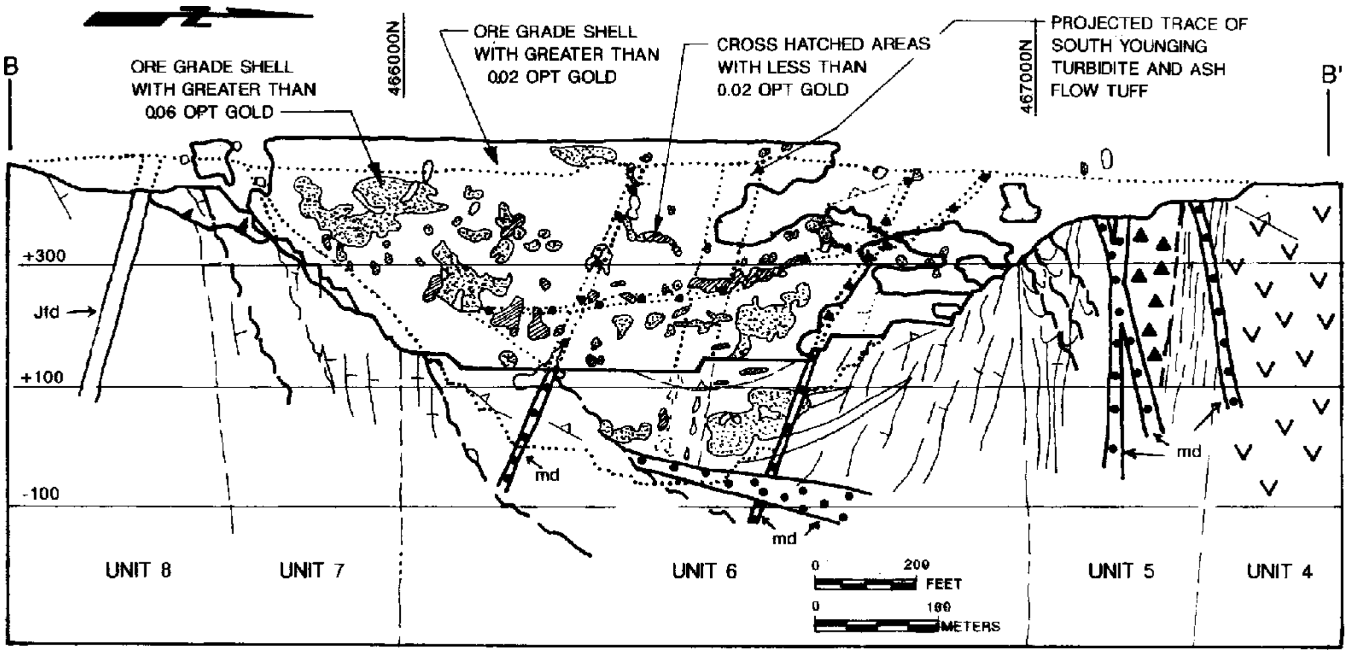

Figure 23. West-looking North Pit cross section B-B', constructed along the trace shown in Figures 20, 22, and 23. Lithology and structure projected to depth below the mined out pit (current as of June 1998) are based on mapping and Kennecott exploration drillhole data. Superimposed on the pit are modeled gold value grade shells constructed from blast hole modeled with MineSight® software. The grade shells represent a three-dimensional slice through the ore deposit starting at line B-B' and proceeding 400 feet west. Light shaded areas represent gold grades greater than 0.02 ounces of gold per ton. Dark shaded areas represent gold grades in excess of 0.06 ounces of gold per ton. White holes are values less than 0.02 ounces per ton gold. See Figure 21 for legend and text for discussion.

evident in South Carolina as large anticlinora in the Kiokee Belt arch. Folds associated with D3 are open to tight, upright, with steeply southeast dipping S3 surfaces manifest as parting planes and a weak preferred orientation of micas.

D4 Dextral Shearing, Quartz Veining, and Mafic Dike Intrusion

A series of east-northeast to west-northwest striking, moderate to steeply north-dipping D4 quartz-veined and mafic dike hosted shear zones traverse portions of the North Pit as well as the entire mine region. Most of these structures show evidence of dextral strike slip folding and faulting. Many are several feet thick and occupied by white quartz veins. Brecciation of these veins is common, and indicates early fault movements were coeval with a phase of hydrothermal silica precipitation, post-dated by later, brittle movement. Similarly, mafic dikes of up to several feet in thickness have been mapped in these zones, both with and without accompanying quartz veining.

In shear zones that cut the North and South Pits, these mafic dikes are complexly deformed and commonly chloritized. Outside of the deposits, these shear zones have strike lengths of up to tens of kilometers. These zones have been recognized both in outcrop and from analysis of aeromagnetic profile peaks compiled by Kennecott geophysicist Paul Lortie (unpublished company files, 1983-1987). The dextral offsets associated with these D4 faults can also be seen clearly in recent mapping of mine stratigraphy (Figures 6-plan view, and 9-cross section view).

One D4 shear zone in the North pit indicates a complex movement history. Termed the central pit shear zone (csz in Figure 20), this zone strikes northeast and dips moderately to the northwest, cutting across the eastern edge of the North pit and bifurcating before continuing on eastward. The central pit shear zone contains an S-C button phyllonite fabric, possibly in association with early, dextral drag folding of S2 fabric in the encompassing, silicified ore horizons. The next phase of movement was brittle, as evidenced by distortion and shearing out of both mafic and felsic dikes which intrude the eastern third of the shear zone. The final phase of movement was either dip-slip or left lateral, as indicated in 50 feet of apparent offset of the North Pit felsic dike. Zircon fission track age dates on the North Pit felsic dike indicate a 236 Ma age (Bornhorst, 1987). Offset of the felsic dike by the central pit shear zone, as well as by quartz-veined shear zones along the north rim of the pit, indicates reactivation of faults during post-Jurassic time. This conclusion is consistent with the observations in Secor and others (this volume) elsewhere in the Ridgeway-Camden area.

The dextral strike-slip character of D4 faulting and folding in the Ridgeway Basin (Figures 3 and 6) suggests it may have formed during the 291-268 Ma age Irmo D4 deformation of Dennis, Sacks, and Maher (1987). The Irmo D4 deformation event produced a ten-kilometer wide zone of dextral strike slip displacement that was mapped as far northeast as the town of Ridgeway. The orientation of D4 zones mapped in the mine region project southwest towards the Irmo structure, which deforms the trace of the Modoc shear zone shown in Figure 5. These workers also reported the deformation event to be characterized by reverse and normal slip crenulations with steeply dipping, northeast striking slip foliations (Dennis, Sacks, and Maher, 1987).

D5 - Late Brittle Deformation

Several post-ductile deformational events are evidenced in the Ridgeway mine region. Most obvious are the intrusions of Mesozoic dikes along fractures or faults. The North pit felsic dike (Figure 20) strikes north-northwest, dips 80 degrees to the southwest, and occupies a fault. The approximately 30 meters of reverse fault movement along this fault was established from premine ore modeling of drill intercepts. Fault movements along the diabase dike mapped east of the North pit have not been verified by map offset of units.

Structural mapping of the North pit (Gillon and others, 1995a) also identified north-south trending and steeply dipping joint sets with small offsets that tilt S2 fabric into east-dipping domains, as well as the east-plunging intersection between S0/1 and S2. This eastward tilted block faulting has also been observed in Kennecott's previous mapping west of the mine, and is of similar orientation to the Ridgeway fault of Barker and others (1998). D5 deformation may also have contributed to form domes and basins of the S2 surface in the North deposit. The existence of such structures at depth and their possible influence on ore grade control was first recognized in structural trend analysis of North deposit trench data prior to mining. Since that time, actual mining of the deposit has substantiated these predictions, with grade control having to deal with shallow dipping, pinching and swelling of ore versus waste zones along the deformed S2 surface.

GEOLOGIC CHARACTERISTICS OF RIDGEWAY-TYPE GOLD MINERALIZATION

The Ridgeway gold deposits represent fossil hydrothermal systems that were active both during and after deposition of the host stratigraphy. The principal geologic and alteration zonation signature of these deposits includes:

- A location that is near the contact between Persimmon Fork Formation felsic volcanics and Richtex Formation sediments containing mafic to felsic volcanics (Figure 3)
- East-west trending, topographically resistant zones of quartz+sericite+pyrite that may extend up to 10,000 feet in length and several hundred feet in width
- A moderate to steeply, north-dipping structural footwall
- The presence of an early slaty cleavage overprinted by a younger crenulation cleavage
- Post cleavage ductile and brittle shear zones overprinted by brittle faulting
- Anomalous concentrations of gold, silver, molybdenum, sulfur, arsenic, and titanium
- Mappable chert horizons which are focused along the structural footwall, extend along the strike of the deposits for hundreds or thousands of feet, and where distal, are typically pyritic, anomalous in molybdenum, but gold poor
- An outer to inner increase in alteration intensity that progresses through the six zones oxide->propylitic->phyllic->quartz-phyllic->potassic->silicic (Figure 22), which are discussed in detail below

A peripheral zone enriched in iron and manganese characterizes oxide zone alteration (Figure 22, zone 6) has been found to extend several hundred feet away from the fringes of these deposits, where it imparts a purplish color to weathered outcrops (Figure 18). Diamond cores into these zones along the west side of the South deposit attributed these “purpleite” zones to hematite lenses and high manganese concentrations.

The mineral association chlorite, epidote, calcite, pyrite, magnetite, and paragonitic muscovite characterize the propylitic zone alteration (Figure 22, zone 1,6). In unweathered lithologies this zone is difficult to distinguish from oxide zone alteration, and thus the two are often combined for mapping purposes. This zone is adjacent to more intense, phyllic alteration and can be anomalous in metals as well. A pyritic siltstone unit likely representing propylitic alteration is mapped across the entire north wall of the pit (Figure 22, zone 1,6).

The phyllic alteration zone consists of paragonitic to phengitic muscovite+quartz+pyrite. Closer in to the deposit, phyllic (sericitic) zone alteration (Figure 22, zone 2) develops and transitions into more silicified and potassium-enriched zones. Compositionally, the white mica varies fro paragonitic (sodium dominant) to phengitic (potassium dominant) muscovite, and titanium also increases in the muscovite with increasing potassium (Barnett, 1992a, 1992b). Fine-grained pyrite along relict bedding is common to phyllic and quartz-phyllic zones. Its deformation and recrystallization into larger pyrite porphyroblasts give the weathered rock a blueberry muffin appearance that is a useful marker for knowing when one is in the vicinity of a Ridgeway-type gold deposit.

The Quartz-phyllic and potassic alteration zones (Figure 22, zones 3, 4) are not distinguishable in the field, and as a result, potassic zones are not mapped out. These zones more often than not contain economic gold concentrations and are typified by fine-grained pyrite and quartz veining. The potassic zone mineral assemblage consists of quartz+phengite+potassium feldspar+pyrite.

The silicic alteration zone (Figure 22, zone 5) is typified by cryptocrystalline quartz dominant over phengite+potassium feldspar+pyrite. This zone is the dominant ore host in the north pit. It is texturally a microcrystalline quartz-dominant “chert” with fine-grained disseminated pyrite, minor phengite mica, and a bluish gray tint attributed to elevated molybdenum. The S2 fabric dominates banding within the cherty alteration of zone 5, and relicts of steep bedding are commonly transposed into the shallow dipping cleavage.

Gold concentrations that are highest in the potassic and silicic zones, and particularly where these are accompanied by cleavage-parallel transposition, quartz veining and dominantly fine-grained rather than coarse-grained pyrite

GENETIC MODEL FOR FORMATION OF THE RIDGEWAY GOLD DEPOSITS

A current view of the Ridgeway North deposit in cross section (Figure 23) provides a basis for presentation and discussion of a genetic model for formation of both North and South deposits.

Current Cross-sectional Geology of the North Deposit

The north-south cross section projected across the North pit as Figure 24 shows the gross relationship in the deposit between parent lithology, structure, and gold mineralization. Superimposed on the pit are modeled gold value grade shells constructed from blast hole modeled with MineSight® software. The grade shells represent a three-dimensional slice through the ore deposit starting at line B-B' and proceeding 400 feet west.

The geometry of gold concentrations projected on this cross section through the deposit is generally representative of the geologic model developed in the pre-mine era from drillhole and trenching data. Gold above a cutoff grade of 0.02 ounces of gold per ton is concentrated in the south half of the deposit. This ore control relationship is consistent with the interpretation that ore in the North pit was originally concentrated in a steeply dipping, exhalative or replacement chert (Figure 24a). Where the chert dominant unit was overprinted by hydrothermal fluids traveling along feeder zones that coincided with the S2- forming, transpressional (?) strain field, gold grades increased, in accompaniment with additional silicification, sulfidation, brecciation, and potassic enrichment (Figures 24b and 25). The geometry of such higher gold value grade shells is readily visible in cross section as Figure 23. Also visible on the section are the effects of D3 warping along the center of the deposit to produce the gross scale synformal geometry to grade shells and associated S2 fabric.

Previous Genetic Models Proposed for Formation of the Ridgeway Gold Deposits

The genesis of the Ridgeway and Haile-type gold deposits of the Carolina terrane has been the subject of considerable debate among explorationists and researchers. Past models can be lumped into two main schools of thought:

- Syngenetic-exhalative (Worthington and Kiff, 1970; Worthington and others, 1980; Spence and others, 1980, 1987; Kiff and Spence, 1987; Gillon and others 1995b)
- Epigenetic-synmetamorphic and shear zone related (Tompkinson, 1985, 1988; Gillon and Duckett, 1988; Duckett and others, 1988; Hayward, 1992)

The syngenetic-exhalative model for gold mineralization in Ridgeway-Haile type systems proposed ore deposition as siliceous sinters formed from felsic volcanic-related hot springs or fumaroles. The deposits were viewed as being distinctly asymmetric in cross sectional view, with an intense sericitic footwall alteration zone, with gold mineralization deformed into a metamorphic cleavage. Mapping of the Ridgeway deposits after the pits were exposed indicated that the North deposit contained a significant amount of chert that was likely formed by exhalative or syngenetic replacement.

The epigenetic and synmetamorphic, shear zone hosted models of Tompkinson (1985), Gillon and Duckett (1988) and Duckett and others (1988) proposed that the deposits formed in structurally dialatant portions of regional shear zones. These workers argued that intense pressure solution and transposition operated to either remobilize syngenetic gold or provide all of the gold mineralization along the S2 deformation fabric under epigenetic, epithermal or mesothermal metamorphic conditions. Tompkinson argued for an Alleghanian age of mineralization to explain associated molybdenum with the deposits. Gillon and Duckett (1988) argued for a synmetamorphic age of undetermined tectonic event.

Genetic model: Neoproterozoic-aged Syngenetic-exhalative Mineralization with a Neoproterozoic-aged Syntectonic-epithermal Overprint

Recent field and laboratory studies on the geology of the Ridgeway gold deposits have placed significant geochemical and geochronological constraints on their formation. Salient observations from each of these areas are summarized below.

Eager (1997), evaluated sulfur and oxygen isotope geochemistry of the Ridgeway North deposit, concluding that:

- Pyrite and pyrrhotite mineralization formed in an environment similar to modern and ancient sea floor systems

- A possible magmatic component is present in the sulfur
- A sea floor, hot spring environment of deposition is indicated by oxygen thermometry rather than formation under greenschist facies metamorphic conditions
- The hydrothermal system was closed to sulfur, even during metamorphism, indicating sulfides along cleavage are also syngenetic.

Two lines of evidence place timing constraints on the formation of the Ridgeway gold deposits. First, the 550 Ma age for the Persimmon Fork volcanics and the synkinematic Longtown metagranite (Barker, et. al., 1998; Secor and others, this volume) indicate this portion of the Carolina terrane evolved very quickly from its incipient arc volcanism, through basin opening and deposition, and subsequent basin closure, deformation, and metamorphism. The S2 cleavage in the Ridgeway deposits is the same style as that reported by these workers to be coeval with the synkinematic intrusion of the Longtown metagranite, thus indicating that a Neoproterozoic metamorphic overprint of the Ridgeway deposits was shortly on the heels of basinal deposition.

Second, the 540Ma and 550Ma ages of molybdenite from the North and South Ridgeway deposits, respectively (Stein and others, 1997; personal communications, 1998) indicates hydrothermal activity in the Ridgeway basin was occurring during the Neoproterozic. Amselco-Kennecott geologists recognized that molybdenite occurs as bedding-parallel stratiform horizons as well as in cross-cutting structural zones in gold deposits of the Ridgeway-Rattlesnake trend. This suggests both syngenetic and possible syntectonic mineralization pulses during which molybdenite crystallized.

Additional petrologic findings on the deposits by Barnett (1992a, 1992b) indicate the deposits were enriched in molybdenum, arsenic, silver, gold, potassium, tellurium, bismuth, antimony, lead, copper, zinc, and rare earth elements. The bismuth and tellurium-rich mineralogy of high-grade portions of North Pit ore, in association with potassium feldspar-stable fluids, argues to Barnett (1992b) that the North deposit has a definite igneous component. White mica compositional analyzes from the deposits and surrounding host rocks indicates a correlation between the influx of potassium and titanium-enrichment in phengite. The existence of undeformed, hydrothermal muscovite and potassium feldspar in S2 cleavage-parallel zones (Barnett, 1992a and 1992b) suggests hydrothermal fluidization may have persisted during cleavage development.

Field and petrographic studies have also evaluated the role of fragmental units in the hydrothermal evolution of the Ridgeway deposits. Hydrothermal breccias with rounded, angular, and slightly flattened, silty clasts, have been observed in the Ridgeway South deposit along S2-cleavage parallel zones that are accompanied by transposition (Figure 26). The lack of flattening in these zones suggests hydrothermal breccia formation was active during or after the peak of S2 flattening deformation. Petrography of ore zones across the South (Figure 27) and North (Figure 28) deposits (Barnett, 1992a) also indicates that episodic, tectonic-hydrothermal processes were active during deformation. This is particularly obvious in the North deposit where k-feldspar clasts (variety adularia), appear to have crystallized both syn and late tectonic with respect to the enclosing S2 fabric.

Based on information gained to date on the Ridgeway gold deposits, the following genetic model is proposed to explain their origin:

- Neoproterozoic, intra-arc development of the Ridgeway basin was accompanied by hydrothermal activity focused around felsic to mafic vent centers
- Formation of incipient, exhalative and replacement hydrothermal alteration with generally low gold values occurred in mafic volcanic and sediment sequences deposited during the hiatus of felsic dome building at the basin transition from calc alkaline Persimmon Fork to predominantly tholeiitic mafic tuffs of the Richtex Formation. Continued, rapid basinal subsidence and contemporaneous, down-to-the basin faulting ensured access of the felsic magmas or hydrothermal waters to the overlying seafloor surface
- Deposition of massive amounts of fine grained siliceous (opal?) sinter on, and beneath the seafloor was the primary ore phase for the Ridgeway North deposit
- Sea floor volcanism continued to erupt during the deposition of the cherts, as evidenced in the felsic ashflow tuff unit on the east side of the North pit, as well as the possible vent breccias that were once present near the structural footwall of the North deposit orebody
- After Ridgeway North deposit formation, continued basin subsidence and turbidite deposition was accompanied by intermittent, mafic dominated submarine volcanism. Syngenetic hydrothermal alteration at this time led to ore deposition along the Rattlesnake trend, deposits which are mostly mafic volcanic/sediment hosted and contain abundant, molybdenum-bearing exhalative cherts at the stratigraphic tops of the hydrothermal systems.
- Deposition of basinal turbidites with hot spring activity and local, heterolithic felsic ashflow tuffs, vent breccia, or epithermal hydrothermal breccia coincided with initial gold mineralization in the South deposit.
- Continued basin subsidence and transpressional closure generated pure shear flattening, folding, and incipient development of the deeper portions of the Ridgeway basin, now S2 buried under at least 14,000 feet (4200 meters).
- Original, steeply south (?) dipping, down-to-the-basin hydrothermal feeder faults were deformed into parallelism with the S2 fabric (or vice-versa). Continued transpressional closure of the basin accessed deeper levels of magma that synkinematically intruded the feeder

Figure 24. Photos of sub-ore grade, laminated to fragmental turbidites of Unit 6. Exposures are at the 180-foot elevation bench near the intersection of cross section B-B' and the Unit 6 and cherty ore boundary (location marked on Figures 22 and 24). Steeply south dipping bedding laminations in A), though warped along the shallow south-dipping S2 fabric, do not show appreciable transposition, quartz veining, or fragmentation. Height of face is approximately 1 meter. A fragmental-textured zone in B), located within 50 feet of A), indicates S2-parallel hydrothermal fluidization to be active on a restricted scale. Pencil measures 6 cm.

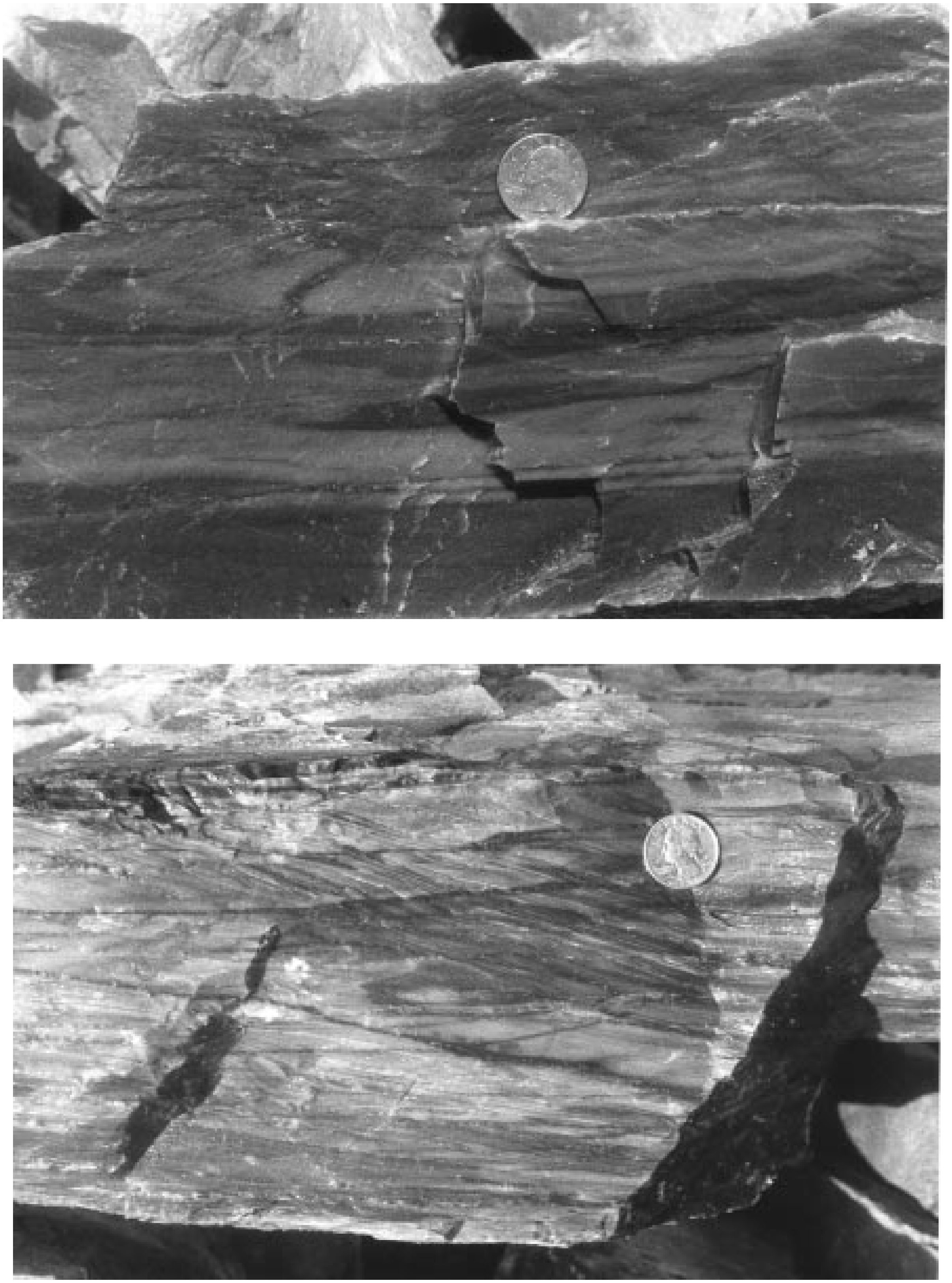

Figure 25. Photographs A) and B) of slabby, fine grained cherty ore from the center of the active pit at the 140-foot elevation bench. Intense transposition along S2 has obliterated any evidence of steeply dipping bedding, and the S2 fabric is nearly recumbent at this location (see Figure 16B). Quarter for scale measures 2.5 cm.

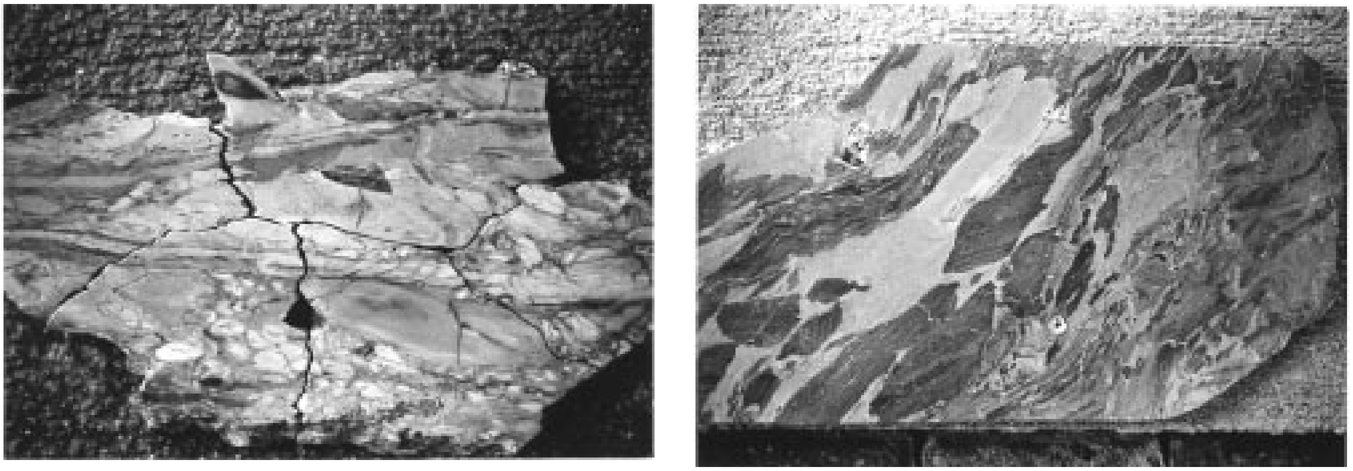

Figure 26. Photos of fragmental textured and quartz-phyllic altered Richtex Formation turbidites from the South orebody. Sample A) contains numerous 1-8cm long, slightly flattened to rounded silty and silicic clasts set in a silty matrix of granular silica The fragments appear to be of hydrothermal rather than depositional origin due to the presence of numerous, veined and previously foliated clasts. Sample was collected by K. A. Gillon in 1992 near the footwall of the ultimate pit, below the oxide/sulfide contact. Sample B is from a 15 cm diameter diamond drillhole into the South orebody conducted in the mid 1980's to determine the feasibility of developing the mine. As with sample A), clasts in sample B are of quartz-phyllic altered, laminated turbidite siltstone float in a granular, silty matrix. These, too, are interpreted to be hydrothermal breccias primarily because of the fluidized character of fragments floating in the silty matrix.

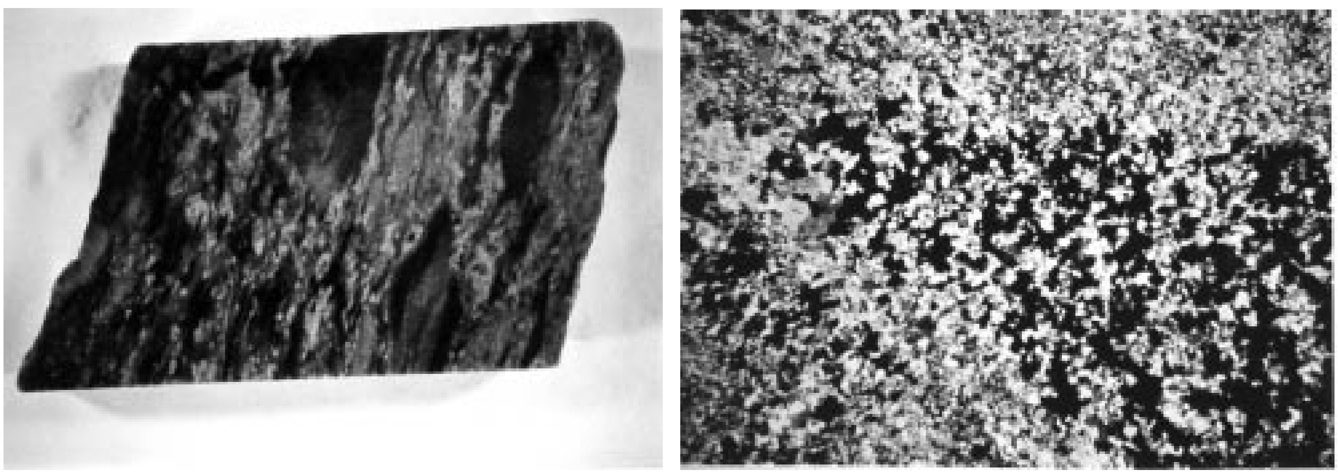

Figure 27. Photomicrographs of fragmental textured quartz-phyllic alteration from the Ridgeway South deposit. A) Fragmental textured core sample from exploration drillhole KSD-6, depth 679 feet (207 meters) which drilled the downdip portion of the south deposit near the current center of the pit. Light to dark rimmed fragments,2 to 3cm in length are elongate parallel to S2 cleavage. In thin section, the fragments consist of quartz + pyrite (B), or massive muscovite (C). Rather that representing original compositional banding, Barnett (1992b) interpreted these and many other adjacent fragmental units in drillhole KSD-6 to have originated as domains or lithons disrupted tectonically and subjected to subsequent hydrothermal alteration and further disruptive deformation processes.

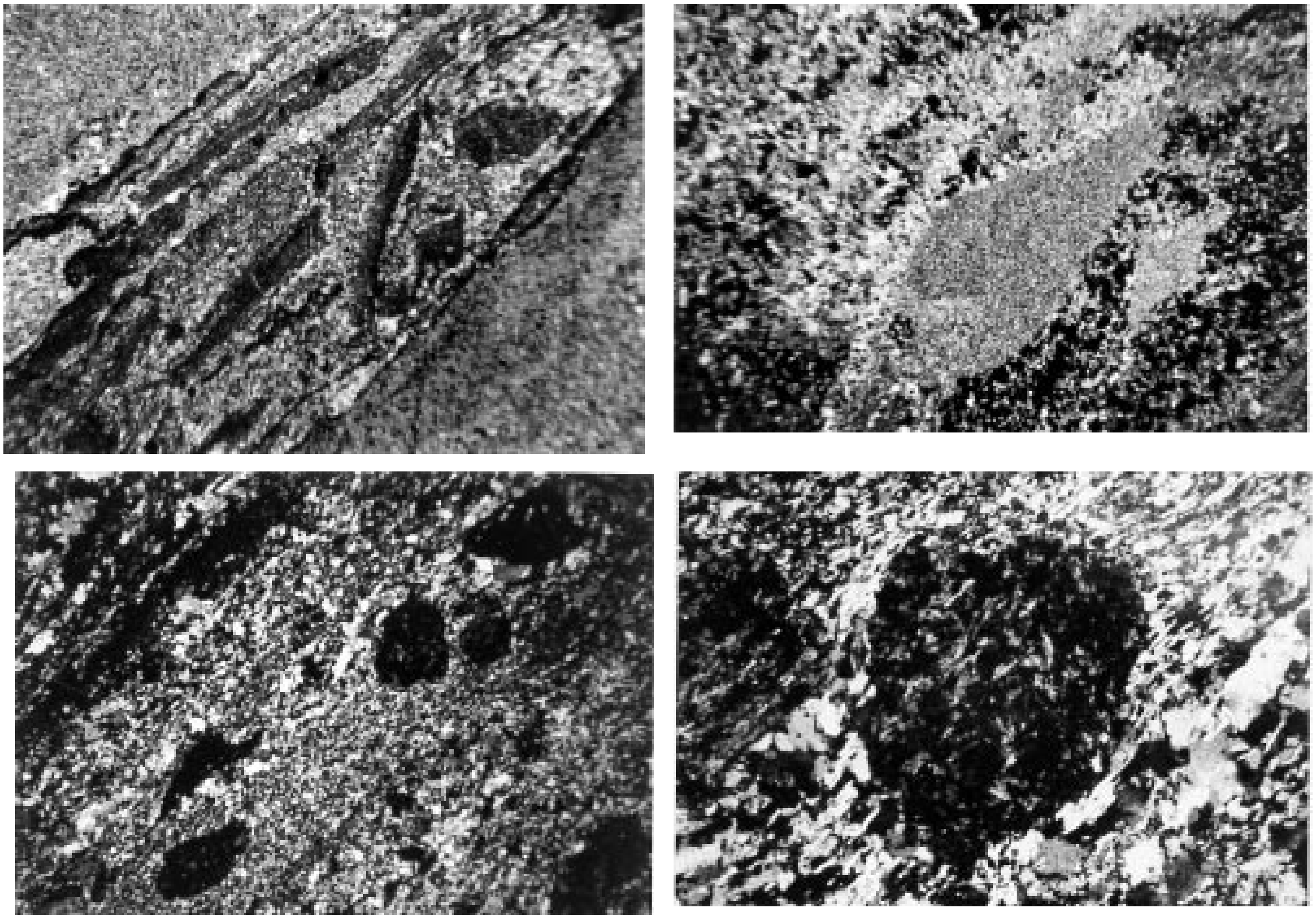

Figure 28. Photomicrographs of interpreted syntectonic alteration mineral assemblages from the Ridgeway North deposit. A) Drillhole APC-33, depth 300 feet (91 meters), showing hydrothermal venial of adularia+quartz+muscovite. The host rock matrix consists of preferably oriented, fine grained quartz and muscovite (S_2 cleavage?). These vein textures indicated to Barnett (1992b) that hydrothermal fluids were muscovite+k-feldspar stable, and that the muscovite was not formed simply by recrystallization of earlier micas. B) Drillhole APC-33, depth 367 feet (112 meters), showing a large fragment of fine grained siliceous host rock sealed by foliated hydrothermal pyrite+k-feldspar+muscovite+rutile, followed by later quartz. Surrounding the clast is a texturally complex hydrothermal vein assemblage where earlier hydrothermal k-feldspar and muscovite have been dismembered and sealed by later quartz. The vein also contains approximately five percent rutile, indicating hydrothermal fluids were open at least locally to titanium migration. Figures 28 C and D are photomicrographs of a North Pit high grade ore zone at the 200-foot elevation bench. Irregular shaped domains of adularia, enlarged as Figure 28 D, are situated in an area of strongly foliated quartz and muscovite As reported by Barnett (1992a), grains of hydrothermal k-feldspar with microcline twinning are also present in these samples, and are overprinted by a later planar cleavage (S2?) which allowed ingress of solutions which induced the growth of adularia.

Figure 29. The first of six Figures representing a clockwise motion photographic panorama of the North Pit as viewed from the south overlook in July 1998. Major structural features readily identifiable from the overlook are marked on each photo panel. Features observable in this panel include mafic dikes (md) and a quartz veined shear zone (qsz). Also in this figure, the marked locationwhere a mafic dike daylights out of the pit corresponds to the footwall shear zone of the North deposit, as is also shown in the photograph included as Figure 19. Distance to the far pit rim measures 800 feet (244 meters).

faults, leading to the epithermal overprinting potassic alteration observed in both the deposit

The Longtown metagranite is sulfide bearing, has a chemistry similar to surrounding Persimmon Fork formation volcanics (Shervais and others, 1996), and its position due north of the Ridgeway mines makes it a suspect for the “friendly stranger” magmatic source of Worthington (1993) that would apply to the proposed, epithermal, syntectonic stage of mineralization recorded by the Ridgeway gold deposits.

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Figure 30. North pit photographic panel located clockwise from Figure 29. Two shallow dipping mafic dike/sill units can be identified crossing the entire pit. Right lateral offset of the main pit mafic dike is also visible. The dark staining on the pit walls are from groundwater seeps into the pit. Distance to the far pit rim measures 1000 feet (305 meters).

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Figure 31. North pit photographic panel located clockwise from Figure 30. Mafic dikes, quartz-veined shear zones, a thin felsic dike (fd) are highlighted, as well as south-dipping, bench faces that are subparallel to the dip of bedding, cleavage, and a prominent joint set identified in the pit. Distance to the far pit rim measures 1200 feet (366 meters).

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Figure 32. North pit photographic panel located clockwise from Figure 31. Major features visible here include the main felsic dike, quartz veined shear zones, a prominent bedding parallel face in the pit floor, andthe trace of cross section B-B' (Figure 24).Distance to the far pit rim measures 1600 feet (487 meters).

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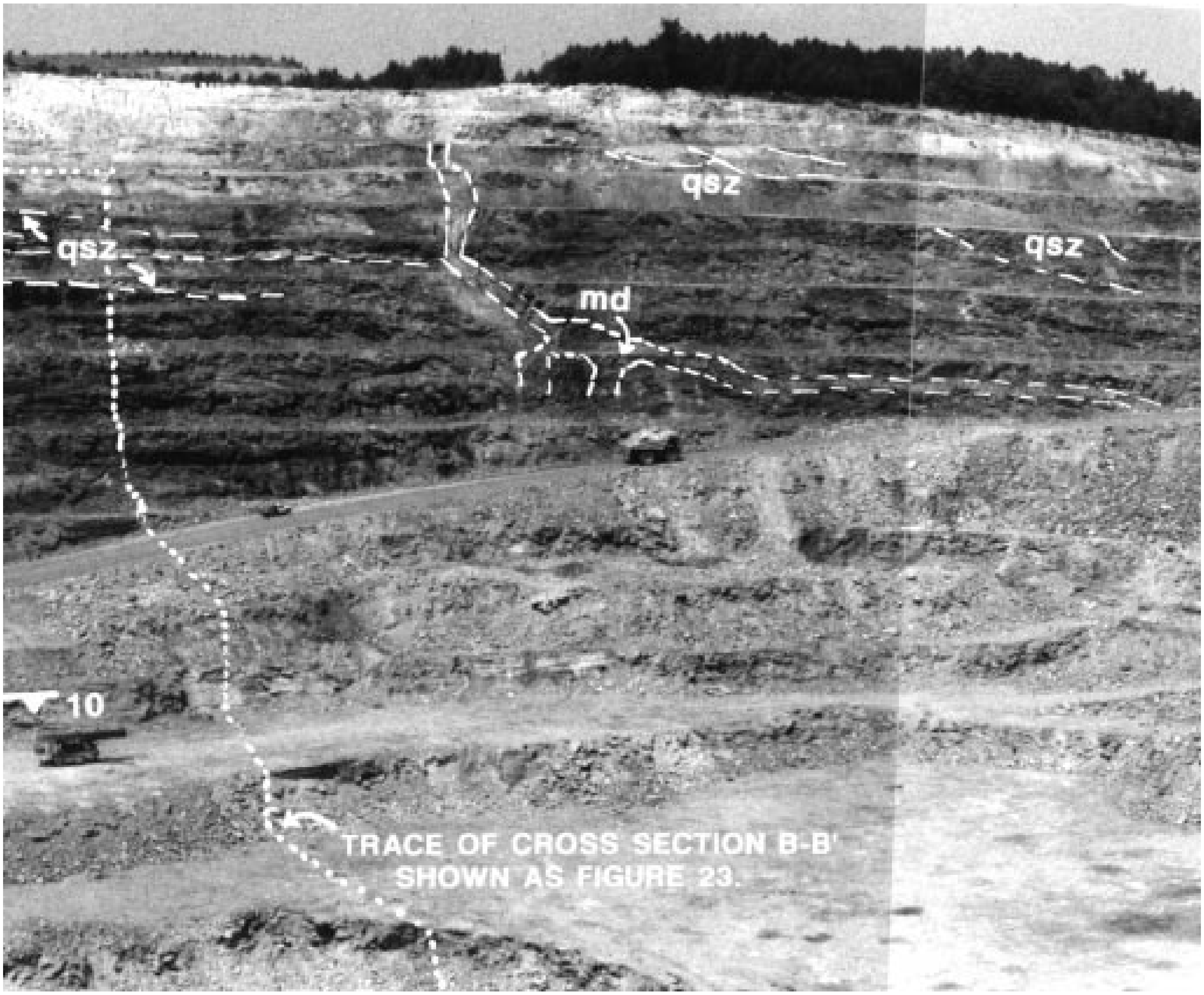

Figure 33. North pit photographic panel located clockwise from Figure 32. Features visible here include a complex of mafic dikes, several quartz veined shear zones, the trace of cross section B-B' and ledges along the pit floor that are a continuation of theface identified in Figure 33. Distance to far pit rim is 1600 feet (487 meters).

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Figure 34. North pit photo panel located clockwise from Figure 33 Numerous structural features are identifiable along the east wall, including mafic dikes, the central pit and footwall shear zones, and the felsic and quartz-eye mafic dikes which have intruded these structures. Distance to east pit rim is 2000 feet (620 meters).

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Guidebook for 1998 Annual Meeting
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A Field Guide to the Geology Of the Ridgeway–Camden Area, South Carolina Piedmont

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INTRODUCTION

In this road log we have attempted to provide enough information that interested persons, with the aid of the Ridgeway, Longtown, and Rabon Crossroads U.S. Geological Survey 7$^1/_2$' quadrangle maps, will be able to find all of the stops described herein. In Figure 1, we provide a road map showing the locations of all stops relative to the cultural framework. Figure 2 is an abstracted version of the geologic map of the Ridgeway–Camden area showing stop locations relative to a geological framework. Figures 3, 4, and 5 consist of small excerpts from the 1:24,000 scale U.S. Geological Survey 7$^1/_2$' quadrangle maps showing the exact position of each stop. **If you do use this guide to visit the stops at a later time, please be aware that all of the stops are on or adjacent to private land. Please obtain permission from landowners before you venture off the road.**

SATURDAY ROAD LOG AND STOP DESCRIPTIONS

Miles from the Northeast Columbia Holiday Inn (kilometers in parentheses)	Description
0.0 (0.0)	As you exit the Holiday Inn parking lot, turn left (northwest) on Nate Road and follow it to the intersection with Two Notch Road.
0.1 (0.2)	Turn left (southwest) on Two Notch Road and proceed through the I-20 underpass.
0.4 (0.6)	Bear right on ramp leading to I-20 east, toward Florence. Stay on I-20 east to exit 92, which is the Lugoff-Camden exit.
8.0 (12.9)	For most of the distance between Columbia and Camden, I-20 follows the Carolina sandhills, which are underlain by the kaolinitic sands o the Upper Cretaceous Middendorf Formation, extensively reworked during the Late Tertiary into the eolian sands of the Pinehurst Formation (Nystrom and others, 1991).
18.6 (29.9)	Bear to the right at exit 92 and proceed north on US-601 to Lugoff.
21.0 (33.8)	Junction with US-1 at Lugoff. Bear right (east) on US-1 and proceed toward Camden.
23.1 (37.2)	Bridge across the Wateree River.
24.1 (38.8)	At the stoplight, turn left (north) on the truck route bypass of US-521/601 (S28-130) around the north side of Camden.
27.6 (44.4)	Junction with SC-97. Turn left (north) on SC-97.
31.4 (50.5)	Turn right (east) on Lorick-Horton Road (unpaved).
33.5 (53.9)	Turn right (south) on Vaughn Mill Pond Road and proceed south. At this location, Vaughn Mill Pond Road is not marked.
35.1 (56.5)	**STOP #1** (Balinsky, Barker, Secor) This stop is located along Vaughn Mill Pond Road, on the bluff overlooking the west end of the pond. The unconformity at the base of th Upper Cretaceous Middendorf Formation is exposed in the road cut at an elevation of about 235'. Beneath the unconformity is deeply weathered felsic orthogneiss. This orthogneiss is a unit (Cogn) in the block of crystalline rock southeast of the Camden fault (Fig. 2). This block is interpreted to be a part of the late Paleozoic Alleghanian Modoc shear zone, because of lithological similarity and position, and because

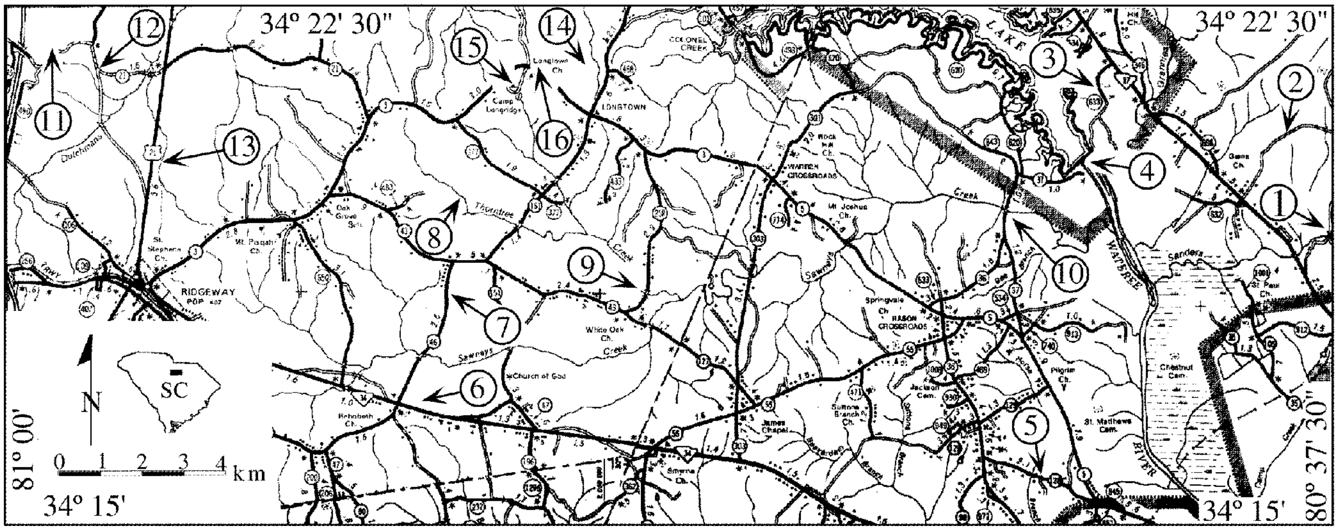


Figure 1. Road map of the Ridgeway–Camden area showing the locations of the numbered field trip stops. Modified from South Carolina Department of Transportation county road maps for Richland, Fairfield, and Kershaw counties.

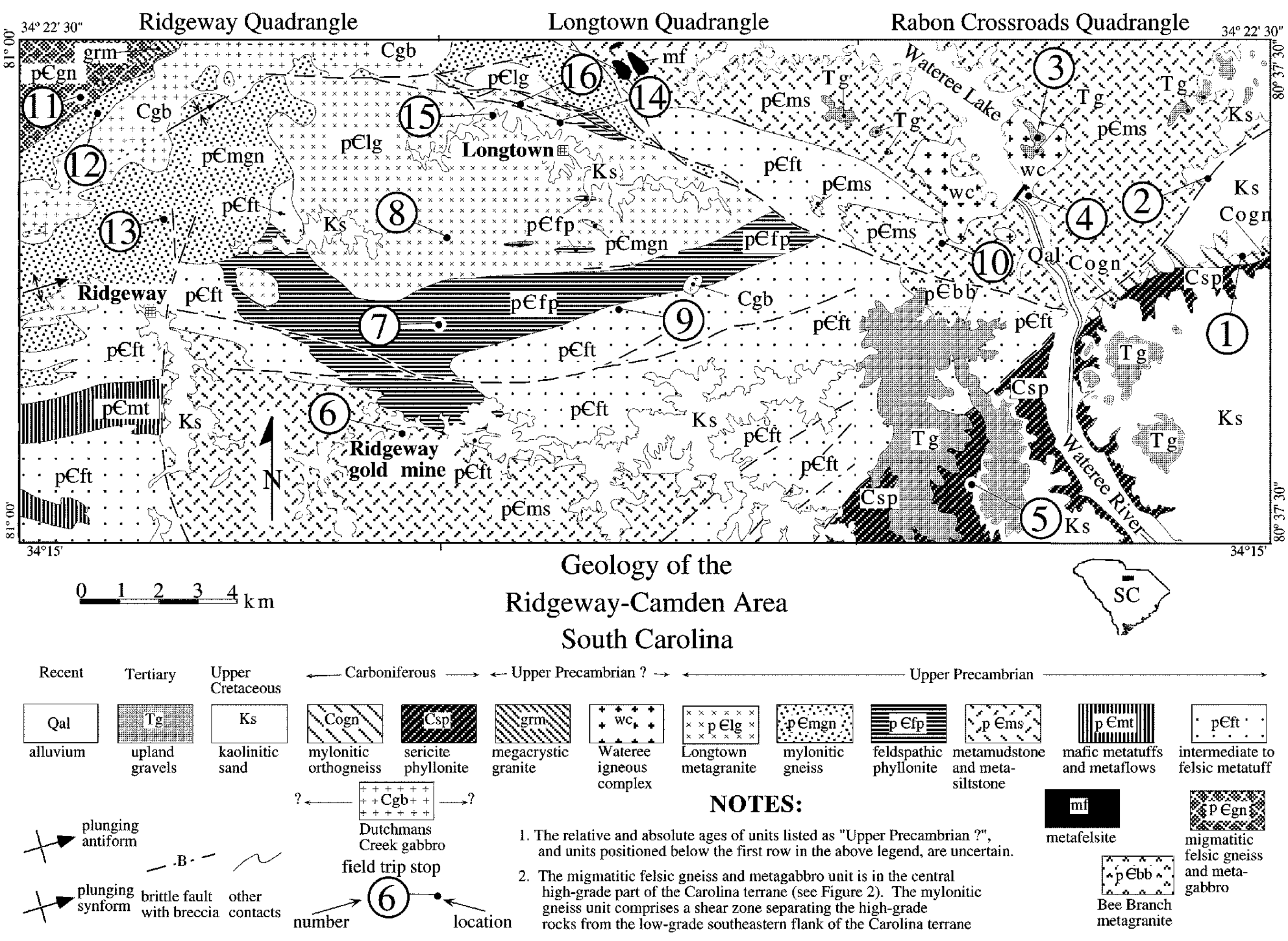


Figure 2. Generalized geologic map of the Ridgeway–Camden area showing the locations of numbered field trip stops. Modified from Figure 3 of Secor and others (1998).

nearby sericite phyllonite (Csp) has ~265 Ma (Alleghanian) $^{40}Ar/^{39}Ar$ cooling ages (Dallmeyer, personal communication, 1997). A 10-30 cm thick angular quartz lag gravel occurs immediately above the unconformity, in the base o the Middendorf Formation. Kaolinitic sand, typical of the Middendorf Formation comprises the remainder of the outcrop. In this region, the Camden fault was reactivated in the Late Cretaceous and/or Early Tertiary, producing mapable up-on-the-northwest separation of the basal Late Cretaceous unconformity. The Camden fault was first recognized in this region because of this tectonic disruption of the Middendorf Formation. The main reason for stopping at this location is to establish the 235' elevation of the unconformity for later comparison with the its elevation north of the Camden fault.

Turn around at the intersection at the top of the bluff overlooking Sanders Creek and Vaughn Mill Pond. Proceed back to the north on Vaughn Mill Pond Road.

36.7 (59.1) Turn left (west) on Lorick-Horton Road.

37.3 (60.0) <u>**STOP #2**</u> (Balinsky, Barker, Secor)

The busses will discharge passengers along Lorick-Horton road near a lane leading left (south), downhill to a small pond adjacent to a power-line right-of-way. The Camden fault crosses the lane about half way down to the pond. Here, the Middendorf Formation occurs on both sides of the Camden fault, and the position of the fault in the lane cannot be precisel located. At the end of the lane, around the head of the pond, there are low outcrops of Middendorf Formation that are interpreted to be in the block southeast of the Camden fault. If you walk out to the power-line right-of-way, you can stand on Middendorf kaolinitic sand, in the southeast block of the Camden fault, and loo <u>uphill</u> to the west across the Camden fault and see a bluff of weathered Late Precambrian metamudstone (p ms). We will walk along the right-of-way to the west to examine the metamudstone, and continue to the west to meet the busses where the right-of-way crosses Lorick-Horton Road. Map relationships in this regio suggest a northwest-side-up vertical separation of the unconformity of ~25 m. Continue west on Lorick-Horton Road.

38.8 (62.4) Intersection with SC-97. Turn right and proceed to the north on SC-97.

41.8 (67.3) Turn left on S28-426, at sign for Wateree Hills Subdivision.

42.1 (67.8) Turn left on Eagles Nest Road (S28-633) leading to Wateree Dam.

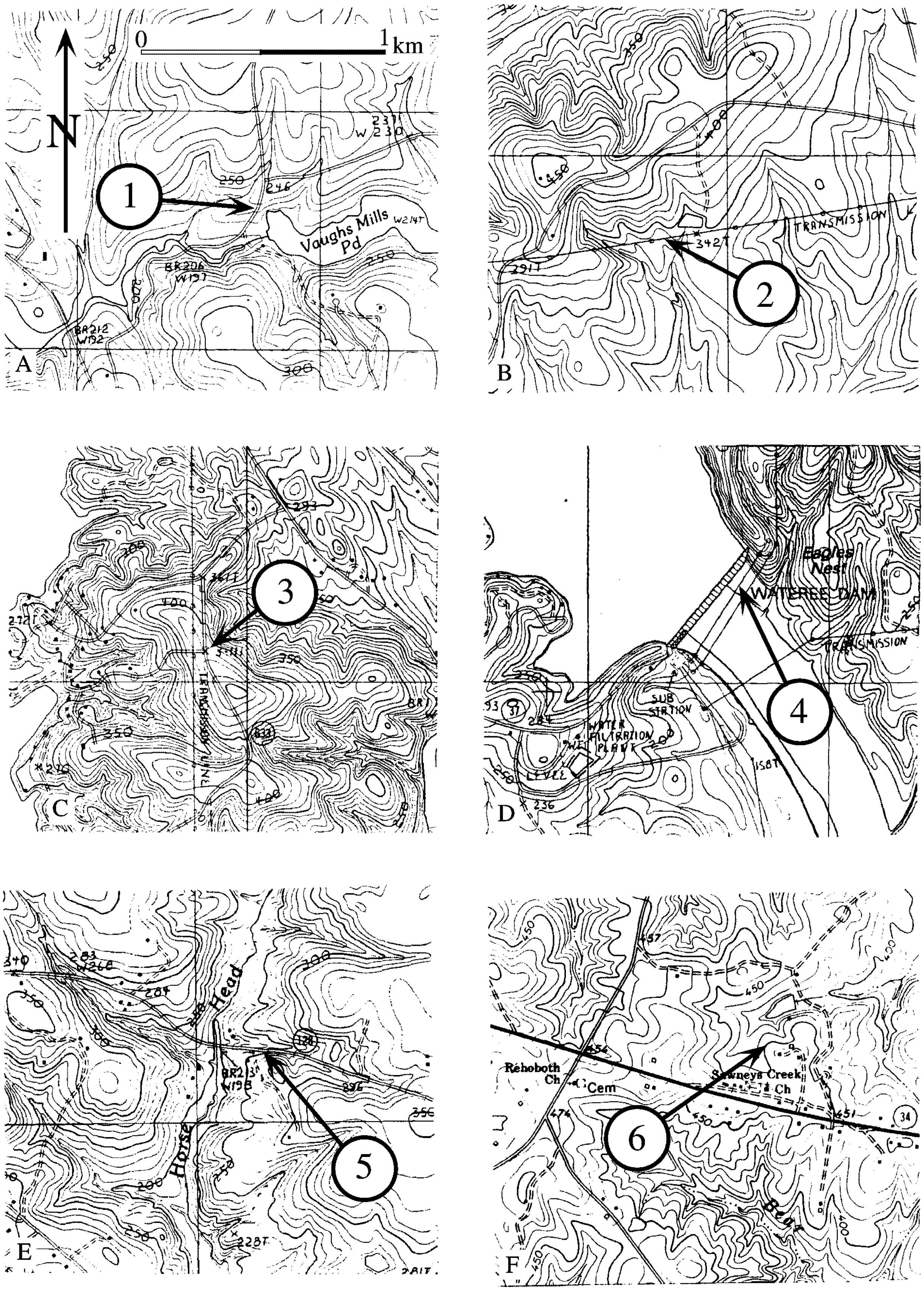
42.3 (68.1) <u>**STOP #3**</u> (Balinsky, Barker, Secor)

Exposures of the upland unit (Tg) occur along the road at the top of this hill. The road cut on the north side of the hill contains red gravels, whereas the road cut to the south contains re sands. At this location, the upland unit rests unconformably on the crystalline rocks of th Wateree igneous complex. Elsewhere in the Ridgeway–Camden area (Fig. 2) the upland unit rests unconformably on kaolinitic sands of the Middendorf Formation. Regionally, the upland unit slopes southeastward at 2-3 m/km, whereas the Middendorf is more steeply inclined southeastward at 5-7 m/km. The upland unit caps low hills flanking the Wateree River in the eastern part of the Ridgeway–Camden area.

Continue south on Eagles Nest Road.

43.5 (70.0) <u>**STOP #4**</u> (Balinsky, Barker, Secor)

The busses will park at the turn-around area near the east end of Wateree Dam, and we will walk down the trail to the south leading to the extensive outcrops exposed in the river below Wateree Dam. <u>**There are some dangerous cliffs immediately adjacent to the east end of Wateree Dam, and trip participants should not attempt to climb up or down these cliffs. Please pay close attention to instructions from trip leaders and take the more gently descending trail to the south.**</u> A variety of rock types, belonging to the Wateree igneous complex, are present in outcrops in the river bed. The Wateree igneous complex outcrops in an irregular area, covering about 8 k ^{2}, and is surrounded by the metamudstone and metasiltstone unit at the south end of Lake Wateree in the northeastern part of the Ridgeway–Camden area (wc in Figure 2). The main rock type is quartz latite metaporphyry, containing conspicuous albite phenocrysts, up to 8 mm in diameter embedded in a fine-grained matrix of plagioclase, alkali feldspar, quartz, and biotite (Mitchell, 1970). In the exposures immediately to the south of Wateree Dam, a variety of north-striking and steeply west-dipping metadikes, described as andesite, diorite, spessartite, and minette by Mitchell (1970), are also present in the complex. The complete absence of fragmental volcanic rocks, together with the porphyritic texture and fine-grained matrix, are interpreted to indicate a hypabyssal intrusive origin for the quartz latite. Incipient alteration to epidote and chlorite, together with the apparent absence of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Cem
Sawneys Creek Ch
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penetrative deformation fabrics, indicates that the Wateree igneous complex was intruded after the development of penetrative deformation fabrics in the metamudstone and metasiltstone unit and during the waning stages of regional metamorphism

Busses turn around and proceed back to the north on Eagles Nest Road.

44.8 (72.1) Turn right (east) on S28-426.

45.1 (72.6) Turn right (south) on SC-97 and proceed back toward Camden.

51.8 (83.4) Turn right (west) on US-521/601, which is the north truck bypass around Camden. This is highway S28-130 on Figure 1.

55.3 (89.0) Turn right on US-1 and proceed west toward Lugoff.

56.6 (91.1) Bear right (north) on Longtown Road (S28-5).

59.2 (95.3) Bear left on Nick Watts Road (S28-128).

60.3 (97.0) **STOP #5** (Balinsky, Barker, Secor)

At this location, the sericite phyllonite unit (Csp) and the unconformably overlying Middendorf Formation (Ks) and upland unit (Tg are exposed in a series of ditch and roadcut exposures east of Horse Head Branch. The sericite phyllonite unit is in the block of crystalline rocks southeast of the Camden Fault. Thi block is interpreted to be a part of the late Paleozoic Alleghanian Modoc shear zone, because of lithological similarity and position, and because the sericite phyllonite has ~265 Ma (Alleghanian) $^{40}Ar/^{39}Ar$ cooling ages (Dallmeyer, personal communication, 1997). The intense deformation manifested in the sericite phyllonite unit is interpreted to be Alleghanian. The age of the protolith of the sericite phyllonite is not known. Questions to be resolved here are the character of the protolith of the sericite phyllonite, and how much (if any) Middendorf Formation is present between the sericite phyllonite and the upland unit.

Continue west on Nick Watts Road (S28-128).

61.2 (99.8) Turn right on S28-36 and proceed north toward Rabon Crossroads.

63.3 (101.9) Turn left on Springvale Road (S28-55) and proceed west to Smyrna Church.

68.3 (109.9) Turn Right on Ridgeway Road (SC-34) and proceed west toward Ridgeway.

72.7 (116.2) Turn left (south) on Smallwood Road (S20-46), and watch for the large white bull quartz boulders that mark the entry to the Ridgeway Gold Mine.

72.8 (117.2) Entrance to Kennecott Minerals Ridgeway Mining Company.

STOP #6 and the Saturday Lunch Stop (Gillon, Mitchell, Bartholomew)

After field trip participants have checked in at the Ridgeway mine office, buses will drive to the North Pit via the haul road beneath SC-34. The busses will turn left (west) onto the overlook constructed on the south edge of the North Pit.

The Ridgeway gold mine is one of four active or recently active large gold mines in South Carolina. The Ridgeway mine is the largest ever to operate east of the Mississippi River, having produced to date 1,300,000 ounces of gold and 820,000 ounces of silver. The Mine is owned and operated by Kennecott-Ridgeway Mini Company, a subsidiary of US-based Kennecott Minerals, whose parent company is London/ Perth-based Rio Tinto. Safety considerations make it impossible for a group of our size to enter either of the two large open pits areas. However, we will have lunch at the overlook area to the north pit, and you will have an opportunity to examine an extensive saprolite exposure of the rocks adjacent to the north pit. The Kennecott-Ridgeway Company will also provide large piles of fresh samples of ore and various rock types from the mine at the overlook area. **We will have a supply of safety goggles available, and we request that you borrow a pair if you plan to bang on rocks with your hammer.** You will also have an opportunity to hear presentations from persons involved with the discovery, development, and operation of the mine. The discovery and development of the mine is discussed in Spence and others (1986), Evans (1988), and Gillon and others (1995). Recent ideas concerning the origin of the Ridgeway gold deposit are discussed in the paper by Gillon and others (1998) in this guidebook. Another paper in this guidebook by Bartholomew and others (1998) presents information on the fracture patterns and fracture his-

Figure 3. Excerpts from U. S. Geological Survey $7^1/_2$' topographic quadrangle maps showing the locations of numbered field trip stops: A. east-central Rabon Crossroads Quadrangle, B. Northeastern Rabon Crossroads Quadrangle, C. Northwestern Rabon Crossroads Quadrangle, D. Northwestern Rabon Crossroads Quadrangle, E. Southwestern Rabon Crossroads Quadrangle, F Southeastern Ridgeway Quadrangle.

tory of the mine rocks.

Turn around at the mine overlook, and return to Smallwood Road.

74.8 (120.4) Turn right on Smallwood Road (S20-46) and continue north across SC-34.

77.0 (123.9) **STOP #7** (Barker, Secor)

Proceed down the lane to the right (east) for about 100 m to an outcrop of the feldspathic phyllonite unit (p fp). This unit outcrops widely in the central parts of the Ridgeway and Longtown Quadrangles. The origin of the phyllonite is something of a mystery. It has well developed foliation and elongation lineation, and contains quartz ribbons and feldspar porphyroclasts with tails, and so we interpret it to occupy a shear zone. In some places, thin layers of chlorite phyllonite are interlayered with the feldspathic phyllonite. The feldspathic phyllonite unit does not contain shear bands, and the fabric elements are not noticeably asymmetric. The sense of shear is therefore uncertain. In most places, the foliation also contains secondary crenulation lineations which result from the intersection of a weak crenulation cleavage with the foliation. The protolith from which the feldspathic phyllonite was derived is uncertain because primar textures have been obliterated by intense deformation. Possible protoliths include intermediate to felsic tuff and/or felsic plutonic rocks.

Continue north along Smallwood Road.

77.6 (124.9) Smallwood Road dead-ends against Bellefield Road (S20-43). Turn right (east) on Bellefiel Road.

78.2 (125.8) Turn left (north) on Park Drive (S20-151).

79.6 (128.1) Turn left (west) on Quail Road (S20-377).

80.6 (129.7) **STOP #8** (Hatcher)

This stop involves walking a 3 km round trip, mostly along a haul road in a recent clearcut. At the bottom of the hill there will be a few hundred meters through brush and rough ground to reach the exposures in Thorntree Creek. **You should not attempt this traverse if you are uncomfortable with moderate physical exertion.**

Our purpose here is to examine an exposure of medium- to coarse-grained Longtown metagranite that contains xenoliths of deformed feldspathic phyllonite and possibly felsic tuff. Foliation in this body is defined by the subparallel orientation of micas, quartz, and feldspa aggregates. Orientation of foliation is reasonably uniform over this exposure, and the nearly E-W orientation of foliation is characteristic o this area. Deformation in the phyllonite consists of a foliation that has been crenulated indicating at least two deformations affected the rock before it was incorporated in the Longtown metagranite. Orientation of the foliation in the metagranite is N 82º E, 48º NE; a lineation here trends S 38º, S 76º W; an open fold is oriented 52º N 02º E (hinge), N 16º E, 58º NW axial surface), west vergence; and the foliation in the phyllonitic xenolith is N 61º E, 59 NW. The rock mass is also cut by systematic joints that were not measured in this investigation.

This small exposure near the mouth of a tributary of Thorntree Creek is one of the most important exposures in the area because of the implications of the deformed xenoliths in the ~551 Ma Longtown metagranite regarding timing of the deformation of the Carolina terrane. If this is a viable radiometric age for this body (Barker and others, 1998), penetrative deformation and possibly metamorphism had to hav affected the xenoliths prior to ~551 Ma, indicating deformation and metamorphism was recorded in the Carolina terrane long before i was accreted to Laurentia.

Turn around and proceed east on Quail Road.

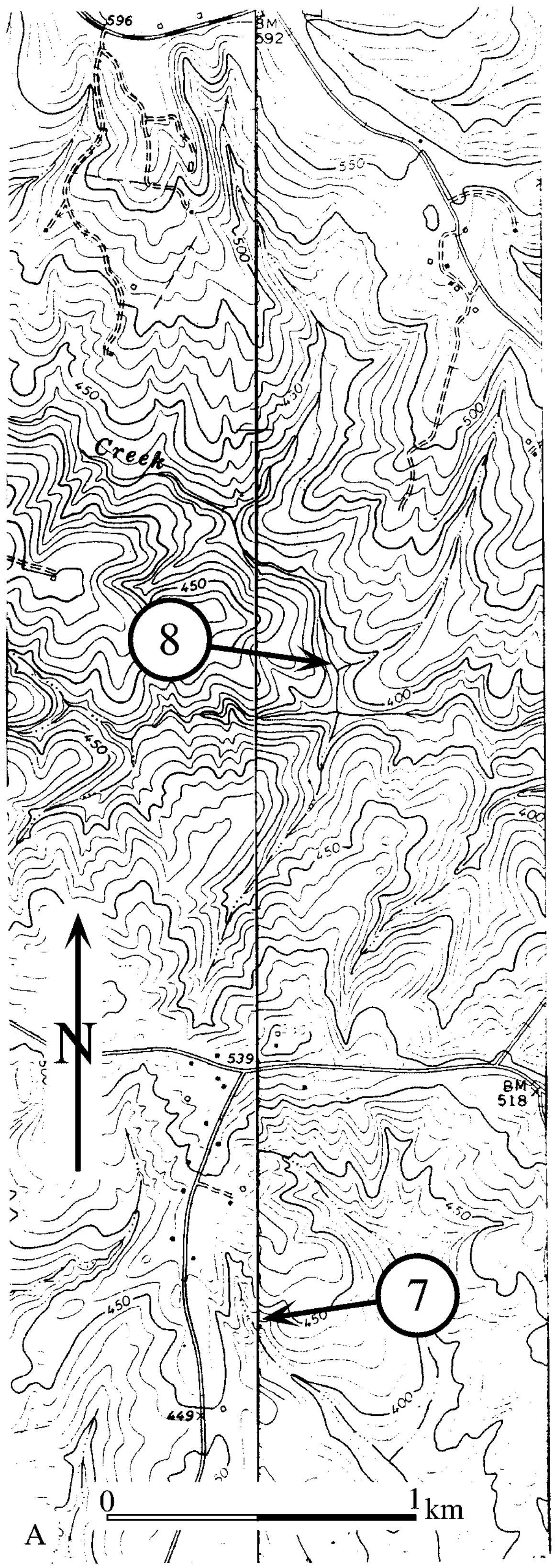
81.7 (131.5) Turn left on Park Road (S20-151) and proceed north to Longtown.

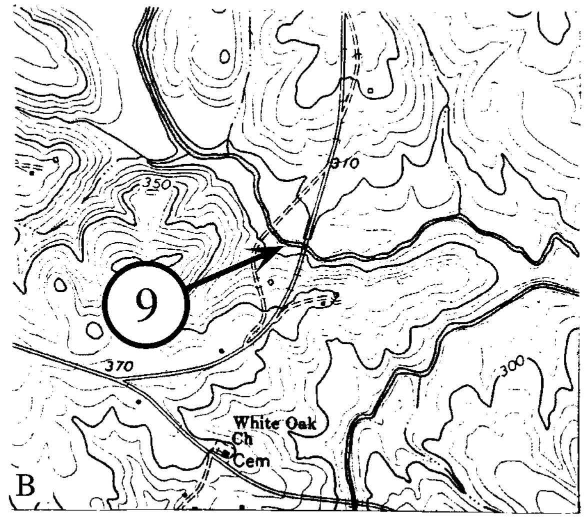
83.3 134.1) At Longtown, turn right (east) on Longtown Road (S20-3).

84.4 (135.8) Turn right on Blink Bonnie Road (S20-258).

86.7 (139.5) **STOP #9** (Barker, Secor)

At this stop the busses will park near the bridge and we will walk for a few hundred feet west along the steep slope south of Thorntree Creek to an outcrop of intermediate to felsic lapilli metatuff. This rock has a well developed foliation oriented N 70º E, 40 º NW, and there ar large light colored pumice (?) lapilli flattened in the plane of the foliation. The foliation has been crenulated, and the crenulations are oriented 6º, S 80º W. We have been unable to obtain sufficient zircons from the metatuff in this vicinity for geochronological studies, but similar metatuffs with similar fabrics in the Irmo Northeast Quadrangle have yielded a U-Pb upper intercept age of 557 ± 15 Ma and a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ age of 550.5 ± 5.9 Ma (Barker and others, 1998). We interpret these ages to indicate that both the eruption of the tuff and the foliation forming deformation event occurred more recently than ~557 Ma. The Longtown metagranite locally intrudes metatuffs like those seen here. The Longtown,





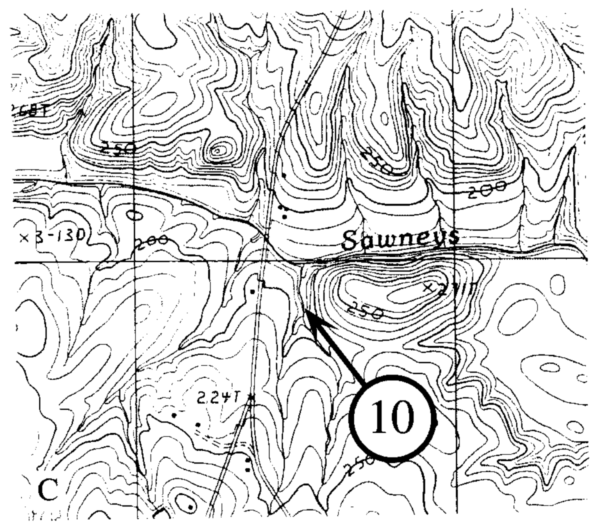


Figure 4. Excerpts from U. S. Geological Survey 7 $^{1}/_{2}$' topographic quadrangle maps showing the locations of numbered field trip stops: A. East-central Ridgeway Quadrangle and west-central Longtown Quadrangle, B. Central Longtown Quadrangle, C. Northwestern Rabon Crossroads Quadrangle.

which was intruded late syntectonically, has a U-Pb upper intercept age of 549.1± 4.7 Ma and a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ age of 551.2 ± 2.6 Ma (Barker and others, 1998). We interpret the above data to indicate that the stratigraphic sequence in the southeastern part of the Carolina terrane was rapidly deposited and deformed in Latest Proterozoic and perhaps Earliest Cambrian time.

Continue south on Blink Bonnie Road.

87.2 (140.3) Blink Bonnie road dead-ends against (S20-25). Turn Left on S20-25 and proceed to the southeast. S20-25 becomes S28-127 at the Kersha County line.

89.9 (144.7) Turn left (northeast) on Springvale Road (S28-55).

93.0 (149.7) Turn left (north) on S28-36 and proceed through Rabon Crossroads.

93.4 (150.3) Stop sign. Continue north on S28-36.

93.7 (150.8) At intersection make a sharp right turn and continue to the northeast on S28-36.

95.3 (153.4) At stop sign, bear left on Wateree Dam Road (S28-37).

95.6 (153.8) **STOP #10** (Balinsky, Barker, Secor)

At this location, the busses will stop immediately south of Sawneys Creek, and we will walk a few hundred yards to the east along a haul road to an outcrop of relatively fresh thin-bedded metamudstone in the bed of a small stream tributary to Sawneys Creek. Both relict bedding and a heterogeneously developed slaty cleavage are present in this outcrop. The cleavage strikes northwest and dips moderately northeast. The relict bedding is folded with a wave length of a few meters, and the cleavage is approximately axial planar to these folds. We interpret these metasediments to be the same as those present in the Ridgeway Gold Mine, an we interpret the slaty cleavage in the metasediments and the foliation in metavolcanic rocks both to be a consequence of the Latest Precambrian-Earliest Cambrian deformation event discussed at the preceding stop.

Turn around and go back to the south on Wateree Dam Road.

97.7 (157.2) Intersection, continue south on Longtown Road (S28-5).

98.5 (158.5) El Bethel Church, at the intersection with S28-129. At this locality, the road crosses the trace of the Camden Fault. At road level, the fault trace is covered with a thin veneer of upland gravel. Field studies and augering at this location suggest that the northwest edge of the Upper Cretaceous Middendorf Formation wa truncated by the Camden Fault and then overlain unconformably by upland gravel (see article by Secor and others, 1998, in this guide).

Continue south on Longtown Road.

103.7 (166.9) Junction of Longtown Road and US-1 in Lugoff. Turn right and proceed to the west on US-1.

104.5 (168.2) Bear right on US-601 south.

107.0 (172.2) Junction with I-20. Bear right on ramp leading to I-20 west toward Columbia.

25.0 (201.2) At exit 74 on I-20, bear to the right on ramp leading to Two Notch Road.

125.3 (201.6) Turn left onto Nate Road.

125.4 (201.8) Entrance to Northeast Columbia Holiday Inn.

SUNDAY ROAD LOG AND STOP DESCRIPTIONS

0.0 (0.0) As you exit the Holiday Inn parking lot, turn left (northwest) on Nate Road and follow it to the intersection with Two Notch Road.

0.1 (0.2) Turn right (northeast) on Two Notch Road and proceed to I-77 exchange.

0.6 (1.0) Turn left on ramp leading to I-77 north.

16.9 (27.2) Bear right at exit 34 on SC-34 and proceed east toward the town of Ridgeway.

19.3 (31.1) Take a sharp left turn on Truck 34 and cross over railroad tracks.

19.4 (31.2) Turn left on US-21 and proceed to the north.

26.3 (42.3) Turn left (west) on Hope Road (S20-41).

27.0 (43.5) Turn left (south) on S20-424.

30.5 (49.1) Turn right (west) on Valencia Road (S20-21).

31.1 (50.0) **STOP #11** (Barker, Secor)

This stop is located in the extreme northwest corner of the Ridgeway–Camden Area, in the migmatitic central high-grade part of the Carolina terrane. In order of decreasing abundance, this unit contains biotite gneiss, amphibolite, hornblende gneiss, leucocratic gneiss, biotite schist, and pegmatite. Relict textures and mineralogy indicate derivation from a plutonic complex, heterogeneously deformed and metamorphosed in the upper amphibolite facies. Geochronological studies of the plutonic complex have not been conducted in the Ridgeway–Camden area, although elsewhere in South Carolina geochronological studies suggest a Late Proterozoic to Cambrian age for its emplacement (Fullagar, 1971, 1981; Gilbert, 1982; McSween and others, 1984; Dallmeyer and others, 1986) and deformation (Dennis and Wright, 1997). Some previous workers (Butler and Ragland, 1969; Weisenfluh and Snoke, 1978; Secor and others, 1982) have suggested

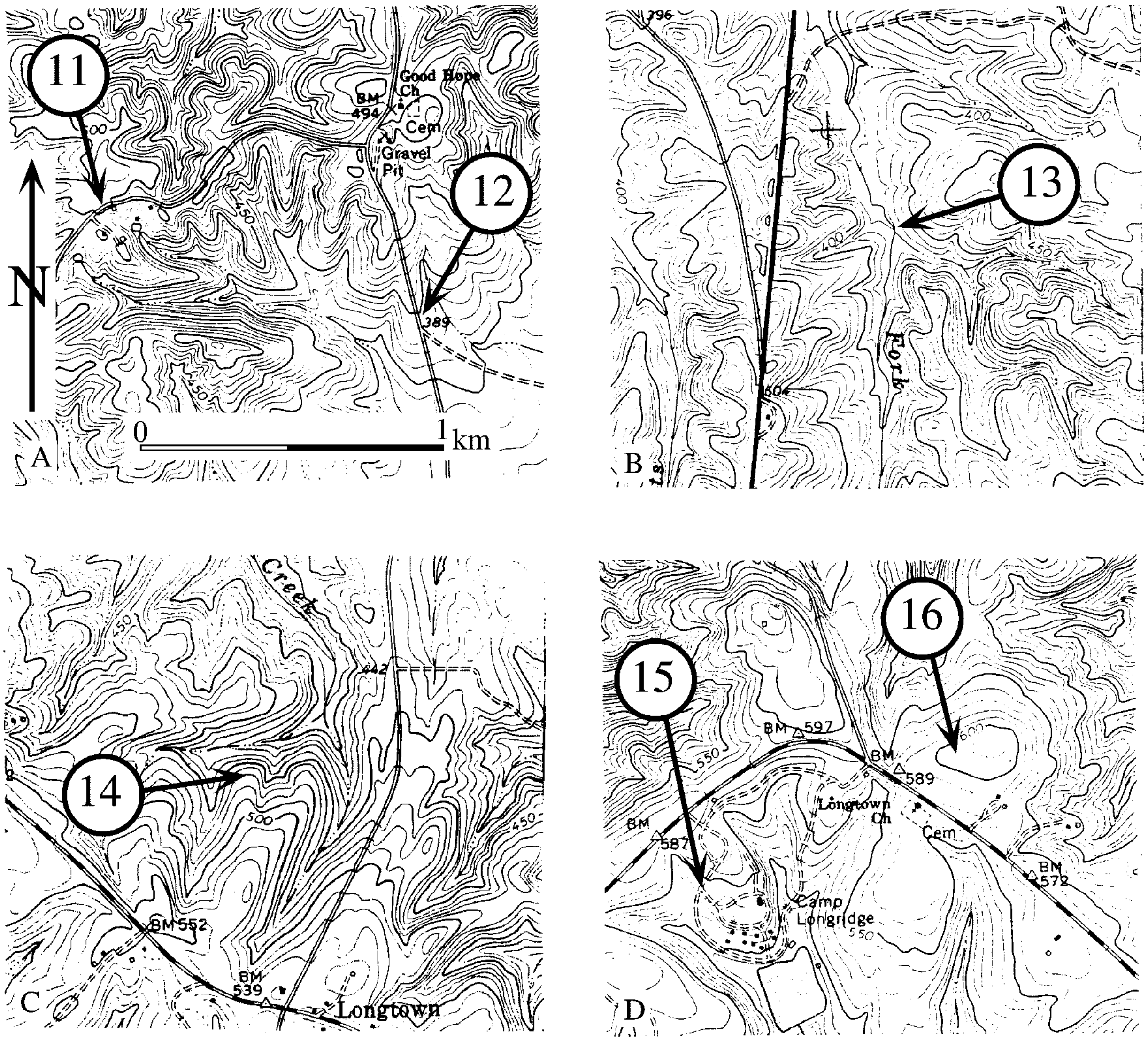


Figure 5. Excerpts from U. S. Geological Survey 7$^1/_2$' topographic quadrangle maps showing the locations of numbered field trip stops: A. Northwestern Ridgeway Quadrangle, B. Northwestern Ridgeway Quadrangle, C. Northwestern Longtown Quadrangle, D. Northwestern Longtown Quadrangle.

that the above plutonic complex is the intrusive equivalent of the metavolcanic arc rocks foun in the southeastern part of the Carolina terrane. This interpretation is supported by similarities in age and composition. However, in thi area, the plutonic complex is separated from the metavolcanic arc rocks by a ductile shear zone containing a thick sequence of high temperature mylonites. We will see these mylonitic rocks at stops 12 and 13.

Turn around and proceed east, back to S20-424.

31.7 (51.0) Turn right (south) on S20-424.

32.1 (51.7) **STOP #12** (Barker, Secor)

At this locality, a sequence of interlayered mylonitic felsic gneiss and mylonitic amphibolite outcrops in the ditches above and below the road intersection. Locally preserved relict textures suggest that this unit is derived from the migmatitic plutonic complex that we saw at the last stop. The mylonitic foliation is oriented 30º E, 64º SE, and there is an elongation lineation oriented 30º, N 34º E. Immediately to the south, the flat terrane in the valley of Dutchmans Creek is underlain by unmetamorphosed Dutchmans Creek gabbro.

Turn around and return north on S20-424.

36.0 (57.9) Turn right (east) on Hope Road.

36.6 (58.9) Turn right (south) on US-21.

42.6 (68.6) **STOP #13** (Barker, Secor)

Here, we will walk a few hundred meters to the east, down a haul road, to view additional exposures of mylonitic gneiss and amphibolite. At this locality, the mylonitic foliation is oriente N 84ºW, 40 º NE. Data on foliation attitudes in the vicinity of Dutchmans Creek indicate that the creek approximately coincides with the axis of a northeast plunging synform, the Dutchmans Creek synform. The axial region of this synform is intruded by the Dutchmans Creek gabbro. However, geophysical studies indicate that the gabbro is a thin horizontal or downward concave sheet (Smith and Talwani, 1987). Because the gabbro does not conform to the shape of the synform, it is interpreted to have been emplaced following formation of the synform. The Dutchmans Creek gabbro has not been dated, but it is interpreted to be Carboniferous because of it location in a belt of Carboniferous plutons (Speer and Hoff, 1997).

Continue south on US-21 to Ridgeway.

43.7 (70.3) At the Ridgeway stoplight, turn left (east) on Longtown Road (S20-3).

52.8 (85.0) **STOP #14** (Barker, Secor)

The last three stops of the trip will focus on various aspects of the geology of a major brittle fault, the Longtown fault, which strikes northwest across the Ridgeway–Camden area (Figure 2). At this location, we will examine the fault below the level of the Coastal Plain sediments at a place where Longtown metagranite is present on both sides of the fault. We will park just west of Longtown on SC 34 and walk about a kilometer to the north, down a haul road. At this location, the only manifestation of faulting is the presence of a NNW-trending, steeply-dipping dike-like mass of silicified breccia. Petrographic studies of these breccias suggest multiple episodes of brecciation and silicification. Partly open cavities and veins containing small euhedral quartz crystals are characteristic of the breccia. Silicified breccias such as those described above are characteristic of Mesozoic faults in the Appalachian Piedmont Garihan and others, 1988), and the Longtown fault is therefore interpreted to have been active in the Mesozoic, although additional displacements, both before and after the Mesozoic, are not precluded.

Turn around and proceed west on Longtown Road.

54.3 (87.4) **STOP #15** (Barker, Secor)

We will stop near the entrance to Camp Longridge and walk a short distance down the entry road to view an outcrop of the unconformity at the base of the Upper Cretaceous Middendo Formation where it rests on the Longtown metagranite. At this location the elevation of the unconformity is ~540'. The geological situation here is similar to that observed at stop 1, although the level of the unconformity is higher and the crystalline rocks are substantially older. The elevation of the unconformity here is important for comparison at the next stop.

Turn around and return east on Longtown Road.

54.9 (88.3) **STOP #16** (Barker, Secor)

At Longtown Presbyterian Church, we note the sandy soil of the Middendorf Formation at road level. We will traverse a few hundred meters along a haul road that goes north and progressively uphill from the church. For most of the distance, the soil in the road is sandy and is interpreted to be derived from the Middendorf Formation. At the highest elevation, at the end of the road (610'), there is an abrupt change in the soil to red sandy clay, containing angular clasts of vein quartz. This point is on line with the projected trace of the Longtown fault, and the abrupt change in the soil is interpreted to indicate that the Longtown Fault was reactivated in Late Cretaceous or more recent time to produce an up-on-the-north vertical separation of the Late Cretaceous unconformity in exce of ~20 m.

Turn around and return west on Longtown Road to Ridgeway.

63.1 (101.6) Longtown Road joins SC-34 at the Ridgeway stoplight. Continue straight ahead (west) at the stoplight on SC-34 across the railroad tracks, then follow SC-34 around the sharp right turn just beyond the tracks.

65.5 (105.4) Intersection of SC-34 and I-77. Turn left on ramp leading to I-77 south toward Columbia.

82.3 (132.4) At exit 17 on I-77, bear right onto ramp and take Two Notch Road to the west toward Columbia.

82.8 (133.3) Turn left (south) on Nate Road.

82.9 (133.4) Turn right into the Northeast Columbia Holiday Inn parking lot.

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