Ophir District, Randolph and Montgomery Counties, North Carolina: Geologic and metallogenic analysis

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Foreword

Introduction and statement of purpose

This report is one of a series of four North Carolina Geological Survey open-file reports and North Carolina Geological Survey, Special Publication 11, prepared in cooperation with the North Carolina Geological Survey, that provide a geologic and metallogenic review and analysis of several groups and associations of historic gold mines in the Carolina Terrane in central North Carolina. Although representing diverse styles of mineralization, the gold deposits reviewed in these reports all appear to represent a broad spectrum of orogenic gold deposits within the classification of **Grooves *et al*. (1998)**. This includes classic low-sulfidation mesozonal orogenic narrow-vein lode gold deposits, represent by mines of the Gold Hill District (Gold Hill-type) and similar deposits along the Gold Hill Fault Zone (**Moye, 2016**); a newly recognized style of large-tonnage, low-grade mesozonal orogenic deposits with disseminated and stockwork vein mineralization (Sawyer Type); and a possibly unique occurrence of epizonal orogenic mineralization with bonanza-grade Au-Ag-Te mineralization. Deposit analysis indicates that, although geographically widespread and hosted by rocks with a wide range of ages, these various styles of orogenic gold deposits all formed during the Cherokee Orogeny in the late Ordovician to early Silurian (**Hibbard *et al.*, 2012**).

Sawyer-type high-tonnage mesozonal orogenic deposits

The newly defined Sawyer-type mesozonal orogenic gold deposits include mineralization at the historic New Sawyer, Sawyer, Jones-Keystone, and Lofflin mines in northwest Randolph County; the Russell and Coggins mines in the Ophir District in Montgomery County; and possibly the Burns-Allen-Red Hill deposit near Robbins in Moore County, North Carolina.

These deposits are characterized by often multiple parallel or *en echelon* lenses of silicic ore-grade mineralization, meters to tens of meters wide and tens to hundreds of meters long, enclosed by zones of pyritic phyllic alteration tens to hundreds of meters wide and often hundreds to thousands of meters long. Alteration and mineralization intensity are heterogeneous and gradational with indefinite boundaries, and ore grade is typically determined by assay. The large volume of rock that has experienced pervasive sulfidation in these deposits could arguably be compared to high-sulfidation alteration.

Gold occurs with disseminated pyrite and narrow, millimeter-scale, cleavage-parallel quartz ± pyrite vein swarms and stockworks. Sulfide minerals average about 2-5 vol%, locally up to 10 vol%, dominated by pyrite ± accessory arsenopyrite ± minor pyrrhotite with trace base metal sulfides. The characteristic trace element association for Sawyer-type gold mineralization is Au ± Ag ± As ± Mo ± Pb ± Sb and trace to geochemically anomalous Cu and Zn.

These deposits appear to have formed within discontinuous deformation zones characterized by reverse faults that are often axial to appressed, northeast-trending meso-scale anticlines with axial planes that dip steeply to the northwest. Although commonly classified as structurally modified syngenetic exhalative gold-rich massive sulfide deposits, alteration and mineralization are confined to the host structures and synkinematic with ductile-brittle deformation under regional lower greenschist facies metamorphic conditions.

Within the oxidized zone, pyrite dissolution results in acid leaching with deep (~30 meters) weathering and the formation of free gold, often with increased fineness and coarser grain size compared to gold in primary sulfide ore, and surface and supergene enrichment to form large-tonnage, low-grade, easily mined and processed ore deposits. These deposits were historically mined by open-pit methods to the water table, with more localized underground mining of narrow, high-grade zones of secondary oxide, mixed, and primary sulfide mineralization.

Considerations of economic potential

Sawyer-type deposits are among the more attractive targets for modern precious metals exploration programs in the Carolina Terrane in central North Carolina. This is based on the indicated potential for large-tonnage, bulk-minable, low-grade deposits with relatively high gold recovery at low unit cost over a significant mine life. Evaluation of these deposits has historically involved extensive surface sampling and a broad variety of geophysical surveys, but minimal subsurface evaluation through drill-hole testing, mostly to relatively shallow depths. Due to the heterogeneity of gold distribution in this style of mineralization, even a few dozen drill-holes are unlikely to provide an adequate estimate of the grade and tonnage of the gold resource.

Additionally, the structural and lithologic controls of mineralization are often poorly understood, and the misapplication of incorrect ore deposit models may result in wasted drill-holes and discouraging results. An early investment in detailed geologic mapping and structural analysis, coupled with comprehensive petrographic and mineralogical analyses to fully constrain ore controls, is strongly recommended for the predictive constraints of this approach.

Historic open cut mining of Sawyer-type deposits typically focused on recovery of oxidized ore with free-milling gold at grades of generally 0.10 to 0.30 oz/t Au, leaving lower-grade (0.01-0.09 oz/t Au) oxide ore on the periphery and as “horses” within the open cuts. Additionally, zones of highly siliceous unoxidized sulfide ore that was difficult to mine and mill was also left as “horses”. Although much of the easily mined and milled oxide ore above the water table (~20-30 meters depth) in many deposits was historically depleted, much of the lower-grade oxide ore remains, along with mixed oxide/sulfide and primary sulfide mineralization present at greater depth.

Intercepts of primary sulfide ore in those deposits that have been drill-hole tested commonly contain tens of meters of low-grade mineralization (0.01-0.10 oz/t Au) with narrow (meters) intervals of higher-grade values (0.10-0.25 oz/t Au). However, few deposits have been adequately drilled to establish a reliable estimate of grade and tonnage, given the notoriously heterogeneous gold distribution in primary sulfide ores. This same problem was inherent in the evaluation of the Kennecott Ridgeway and Oceanagold Haile deposits in South Carolina, where hundreds of drill-holes were required to define the minable resources.

One of the only Sawyer-type deposits to be adequately drill-hole tested is the Russell Mine in the Ophir District in northwest Montgomery County, North Carolina. The deposit has an estimated historical production of around 37,500 ounces Au, plus drilling-based estimates of proven, probable, and possible reserves of over 300,000 ounces of gold (**Maddry *et al.*, 1992**) with a total resource around 350,000 ounces in oxide, sulfide, and mixed ore. This resource represents only the upper 150 meters of two of the five known mineralized zones on the property.

The vertical extent of Sawyer-type mesozonal orogenic gold deposits has not been tested, although historic mining, topographic exposures, and modern drill-hole testing suggest a vertical extent of at least 500 meters. The character of the structural controls of ore fluids and their likely source in the middle crust suggests possible vertical extents of over a kilometer. The presence of narrow zones of bonanza-grade Au mineralization in some deposits suggest a distinct potential for underground mining targets, possibly within ore fluid feeder zones similar to those discovered at the Haile Mine and associated with Carlin-type disseminated gold deposits in Nevada.

Star-Carter bonanza-grade epizonal orogenic deposits

The Star-Reynolds and Carter gold mines in Montgomery County, North Carolina are located about 2,000 meters apart along narrow faults that strike 030° and dip ~50° northwest, possibly as part of an *en echelon* fault zone with a strike length of at least 2,000 meters. Both mines produced around 20,000 ounces of gold from surface placer deposits and narrow zones of high-grade lode mineralization along strike-lengths of less than 100 meters to a depth of 20-30 meters. Bonanza grade shoots rich in Au-Ag tellurides at the Star Mine contained as much as 10-20 oz/t Au (**Phifer, 2004)**, with similar grades from selected vein samples at the Carter Mine.

There appear to be two stages of mineralization present. The dominant form is narrow (<2 meters), cleavage-parallel shear zone hosted sheeted or stockwork quartz veins and silicic alteration with disseminated sulfides and carbonates. These zones carry locally high-grade Au-Ag mineralization and are enclosed by narrow haloes of phyllic alteration with disseminated auriferous pyrite. Sulfides are dominantly pyrite with minor accessory chalcopyrite ± molybdenite ± gold telluride ± minor bornite and chalcocite with geochemically anomalous Sb, As, Pb, and Zn. This style of mineralization is consistent with mesozonal orogenic gold deposits formed at depths of 6-12 kilometers and temperatures of 300°-475°C (**Grooves *et al.*, 1998**).

This mesozonal orogenic vein mineralization is overprinted by brittle faulting at the Star and Carter mines, with locally bonanza-grade Au-Ag-Te mineralization (**Powers, 1989**, **Phifer, 2004**). At the Star Mine, high-grade gold + sylvanite [(Au,Ag)Te_2] + calaverite ($AuTe_2$) occur in chimneys within the plane of the brittle fault zone, characterized by silicified clasts in a clay-rich gouge matrix. In the absence of associated felsic igneous intrusive rocks, this mineralization is consistent with epizonal orogenic deposits formed in the upper 6 kilometers of the crust at temperatures of around 150°-300°C (**Grooves *et al.*, 1998**; **Cook *et al.*, 2009**).

Trace element associations suggest that both styles of mineralization are associated with a single hydrothermal event. The transition from ductile-brittle to brittle deformation is possibly due to orogenic crustal thickening and uplift, followed by rapid denudation through gravitational collapse or rapid weathering within the duration of the mineralizing event.

Evaluation of the Carter Mine by Noranda in 1987-1988 suggests that the presence of a large-tonnage, bulk minable gold mineralization target is unlikely (**Powers, 1989**). However, a total of 40,000 ounces Au was produced from only 200 meters of strike along a fault zone at least 2,000 meters long, and mostly from surface accumulations and the upper 20-30 meters of the lodes. There is a distinct possibility that a series of bonanza-grade Au-Ag-Te ore bodies may be present along the 2,000-meter strike of the Star-Carter fault zone in Montgomery County, North Carolina, both near the surface and at depth, that could be mined profitably with a small footprint.

Acknowledgements

This series of reports is the result of a productive relationship with the North Carolina Geological Survey, dedicated to providing mining industry-based information and insights into the character and economic potential of base and precious metal mineralization in the Carolina Terrane in central North Carolina.

The success of this partnership is directly attributed to the indefatigable energy and commitment of Dr. Jeffrey C. Reid PhD, PG, CPG, Senior Geologist, Energy and Minerals of the North Carolina Geological Survey, Division of Energy, Mineral and Land Resources, North Carolina Department of Environmental Quality. His encouragement and organizational and editing skills have been instrumental in bringing this project forward.

Additionally, these studies have benefitted enormously from the published resources of the North Carolina Geological Survey, the United States Geological Survey, and the remarkable academic achievements in constraining the stratigraphy, structure, and geochronology of the Carolina Terrane in North Carolina over the past 20 years. These contributions are reflected in the list of References Cited in these papers.

Many accomplished geologists have contributed to understanding the character and evolution of the geology of the Carolina Terrane and the hydrothermal ore deposits that it hosts. It is important to remember that well-trained geologists make accurate and useful observations. It does not dismiss or diminish their contributions to modify or disagree with their interpretations.

Finally, I strongly encourage the mineral deposit exploration geologists who were active in the Southeastern USA piedmont in the 1970s-1990s to contribute their reports, maps, and data to public institutions, such as state geological surveys and universities, to preserve and pass on hard won and valuable natural resource knowledge for the benefit of society. Don't allow information to languish and disappear. You had a fair go; now give someone else a chance.

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Ophir District, Randolph and Montgomery Counties, North Carolina - geologic and metallogenic analysis

By Robert J. Moye

Abstract

The Ophir mining district in northern Montgomery County and southwest Randolph County, North Carolina consists of over a dozen historic gold mines and prospects that cluster within an area of about 5 x 8 kilometers centered near the town of Ophir. Gold and silver are the only metallic mineral production reported for the area. Significant historic gold producers in the district include the Russell, Coggins, and Steel mines. Total estimated historical production of around 37,500 ounces Au, plus drilling-based estimates of proven, probable, and possible reserves for the Russell Mine, represents a total resource that may exceed 350,000 ounces Au (**Maddry *et al.*, 1992**). Limited production records for the Steel Mine, with an output of 7478 ounces Au in 1887 alone (**Pardee and Park, 1948**), suggest that total production may have exceeded 30,000 ounces.

Two contrasting styles of lode gold deposit are present in the Ophir District, most hosted by metasedimentary siltstone of the Tillery Formation of the Albemarle Sequence of the Carolina Terrane. Both deposit types are characterized as sulfide-bearing quartz veins, stringer zones, and stockworks associated with pyritic silicic, phyllic, and chloritic alteration developed along shear zones that strike northeast and dip steeply to the northwest. Both types are synkinematic and synmetamorphic.

One group of deposits, represented by the Steel Mine, are developed along single, narrow, reverse or oblique strain shear zones that strike 025°, parallel to the dominant tectonic fabric, and are typical of low-sulfidation orogenic lode gold deposits formed during the Cherokee Orogeny (**Hibbard *et al.*, 2012**; **Moye, 2017**). The Steel Mine is characterized by two phases of mineralization, with lower-grade Au associated with a zone of intense silicic alteration 3-6 meters thick. The second style is bonanza-grade gold associated with thin, cleavage-parallel polymetallic sulfide veins in a zone less than a meter thick. Both phases of mineralization appear to have formed during the same metallogenic event, possibly from two different ore fluids.

The second group of deposits, represented by the Russell Mine, are developed on complex shear-fold zones that strike 045° and are characterized by multiple parallel silicic ore bodies, ranging from three to over twenty meters in thickness, surrounded by broad zones of pyritic phyllic alteration tens of meters to over 100 meters thick. At the Russell Mine, a series of 5 to 6 ore bodies are localized along the sheared and reverse-faulted axes of parallel appressed, meso-scale anticlines, overturned to the southeast, with strike lengths of less than 300 meters. The Russell Mine and similar deposits of the Ophir District are very similar to the Sawyer-type Au-Ag-As deposits of northwest Randolph County, North Carolina, and appear to be a poorly described style of shallow mesozonal orogenic gold deposit formed during the Cherokee

Orogeny. Like the Sawyer-type deposits, the Russell Mine, Coggins Mine, and similar deposits of the Ophir District represent potentially economic precious metal exploration opportunities for large tonnage, bulk-minable oxide and primary sulfide mineralization. Additionally, assay results of 8-11.0 oz/t Au, and locally up to 32.2 oz/t Au from the deepest levels of the Coggins Mine (**Pratt, 1915**), and narrow intervals of bonanza-grade (locally > 100 oz/t Au + Ag) ore from the Steel Mine (**Pardee and Park, 1948**) suggest the possibility high grade feeder zones at depth.

Introduction

Over a dozen historic gold mines and prospects cluster within an area of about 5 x 8 kilometers centered near the town of Ophir in northern Montgomery County and southwest Randolph County, North Carolina (**Figure 1, Figure 2**). Significant gold producers in the district include the Russell, Coggins, and Steel mines. Gold and silver are the only metallic mineral production reported for the area. The lode gold deposits of the Ophir District are hosted by the Tillery Formation of the Albemarle Sequence of the Carolina Terrane. All are characterized as sulfide-bearing quartz veins, stringer zones, and stockworks associated with pyritic silicic, phyllic, and chloritic alteration developed along shear zones that strike northeast and dip to the northwest.

The Russell, Steel, and Coggins mines are the largest historic gold producers in the district, but the Russell and Coggins are better known and have better documentation. The Russell Mine produced over 15,110 ounces troy (470 kg) of gold from ore with an average grade of around 3.4 g/t (0.10 oz/t) Au between about 1882 and 1894 (**Nitze and Hanna, 1896**; **Pardee and Park, 1948**; **Klein *et al.*, 2007**). However, **Maddry *et al.* (1992)** estimate total past production as high as 37,500 ounces (1166 kg). Based on modern drilling and sampling of the Russell Mine deposit, Piedmont Minerals defined a remaining proven plus probable resource of 4 Mt of ore with an average grade of 1.6 g/t (0.047 oz/t) gold, containing 209,380 ounces Au (6.5 metric tonnes), along with an additional possible resource of 3.2 Mt at 1.2 g/t (0.035 oz/t) Au, for a total of 331,100 ounces (10.3 metric tonnes) Au (**Maddry *et al.*, 1992**). The total gold resource for the Russell Mine deposit may exceed 350,000 ounces.

The smaller Coggins Mine to the south produced around 5000 ounces of gold between 1882 and 1926 (**Pardee and Park, 1948**). Little detailed information is available regarding the older Steel Mine and Saunders extension. It was discovered around 1832 and worked extensively before 1853, with a new phase of mining from 1876 to 1888 (**Pardee and Park, 1948**). Although few production figures are available, gold output for 1887 alone was around 7478 ounces (**Pardee and Park, 1948**), suggesting that total historic production may have been similar to that of the Russell deposit.

Other historic mines in the district are small with limited development and production. These mines (**Figure 3**) include the Griffin and Stafford mines, located in the southwestern corner of Randolph County, and the Riggon Hill Mine, the Sallie Coggins Mine, The El Dorado Mine, and the Morris Mountain Mine in Montgomery County.

Mineralization and alteration in the Ophir District is typically low total sulfide (≤ 5%), pyrite-dominant, and hosted by zones of strongly foliated and sheared metamorphosed mudstone and siltstone of the Tillery Formation. Gold is associated with pyrite in quartz veins and stringers and as disseminated grains in zones of intense phyllic and silicic alteration. Minor base metal sulfides including chalcopyrite, sphalerite, and galena, with rare arsenopyrite are present in some deposits and molybdenite reported at the Russell Mine (**Klein *et al.*, 2007**). Historically mined ore bodies show distinct local structural control with discontinuity along strike and dip (**Pratt, 1915**; **Pardee and Park, 1948**; **Klein *et al.*, 2007**). Early production was probably facilitated by supergene oxidation and probable gold enrichment to a depth of 10-30 meters.

Maddry *et al.* (1992) document significant exploration activities in the Ophir District by at least seven mining companies since 1939. Other companies have examined the mines in the area, but did not acquire land positions. The larger deposits of this group, especially the Russell and Coggins mines, have been the focus of interest since the mid-1970s as possible economic targets for large tonnage, low grade, and bulk-minable gold mineralization. A total of 35 diamond core holes and 14 reverse circulation drill holes totaling over 10.8 kilometers aggregate length have been completed in the area, largely in and around the Russell Mine. The width, extent and Au-grade of mineralization in the district suggest significant potential for resources that could be economically mined, either individually or collectively.

Two gold deposit types or two metallogenic events?

All past examinations of the gold deposits of the Ophir District have focused on the historically mined deposits and their immediate geologic environments. The present analysis is an attempt to better understand the character and origin of the gold deposits of the Ophir District in the context of the larger geologic environment and the structural, tectonic, and metallogenic evolution of the Carolina Terrane in central North Carolina.

Two distinct styles of gold mineralization are present in the Ophir District. One is characterized by narrow zones of alteration and mineralization along single reverse or oblique-slip faults or shear zones. These occurrences are consistent with low-sulfidation orogenic gold lode deposits, such as those formed within the Gold Hill Fault Zone to the west (**Figure 1**) during the Cherokee Orogeny the late Ordovician to early Silurian (**Hibbard *et al.*, 2012**; **Moye, 2017**). Deposits of the Gold Hill Fault Zone include the historic gold mines of the Gold Hill District of Rowan and Cabarrus counties and many of those in Union County, North Carolina (**Pardee and Park, 1948**; **LaPoint and Moye, 2013**; **Moye, 2017**). In the Ophir District, narrow fault-hosted low-sulfidation orogenic gold deposits include the Griffin and Stafford mines, the Steel Mine, the Eldorado Mine, and the Morris Mountain Mine.

The Russell Mine, the Coggins Mine, and possibly the Riggon Hill Mine are characterized by multiple, parallel zones of intensely deformed, highly siliceous, pyritic gold mineralization enclosed by broad zones of much less deformed phyllic alteration (**Pratt, 1915**; **Pardee and Park, 1948**; **Klein *et al.*, 2007**). The siliceous gold lodes are localized within zones of intense reverse shearing and faulting and, at the Russell Mine, are developed along the axial planes of northeast-striking asymmetric anticlines overturned to the southeast. The character and origin of these deposits have been contentious, generally divided between epigenetic (**Pardee and Park, 1948**; **LaPoint and Moye, 2013**) and structurally modified and remobilized volcanogenic-syngenetic models (**Worthington and Kiff, 1970**; **Klein *et al.*, 2007**).

Although currently classified in the USGS MRDS database (#10026493, URL https://mrdata.usgs.gov/ mrds/show-mrds.php?dep_id=10026493, viewed 01 January 2018) as ore deposit *Model 25a: Hot-spring Au-Ag* (**Berger, 1985**), the currently accepted model for the Russell deposit is that proposed by **Klein *et al.* (2007)**. They suggest a "gold-rich, base-metal poor, volcanogenic massive sulfide deposit in which gold was remobilized, in part, during Ordovician metamorphism" into shear zones along the axes of asymmetric NE-trending, SE-verging meso-scale folds. This model is lateral secretion (*sensu stricto*), with ore zone components sourced from lower-grade, syngenetic exhalative sulfide mineralization in adjacent "source" rocks. A small rhyolite intrusive-extrusive center located a little over a kilometer to the east is proposed as a possible source of exhalative hydrothermal fluids or heat to drive sub-seafloor convection.

This study will examine the possibility that two separate and distinct styles of gold mineralization are present in the Ophir District, possibly formed during two separate geologic periods, and how these may be related to the formation other gold and base metal sulfide deposits in this part of the Carolina Terrane.

In this report, historic gold values reported as dollar amounts have been converted to ounces per ton (oz/t) using historical USA gold prices for the year of publication. Except in discussions of geochemistry, mineral chemistry, and trace element concentrations, gold values reported as part per million (ppm) or parts per billion (ppb) are reported in grams per tonne (g/t) and ounces per ton (oz/t); where 1ppm Au = 1 g/t Au, 34.28 g/t Au = 1 oz/t Au.

Limitations of the study

This study is based largely on available published geologic studies and documentation of the gold deposits of the Ophir District and the direct personal experience of the author as an exploration geologist working throughout the region during the 1980s and 1990s. A much larger body of information exists in the proprietary files of individuals and corporations, but is not available in the public sector.

Numerous small mines and prospects in the Ophir area for which there is little known production or geologic information and no MRDS location or record are not included. Additionally, similar and possibly related gold deposits in the adjacent Uwharrie and Cid formations are not discussed in this study.

The major historical mines of the Ophir District now lie within the boundaries of the Uwharrie National Forest, a multiple use domain open to exploration, evaluation, and possible economic development of mineral resources. This study seeks to assess the economic potential of Ophir District gold deposits. Additionally, a better understanding of the character and origins of these deposits may facilitate exploration for gold or other metals in other parts of the Carolina Terrane in North Carolina.

This study is part of a larger research project into the character and evolution of metallic mineral deposits of the Carolina Terrane in the context of metallogenic events associated with specific tectonic events and constrained to local or regional geologic environments; including rifted-arc basins, terrane boundary collision zones and associated structures and magmatism, 1st and 2nd order fault zones, and major magmatic complexes.

Regional geologic setting

Gold mineralization in the Ophir District is hosted by generally fine-grained, thinly bedded siltstone and mudstone of the Tillery Formation of the late Proterozoic-early Cambrian Albemarle Sequence of the Carolina Terrane in central North Carolina (**Figure 1, Figure 2**). The Albemarle Sequence was deformed and metamorphosed to the greenschist facies during the Cherokee Orogeny in the late Ordovician (**Hibbard *et al.*, 2012**). In the Ophir region, bedding (S_0) in the Tillery Formation metasediments typically strikes about 045° and dips gently to moderately northwest (**Stromquist and Henderson, 1985**) on the common limb between the axis of the Troy Anticlinorium to the east and the New London Synclinorium to the west (**Figure 1, Figure 2, and Figure 4**). Axial planar cleavage associated with F_1 regional folding is typically absent (**Conley, 1962**; **Klein *et al.*, 2007**).

At the north end of the Ophir District, **Seiders (1981)** mapped a series of third-order folds in the Tillery Formation with wavelengths of about 500 meters and axes that strike 040° and dip steeply NW (**Figure 5**). These may be part of a series of asymmetric parasitic second- to third-order folds on the eastern limb of the New London Synclinorium (**Figure 5**), as shown on the compilation geologic maps of **Stromquist and Henderson (1985)**. To the south of the Ophir District**, Conley (1962)** mapped a series of asymmetric, southeast-verging parasitic folds striking 040° to 045° along the eastern limb of the New London Synclinorium (**Figure 5**). The second-order folds have wavelengths of 1500 to 1000 meters and amplitudes of 30-60 meters. These folds may become progressively tightened and appressed to the northeast in the Ophir area. Folds of similar magnitude have not been recognized in the Ophir District, but smaller meso-scale folds of similar character and orientation are associated with gold mineralization at the Russell Mine (**Klein *et al.*, 2007**).

Occurrences of strong penetrative cleavage or foliation in the Ophir District are restricted to generally narrow (tens to hundreds of meters), discontinuous, northeast-trending shear zones (**Pratt, 1915**; **Conley, 1962**; **Pardee and Park, 1948**; **Klein *et al.*, 2007**), some of which host localized gold mineralization (**Figure 4**). This fabric (S_1) generally strikes either 045° or 025° and dips steeply (60°-80°) northwest. These shear zones are ductile-brittle structures and most appear to be associated with reverse faults; those at the Russell Mine developed by structural failure along the axes of meso-scale asymmetric folds overturned to the southeast (**Klein *et al.*, 2007**).

Conley (1962) noted the presence of a broad zone of heterogeneous shearing along the 027°-trending Uwharrie-Tillery formation contact on the western limb of the Troy Anticlinorium in Montgomery County (**Figure 4**). This shear zone is up to a kilometer wide over a strike length of more than 15 kilometers. A second shear zone up to about 100 meters wide was mapped for several kilometers at a strike of about 034°, passing though a quartz vein deposit near Eldorado and to the east of the Coggins Mine (**Conley, 1962**).

The intensity of deformation within these shear zones contrasts sharply with the relatively undeformed adjacent rocks of the Tillery Formation. The shear zones may be part of a 5-6 kilometer wide zone of heterogeneous compression along the western limb of the Denton Anticlinorium. It is characterized by NE-trending meso-scale (tens to hundreds of meters wavelengths) asymmetric, SE-verging folds, reverse faults, and shear zones (**Figure 4, Figure 5**). This deformation zone is informally designated the Ophir Zone.

The Ophir Zone is oriented 025°, about 20° to the axes of the regional first-order folds that dominate the Albemarle Group in central North Carolina, and subparallel to the orientation of the Gold Hill Fault Zone to the west (**Figure 1, Figure 5**). Similar to the large-scale reverse-dextral displacement on the Gold Hill Fault Zone (**Hibbard *et al.*, 2012**), deformation along the Ophir Zone may post-date formation of the regional first order folds in the Albemarle Sequence, including the New London Synclinorium and the Troy Anticlinorium. The southeastern limb of the New London Synclinorium appears to be deflected into parallelism with the Ophir Zone (**Figure 1, Figure 2**). Farther to the north along this trend, the axes of the New London Synclinorium and Denton Anticlinorium also appear to be deflected into a more northerly strike (**Figure 1**).

The Ophir Zone (**Figure 4**) is expressed primarily within the Tillery Formation and most strongly developed in northwest Montgomery and southwest Randolph counties, North Carolina. The Albemarle Sequence appears to be compressed or attenuated in this area. The outcrop width of the Tillery Formation is significantly narrowed through the Ophir District, coincident with an apparent north and west step-over between linear segments of the Tillery-Uwharrie contact to the north of the town of Ophir (**Figure 5**). This step-over may involve a series of meso-scale folds or faults. North of this apparent step-over, interdigitation of Uwharrie Formation and Tillery Formation lithologies (**Seiders, 1981**) suggests either interbedding at a scale not seen to the south in Montgomery County, or possibly imbrication by faulting or folding along NNE-trending axes.

Local geologic setting

The geology of the Ophir District is dominated lithologically by the Tillery Formation, characterized by finely laminated mudstone and siltstone of the Tillery Formation that are metamorphosed to the greenschist facies. Original sedimentary features are largely well-preserved. Structurally, the Tillery Formation metasediments in the Ophir District are upright and dip gently or moderately to the northwest on the western limb of the Troy Anticlinorium.

This homoclinal sequence is locally disrupted by a series of meso-scale asymmetric folds and NE-striking shear zones (**Figure 4**).

Lithology in the Ophir District

The Tillery Formation is characterized by thin-bedded, fine-grained epiclastic metasedimentary rocks dominated by laterally persistent 1-3 millimeter thick beds that typically grade upward from fine-grained sand or silt to clay, suggesting quiescent, deep marine deposition. These sediments are locally interbedded with subordinate felsic and mafic intrusive and extrusive metavolcanic rocks (**Conley and Bain, 1965**; **Seiders and Wright, 1977**; **Gibson and Teeter, 1984**). The thickness of the Tillery Formation is estimated at about 1500 meters in the Albemarle area (**Stromquist and Sundelius, 1969**). The basal Tillery Formation appears to be in conformable and gradational contact to the east with the Uwharrie Formation (**Conley, 1962**; **Seiders, 1981**; **Gibson and Teeter, 1984**; **Boorman *et al.*, 2013**).

The Russell Dome is an elongate 0.6 × 2 kilometer rhyolite dome or cryptodome (**Figure 6, Figure 12**) striking 021°. It is conformable within Tillery Formation stratigraphy about 1.1 kilometers northeast of the Russell Mine, and appears to have been emplaced synchronous with sedimentation (**Klein *et al.*, 2007**). The rhyolite is sparsely feldspar-biotite-almandine phyric, flow banded to locally spherulitic, and enclosed by units of tuff breccia or hyaloclastite breccia with rhyolite clasts, and breccia with mudstone and rhyolite clasts (**Klein *et al.*, 2007**) that extend for 1.5 kilometers to the southwest.

A unit interpreted as felsic metavolcanic rocks extends in an arcuate band northwest from the northern end of the rhyolite cryptodome and hosts shear zone related gold mineralization at the Griffin Mine (**Maddry *et al.*, 1992**). This unit may be similar to the fragmental units mapped by **Klein *et al.* (2007)** to the south of the Russell Dome.

Kozuch (1994) reports a U-Pb zircon age of 554 ± 14 Ma for metarhyolite from the lower Tillery Formation near Asheboro. Rhyolite of the Morrow Mountain complex in the upper part of the Tillery Formation returned U-Pb zircon age of 539 ± 6 Ma (**Ingle, 1999**). Detrital zircon U-Pb ages from the Tillery (**Pollock, 2007**) show a major peak at about 550 Ma from a range of 541 ± 9 to 591 ± 10 Ma (26 analyses) and a secondary peak at about 630 Ma from a range of 598 to 698 Ma (21 analyses). **Pollock (2007)** suggests a maximum age of around 552 Ma for the Tillery Formation.

Structure in the Ophir District

The metasedimentary and metavolcanic strata of the Tillery Formation strike about 025° and dip at moderate to shallow angles to the northwest in the Ophir District, parallel to the contacts with the Uwharrie Formation to the east and the Cid Formation to the west. Divergent strike and dip readings in available structural data (**Conley, 1962**; **Seiders, 1981**; **Stromquist and Henderson, 1985**) suggest the presence of meso-scale folds with wavelengths of hundreds or thousands of meters, but poorly defined in the absence of distinct marker units. These folds may be similar to the second- and third-order folds mapped to the northeast and southwest of the Ophir District (**Conley, 1962**; **Seiders, 1981**; **Stromquist and Henderson, 1985**).

Structural controls appear to be central to the occurrence and formation of gold mineralization and associated hydrothermal alteration in the Ophir District. Alteration and mineralization are present locally along a series of narrow shear zones that typically strike either around 025° or 045°, but all dip steeply to the northwest. These shear zones are characterized by a strong, localized S_1 cleavage or foliation developed at an oblique angle to primary bedding (S_0) in the host metasedimentary rocks. The mineralization is associated with generally narrow, elongate zones of variable chloritic, phyllic, and silicic alteration with veins, stringers, or stockworks of quartz veins with a few percent sulfides, dominantly pyrite, and minor accessory carbonate (**Pratt, 1915**; **Conley, 1962**; **Pardee and Park, 1948**, and **Klein *et al.*, 2007**).

Many of the larger, more continuous shear zones recognized in the Ophir District strike about 025°, subparallel to the contact between the Tillery Formation and the Uwharrie Formation to the east, but dip steeply to the northwest at a high angle to bedding (**Conley, 1962**; **Pardee and Park, 1948**). Shear zones at this orientation host the Griffin and Stafford deposits in the northern part of the district, the Steel-Saunders deposit along the eastern side, and possibly the Morris Mountain Mine on the west side (**Figure 3**, **Figure 5**). These mineralized shear zones are single structures and typically narrow, often a few to ten meters wide, with strike lengths of hundreds of meters to a few kilometers.

The Griffin and Stafford mines appear to be located about 100 meters apart on the same shear zone, striking 025° and dipping about 70° northwest (**Figure 5**, **Figure 6**). Alternatively, they may be located on *en echelon* shear zone segments. The Steel Mine and the Saunders extension lie along a shear zone that strikes 025°, dips 70°NW, and is traced along strike for at least 1.6 kilometers (**Kerr and Hanna, 1888**).

Shear zones that strike 045° host gold mineralization at the Russell, Coggins, Sallie Coggins, Eldorado, and Riggon Hill mines (**Figure 3**). Typically, these shear zones have limited strike continuity but most occur as multiple parallel ore lodes 3-20 meters thick developed along reverse faults within often broad zones of silicic to phyllic alteration (**Pratt, 1915**; **Klein *et al.*, 2007**). Additionally, the shear zone-hosted gold lodes at the Russell Mine are axial planar to a series of meso-scale asymmetric anticlines (**Klein *et al.*, 2007**). No anticlinal structures have been identified at the Coggins, Sallie Coggins, Eldorado, or Riggon Hill mines; however, the character of the lodes and the orientation of the parallel shear zones are very similar to those of the Russell Mine. It is possible that the shear zones at these mines are also developed along a similar series of tight, asymmetric, overturned anticlines.

The shear zones of the Ophir District are discontinuous ductile-brittle structures. **Pratt (1915)** suggests that brittle faulting and formation of quartz veins at the Coggins Mine post-dates formation of the intense foliation that characterizes the shear zone. A similar overprint of earlier ductile fabrics by fault-related brittle deformation is noted at the Russell Mine (**Klein *et al.*, 2007**). The earlier development of intense foliation at these deposits may be associated with formation of meso-scale asymmetric anticlines with axial-planar cleavage. Brittle structures and mineralization may be associated in part with the failure of fold axes or limbs as reverse faults.

The Russell dome, located northeast of the Russell Mine, is cut by two sets of quartz veins; one set strikes 050° and dips 65°-70° SE and is composed of 1.5-4.0 centimeters thick pale gray vitreous quartz with up to 1 vol% pyrite (**Klein *et al.*, 2007**). These veins are cut by a younger set of 0.5-1.5 centimeter thick veins with only trace pyrite that strike 005° and dip 80° SE. The 45° angle between the strikes of these veins sets, almost bisected by the 021° strike of the dome, suggests that they are conjugate tension fractures. The Tillery metasediments adjacent to the unit of breccias that extend to the southwest of the dome (**Klein *et al.*, 2007**) are sheared and mineralized with disseminated pyrite and stockwork quartz-carbonate veinlets (**Maddry *et al.*, 1992**). This is the 4.5-6 meter thick Contact Lead of **Maddry *et al.* (1992)**, who report rock-chip gold values of 0.1-0.8 g/t (maximum 0.03 oz/t Au) along a strike length of one hundred meters. It is likely that the conjugate extensional quartz vein sets formed within the rheologically competent rhyolite dome during the Cherokee Orogeny (**Hibbard *et al.*, 2012**), synchronous with shearing-related mineralization of the Contact Lead along the contact with the rheologically incompetent adjacent metasediments.

Descriptions of Ophir District mines and prospects

The following is a brief review of published information on the various gold mines and prospects in the Ophir District of Montgomery and Randolph counties, North Carolina. The more important and well-documented mines are discussed in greater detail throughout the study.

Griffin Mine (Au)

The mine is located in the southwest corner of Randolph County, North Carolina, 2.4 km northeast of the Russell mine in Montgomery County at coordinates -80.00088, 35.5251 (WGS84). Gold mineralization is scattered through a 2-meter wide, Fe-stained schistose to mylonitic shear zone that strikes 025° and dips 70°NW in phyllic to silicic altered Tillery Formation felsic metavolcanic rocks (**Carpenter, 1976**). These rocks appear to an arcuate extension of the Russell rhyolite dome (**Klein *et al.*, 2007**), possibly within a meso-scale fold.

A large open cut was seen in 1934 when the mine was owned by Arthur Ross (**Luttrell, 1978**), and a water-filled shaft was present in 1976 (**Carpenter, 1976**) with a drift oriented 070° at a depth of 3 meters. Production from this mine was minor (**Carpenter, 1976**).

The Griffin and Stafford mines (**Figure 6**) were included in an exploration of the Russell Mine deposit by the Tenneco Mineral Company in 1984 (**Maddry *et al.*, 1992**). Stream sediment and panned concentrates and soil samples were collected over a broad area, outlining areas of anomalous gold. Two core drill-holes were completed at the Griffin Mine to test the mineralization (**Figure 6**). Drill hole TGS-4 (-45° dip on a bearing of 305° to a depth of 65 meters) intersected 37 meters (0-37 meters down-hole) of mineralization ranging from below detection to 1.34 g/t Au (0.04 oz/t).

Stafford Mine (Au)

The mine is located in the southwestern corner of Randolph County, North Carolina, on a hill about 100 meters southwest of the Griffin Mine at coordinates -80.00422, 35.5176 (WGS84). Pyrite, pyrrhotite, minor chalcopyrite and free gold were found in saccaroidal quartz veins or stringers in a shear zone with silicic to phyllic altered metasedimentary rocks of the Tillery Formation (**Carpenter, 1976**). Gangue minerals include quartz, chlorite, and carbonate. In 1934 the workings consisted of a 3 x 3 meter shaft with a stope and a short adit. The Stafford Mine appears to lie along the same shear zone, or an *en echelon* segment, that hosts the Griffin Mine.

Two drill core drill-holes (**Figure 6**) that tested the mineralization were completed by the Tenneco Mineral Company in 1984 (**Maddry *et al.*, 1992**). Drill hole TGS-2 (-45° dip on a bearing of 120° to a depth of 66 meters) intersected three intervals of gold mineralization; 11 meters (21-32 meters down-hole) ranging from 0.11-1.33 g/t Au and averaging 0.67 g/t Au (0.02 oz/t), 4.6 meters (44.0-48.6 meters down-hole) ranging from 0.69-1.20 g/t Au and averaging 0.02 oz/t Au, and 11 meters (55-66 meters down-hole) ranging from below detection to 1.52 g/t Au and averaging 0.6 g/t Au (0.02 oz/t).

Riggon Hill Mine (Au-Ag)

The Riggon Hill Mine is located about 1.6 kilometers northwest of the town of Ophir in Montgomery County, North Carolina, at coordinates -79.99645, 35.50204 (WGS84). High-grade gold and silver mineralization is reported from a quartz vein 76 centimeters thick that was worked from a 30 meter shaft in 1896 (**Pardee and Park, 1948**). Several lenticular mineralized zones are reported within a broad zone of shearing and phyllic alteration conformable with a strong schistosity developed in the host Tillery Formation metasiltstone and metamudstone. The distribution of shafts, pits, and trenches (**Maddry *et al.*, 1992**) suggest that the entire alteration zone is at least 30 meters wide and strikes about 045°-050°, with shafts and larger pits developed along a series of narrow, more strongly mineralized lenses (**Figure 7**).

Piedmont Minerals core drill-hole ERH-2 (**Figure 7**) on the eastern portion of the zone (at -50° dip on a bearing of 132° to a depth of 166 meters) intersected two narrow zones of gold mineralization; 6 meters (9-15 meters down-hole) that averaged 0.03 oz/t Au, and 1.5 meters (53.5-55 meters down-hole) that averaged 0.03 oz/t Au (**Maddry, 1993**).

Russell (Palmer, Peebles) Mine (Au-As)

This group of workings is located in the northwest corner of Montgomery County, near the Randolph County line, North Carolina, at coordinates -80.02308, 35.5026 (WGS84). Gold-bearing ore occurs in six parallel mineralized zones, each 3 to 21 meters wide, in a belt 500 meters wide (**Figure 8**). Discontinuous siliceous zones composed largely of silica and fine-grained disseminated pyrite are enclosed by quartz-sericite-pyrite schist (phyllic alteration), and hosted by a sequence of strongly foliated Tillery Formation metasediments. The mineralized trends are, from NW to SE; the Little Lead, Big Cut Lead, Riggins Hill Lead, Soliague Lead, Walker Lead, and Laurel Hill Lead. The Palmer workings are on the southwest extension of the Riggins Hill Lead. **Maddry *et al.* (1992)** report the presence to two additional parallel mineralized trends in this group located farther southeast.

The historic workings of the Russell Mine include clusters of open pits and underground shafts, drifts, and stopes that attain a depth that may exceed 60 meters. The largest working, the Big Cut, is about 91 meters long, 46 meters wide and 18 meters deep with underground stopes accessed through a shaft at the northeast end of the pit. There was a 40-stamp mill on the property in 1894, but the mine was idle at that time. In 1895 the mine was owned by the Glenbrook Mining Company. In 1896 the American Cyanide Gold and Silver Recovery Company of Denver, Colorado, erected a 30-ton cyanide plant. The total production of the mine is said to have exceeded $300,000, about 15,000 ounces Au, but other estimates are as high as 37,500 ounces (**Maddry *et al.*, 1992**).

The entire mass of altered rock in each lode is gold-bearing, but only certain parts were rich enough to mine profitably (**Figure 9**). Rich seams appear and disappear abruptly, and the ore is difficult to distinguish from waste, except by assay. The ore commonly assayed about 0.10 oz/t gold and 0.05 oz/t silver (**Pardee and Park, 1948**). The schists carry 2-4 volume percent pyrite with traces of chalcopyrite. Pyrite occurs as disseminated fine grains, concentrated along foliation planes, and as bedding-parallel laminae. All of the Russell Mine ore zones were mined to varying degrees by a combination of surface and underground workings.

The mineralized zones strike about 045° and most occur along high-angle reverse faults axial to meso-scale northeast-trending, asymmetric, doubly plunging folds overturned to the southeast (**Klein *et al.*, 2007**). A reverse fault zone axial to an asymmetric, doubly plunging anticline is the dominant structure of the Big Cut open pit at the Russell Mine (**Klein *et al.*, 2007**). The fold axis trends 045° and is overturned to the southeast, with the NW limb dipping 50°NW and the SE limb 80°SE. The lower limb is truncated against a high-angle reverse fault that also truncates mineralization (**Klein *et al.*, 2007**). Silicification and pyritic gold mineralization parallel the axial planar cleavage along the axis of the anticline. The ore body plunges to the southwest along the anticline axis, but does not continue to the northeast. Mineralization in the Riggins Hill and Soliague lodes also appear to be localized along the axes of southeast-verging folds. High-angle reverse faults with only minor offsets cut the anticline at Riggins Hill (**Klein *et al.*, 2007**).

Disseminated pyrite in bedding-parallel laminae and lenses of "massive" pyrite 30-100 centimeters thick are locally present in strongly phyllic-altered metasediments peripheral to the ore zones (**Klein *et al.*, 2007**). The asymmetric distribution of disseminated pyrite within bedding planes is interpreted by **Klein *et al.* (2007)** as graded bedding of exhalative sulfides. Similar textures at the Ridgeway Mine in South Carolina are interpreted as the product of the sulfidation of detrital Fe-Ti oxides along the coarser-grained base of turbidite beds (**Moye, 2012**). In Au-mineralized zones at both the Russell Mine and Ridgeway Mine, bedding-parallel pyritic laminae are strongly dismembered and the rocks silicified in zones of intense small-scale reverse shear-folding and faulting that parallel the dominant cleavage (**Klein *et al.*, 2007**; **Moye, 2012**).

Coggins (Appalachian, Rich Cog) Mine (Au-As)

This mine is located 2.4 kilometers north-northeast of Eldorado at coordinates -80.01978, 35.48704 (WGS84). Mineralization occurs along shear zones in sericitized, chloritized, and silicified metasediments of the Tillery Formation. The mineralized zone is up to 15-18 meters wide. Sulfide minerals, dominantly pyrite, are disseminated throughout the sheared and altered host rocks, present in cleavage-parallel quartz stringers and veins, and most abundant in lenticular silicic ore zones up to 3 meters thick and 15-18 meters long. Two higher Au-grade zones were mined as the East Vein and the West Vein. These are not distinct veins, but gradational alteration zones with grade determined by assay (**Pratt, 1919**). Free gold is found in the upper weathered zone.

The deposit was discovered in 1882 and workings extended to a depth of 15 meters by 1886, with a 40-stamp mill constructed in 1887 (**Pardee and Park, 1948**). Shafts reached a depth of 61 meters by 1890, but the mill was moved to the Jones mine in Randolph County in 1896. In 1911 the Whitney Company operated the property as the Coggins Mine and reached a depth of 70 meters with drifts 200 meters long (**Pardee and Park, 1948**). The ore was processed in a 40-ton lane mill and treated by amalgamation. A September 1911 report notes that 1698 tons of ore averaged 0.14 oz/t Au (**Pardee and Park, 1948**). In that year the mine was one of the principal gold producers in North Carolina; but the mill burned in 1912, halting production.

Between 1913 and 1916 the property was operated as the Rich Cog Mine and worked through an inclined shaft 82 meters deep with over 300 meters of drifts and crosscuts (**Pratt, 1919**). The ore was treated in a newly constructed 10-stamp amalgamation and concentrating plant with a capacity of 40 tons per day. Free gold was recovered on site, gold-bearing sulfide concentrates were stored for shipping and off-site treatment, and tailings were impounded for future treatment (**Pratt, 1919**).

Activity at the mine during 1915-1917 was largely development work. By 1919 the mine had reached a depth of 168 meters. It is estimated that more than 65,000 tons of ore worth $5-7 per ton (0.2-0.3 oz/t Au), and 3000 tons of ore worth $9 per ton (0.43 oz/t Au) were extracted between 1922 and 1925 and treated in a 50-stamp mill. The mine was closed in 1926, but was unwatered, mapped, and sampled in 1934. It is estimated that the total yield of the mine was at least $100,000 (5000 ounces Au).

Silicification and mineralization are generally parallel to a penetrative cleavage that strikes 042° and dips 75°-80°NW, and associated with a zone of faults that parallel the cleavage or cut it at a small angle (**Pratt, 1915**). Mineralization includes zones of cleavage-parallel quartz stringers in quartz-sericite-pyrite schist or phyllite, and larger quartz veins or lenses enclosed by variably silicified and pyritic phyllite. Higher Au-grades appear to be restricted to indefinite shoots that cannot be visually distinguished from the enclosing lower-grade mineralization. Silica is the dominant alteration mineral and sulfides are largely pyrite with minor arsenopyrite.

The main 3-compartment shaft (**Figure 10**) is vertical to 2.5 meters, then angles to parallel cleavage to a depth of 79 meters, with levels at 17 meters (50-foot Level), 30 meters (100-foot Level), 60 meters (200-foot Level), and 76 meters (250-foot Level). Drifts on the 17 meters level extend 52 meters NE, cutting a diabase dike 40 meters from the shaft; and 42 meters to the SW, cutting a second diabase dike at 18 meters. The east and west ore bodies were extensively stoped for a strike length of 58 meters between the two dikes, down dip between the 17 and 30 meter levels, and also towards the surface (**Pratt, 1915**). Ore was also stoped for 9-12 meters southwest of the southern dike. No significant mineralization is indicated north of the northern diabase dike.

Drifts were opened on the 30 meter level for 31 meters to the northeast and 18 meters to the southwest. Underhand stoping continued along the northeast drift, and a winze extended to the 60 meter level. The low-grade zone separating the two ore shoots assayed 0.10-0.12 oz/t Au. One of the ore shoots on this level assayed an average of 0.43 oz/t Au over 6 meters (**Pratt, 1915**). Drifts on the 60 meter level extend 37 meters northeast and 27 meters southwest, with limited overhead and underhand stoping near the ends of both levels. The east and west “veins” appear to merge on this level, to form an ore shoot 13 meters thick that averages about 0.29 oz/t Au (**Pratt, 1915**).

A cross-cut on the 76 meter level extends 310° for 14 meters, and intersects the ore shoot 11 meters from the shaft. Work had recently begun on this level at the time of Pratt’s visit in 1914, with assays for the lode of 8.1 to 11.0 oz/t Au, and a 60-centimeter interval of 32.2 oz/t Au (**Pratt, 1915**). The percentage of free gold in the ore was similar at the 30, 60, and 76 meter levels of the mine (**Pratt, 1915**), suggesting that it was not the result of supergene enrichment but free gold in primary sulfide ore.

A pit 4 x 4 meters and 4.6 meters deep is located 122 meters 042° from the main shaft, and exposed a 2-meter wide zone of numerous stringers and veins of quartz that contained free gold. A second pit to the southwest of the shaft did not intersect the ore zone.

Sallie Coggins Mine (Au-Pb-Zn)

These workings are reportedly a short distance west of the Coggins (Appalachian) Mine, but the location is indefinite. Stringers and lenses of rusty quartz carrying sphalerite, galena, and pyrite, occur in a 9 meters wide zone parallel to the schistosity of the sheared metasedimentary host rocks, which strike 045° and dip 65°NW (**Pardee and Park, 1948**). The main opening is a water-filled open cut about 23 meters long and 9 meters wide in a hillside, with the back of the cut rising up to 10 meters above the water level (**Pardee and Park, 1948**). The bottom of the cut is reported to be about 10 meters below the water surface, with an 18-meter deep shaft at the base (**Pardee and Park, 1948**).

Around 76 meters to the northeast, stringers and lenses of Fe-strained quartz are exposed in a series of hydraulic pits and open cuts. About 46 meters to the northwest of the open cut is an outcropping ledge known as the "West Lead," with a 4.5 meter wide zone of quartz stringers striking 320° (**Pardee and Park, 1948**).

In 1896 and 1897 a hydraulic plant and a 10-stamp mill were operated at the Sallie Coggins Mine, and a zone about 15 meters wide mined by hydraulic washing (**Pardee and Park, 1948**). This material yielded about 0.015 ounces of gold per cubic meter. Hydraulic stripping exposed mineralized stringers containing pyrite, sphalerite, and galena. Between 1906 and 1916 about 123.5 ounces of gold were produced, but total mine production is unknown (**Pardee and Park, 1948**).

Henderson (Eldorado) Mine and Russell Prospect

The Henderson Mine is located about 90 meters southeast of the village of Eldorado at coordinates -80.02589, 35.4676 (WGS84). The workings consist of a 3 x 3 meter shaft with a limited volume of spoil. The Russell Prospect is located 60 meters southwest of the Henderson Mine shaft, and consists of an open cut 15 meters long, 4.5 meters wide, and about 2 meters deep. Both are located on a narrow fault zone that strikes 045° and dips 75° NW (**Carpenter, 1976**), characterized by sheared and Fe-stained Tillery Formation metasediment with milky quartz veins containing 3 millimeter wide veinlets or stringers of galena + sphalerite + pyrite + chalcopyrite (**Carpenter, 1976**). Minor pyrite, chalcopyrite, and pyrrhotite are disseminated through the chlorite-sericite altered host rocks.

Morris Mountain (Davis, Dutton, Ophir) Mine (Au)

The mine is located a kilometer north of Eldorado, a few hundred yards northwest of the Eldorado-Coggins mine road, and 1.6 km west of the Appalachian or Coggins mine, on the west flank of the Uwharrie Mountains at coordinates -80.03728, 35.4826 (WGS84). Mineralization occurs in quartz stringers within a fault zone in metasedimentary rocks of the Tillery Formation near their contact with flow-banded rhyolite. The host metasiltstone and metamudstone is crushed, fractured, silicified, and mineralized with fine disseminated pyrite (**Luttrell, 1978**). Coarse native gold occurs in quartz stringers and in joint planes in the schist.

Two shallow shafts were present around 1890. The mine was last worked in 1910 by Louis Dunkard, who milled the ore at the Dark Springs Mine mill. **Carpenter (1976)** reports an open cut 30 meter long, 4.5 meters wide, and 9 meters deep cut oblique to the strike of the rock, with a 3 x 3 meter shaft near the north end and a small prospect pit 15 meters to the east of the cut.

Steel and Saunders Mines (Au-Cu-Pb-Zn)

The map location of this mine is poorly constrained, but it is apparently sited around 2.5 to 3 kilometers southeast of Eldorado on the east side of the Uwharrie River at coordinates -80.00256, 35.47288 (WGS84). The Saunders is an extension of the Steel Mine and the lode structure was reportedly traced for 1.6 kilometers along a shear zone that strikes 025° and dips 70°NW (**Kerr and Hanna, 1888**). The country rock is similar to that at the Russell Mine, and consists of silicic to sericitic, chloritic, and possibly talcose schist and phyllite formed by alteration of sheared, thinly bedded mudstone and siltstone of the Tillery Formation.

Gold was discovered at this site about 1832 and the mine was worked extensively before 1853. In 1876 the mine was purchased by the Genesee Gold Mining Company, which mined and treated the ore in Chilean mills for some years. A 40-stamp mill was in operation in 1887. At that time the deepest shaft extended to 67 meters. There is no record of much activity since 1888. The ruins of the mill were seen in 1934. Production reported for 1887 was $150,000, or about 7100 ounces of gold.

Mining appears to have focused on a section of the shear zone with a strike length of 150-160 meters that was mined to a maximum depth of 67 meters. The mineralized zone is typically 2.7 to 3.7 meters thick, but locally up to 6.0 meters thick (**Kerr and Hanna, 1888**). Lower-grade mineralization (No. 2 ore) is generally siliceous with 1-3% pyrite and similar to that of the Russell and Coggins mines (**Kerr and Hanna, 1888**). However, this lower-grade mineralization (No. 2 ore) locally contains a 40-90 centimeter thick zone of high-grade mineralization (No. 1 ore) characterized by free gold associated with thin, cleavage-parallel seams of galena, sphalerite, chalcopyrite, and pyrite (**Kerr and Hanna, 1888**; **Pardee and Park, 1948**). This ore assayed up to several hundred oz/t gold and over a hundred oz/t silver (**Pardee and Park, 1948**). Selected intervals reported values of up to $9800 per ton of ore (~460 oz/t Au).

There is no information available on the character and width of the alteration zone enclosing the ore lodes at the Steel Mine, or the width and kinematics of the host shear zone. **Pardee and Park (1948)** reported that waste rock on the mine dumps was largely silicified schistose metasediment with disseminated fine-grained sulfides and stringers of quartz ± carbonate. The schists are typically dark-greenish in color due to the presence of relatively abundant fine-grained chlorite. This material probably represents subeconomic mineralization peripheral to the ore zones, possibly propylitic alteration transitional from silicic and phyllic alteration into unaltered host rocks.

Recent exploration history of the Ophir District

Maddry *et al.* (1992) document exploration and evaluation of Ophir District gold deposits by at least seven mining companies since 1939. Many others have examined the mines in the area, but not acquired land positions. A total of 35 diamond core holes and 14 reverse circulation drill holes totaling over 10.8 kilometers aggregate length have been completed in the area, largely around the Big Cut of the Russell Mine (**Figure 11, Table 1**).

Haile Gold Mine Incorporated drilled 5 core holes around the Big Cut of the Russell Mine in 1939, but with poor recovery. ASARCO completed two core holes through the Little Lead and Big Cut zones in 1969. The best result was 23 meters of 0.07 oz/t from the Big Cut ore zone. Cyprus did extensive work at the Russell Mine in 1974 and 1976, with extensive soil and rock chip sampling, detailed geologic mapping, and 1341 meters of trenching. They also drilled 3 core holes at the Big Cut and two at the Riggons Hill Mine. Results included 37 meters averaging 0.066 oz/t Au from the Russell Big Cut ore zone.

GRC Exploration Company conducted extensive geophysical and geochemical surveys of the area in 1979, and drilled 4 core holes collared southwest of the Big Cut that intersect the main ore zone. A single core hole sited northeast of the Coggins Mine intersected weak Au mineralization over a 7.6 meter interval at a depth of about 140 meters. Gold Fields Mining Corporation conducted soil and rock chip sampling around the Russell Mine in 1983.

Tenneco Minerals Company conducted a comprehensive evaluation of the area in 1984, including detailed geologic mapping at 1:1000 scale over a 78 km^2 area. Stream sediment silt and panned concentrate sampling vectored to known gold workings and rhyolite domes. Extensive soil sampling was conducted, and accessible mine workings mapped and sampled. A total of 1100 meters of exploration trenches were excavated and sampled across the Little Lead, Big Cut, Palmer, and Walker zones. Airborne EM and magnetic surveys of the area by Geoterrex were unsuccessful in defining the mineralized zones.

Tenneco drilled a total of 7 core holes in the Russell Mine Big Cut, Riggon Hill, and Parmer zones, and 4 holes in the Griffin and Stafford prospect area to the north. One shallow rotary hole was also drilled at the Griffin Prospect. The drilling successfully tested the main Big Cut lode and discovered the lower lode, with results that included 49 meters averaging 0.044 oz/t Au in the main zone and 23 meters of 0.111 oz/t Au in the lower lode. Broad intervals of lower Au-grade mineralization were also intersected in the Big Cut, Little Lead and Palmer zones. Only narrow intervals of anomalous gold mineralization are reported from the Griffin-Stafford area.

Piedmont Mining Company Incorporated evaluated deposits in the area from mid-1989 through 1994. Ground geophysical surveys included magnetic, SP, VLF and VLF-resistivity. Detailed geologic mapping was completed around all known mineralized zones, and four trenches totaling 239 meters were excavated across the Coggins Mine zone. A total of 11 core holes and 14 RC holes were drilled in the Russell Mine area, largely to test the main and lower Big Cut zones. Results included 100 meters averaging 0.045 oz/t Au in the Big Cut main zone and 98 meters of 0.109 oz/t Au in the Big Cut lower zone.

Proven + probable reserves for the Big Cut zone were calculated at 4.128 Mt averaging 0.051 oz/t Au, containing 209,380 ounces Au. Additional possible reserves of 3.168 Mt at 0.038 oz/t Au add another 121,250 ounces, for an estimated total of 7.296 Mt at 0.045 oz/t, containing 331,130 ounces of gold (**Maddry *et al.*, 1992**). Piedmont Minerals sold the mineral rights to the Russell Mine area to *The Land Trust for Central North Carolina* in 2006, and the Ophir District now lies within the Uwharrie National Forest.

Gold mineralization style, paragenesis, and local controls

Zones of alteration and gold mineralization in the Ophir District are typically about 3-20 meters thick and invariably described as located within shear zones (**Pratt, 1915**; **Pardee and Park, 1948**; **Conley, 1962**; **Klein *et al.*, 2007**). Where adequate information is available, alteration and mineralization are reported as conformable with and overprinting a strongly developed cleavage, often at a high angle to bedding in the host metasediments (**Pardee and Park, 1948**; **Klein *et al.*, 2007**).

The major ore bodies of the Ophir District, such as those of the Russell, Coggins, and Steel mines, are described as having indefinite boundaries determined largely through sampling and assay (**Pratt, 1915**; **Pardee and Park, 1948**; **Klein *et al.*, 2007**); however, discrete, typically higher-grade zones of stringer sulfide ± quartz veins or lenses may also be present (**Kerr and Hanna, 1888**). Hydrothermal alteration is typically strongly silicic in ore zones, grading outward into phyllic alteration (quartz-sericite-pyrite and quartz-sericite-chlorite-pyrite) and possibly peripheral propylitic (chloritic) alteration in some deposits. Sulfide content is typically 3-5 wt% and dominated by pyrite, with subordinate chalcopyrite, galena, and sphalerite in some deposits. Minor arsenopyrite is reported at the Russell (**Klein *et al.*, 2007**) and Coggins (**Pratt, 1915**) mines, and molybdenite is present at the Russell Mine (**Klein *et al.*, 2007**).

The shear zones that host gold mineralization in the Ophir District strike either around 025° or 045° but all dip steeply to the northwest. Although there are distinct differences between gold deposits at these two orientations, they also share many features in common. All appear to have formed in association with compressional deformation and regional greenschist facies metamorphism during the Cherokee Orogeny (**Hibbard *et al.*, 2012**). All are characterized by a strong S_1 cleavage or foliation at an oblique angle to primary bedding (S_0) in the host Tillery Formation metasedimentary rocks. Where the kinematics of deformation is defined, these structures all appear to be developed along reverse faults. Finally, the gold deposits hosted by shear zones in both orientations are characterized by similar alteration assemblages, zonation, and styles of mineralization.

Hydrothermal alteration

The hydrothermal alteration in all of the deposits of the Ophir District is typically silicic or silicic-phyllic in association with higher-grades of golf mineralization, surrounded by phyllic to chloritic alteration that may carry anomalous but subeconomic gold values. Silicic alteration (**Kerr and Hanna, 1888**; **Pratt, 1915**; **Pardee and Park, 1948**; **Klein *et al.*, 2007**) includes pervasive to selective replacement by fine-grained quartz parallel to the S_1 fabric, stockworks or swarms of quartz veinlets, and single or multiple larger quartz veins (1-100 centimeters thick). The color of silicic alteration and quartz veins ranges from white through light-to dark-gray and sometimes has a bluish tint, which **Kerr and Hanna (1888)** suggest is indicative of higher gold content. The color may be due to the presence of disseminated microscopic sulfide grains.

Silicic alteration is typically gradational into phyllic alteration, composed of often strongly foliated quartz + sericite + pyrite ± chlorite ± carbonate. There is little information available regarding the distribution of phyllic alteration peripheral to the silicic gold ore zones at most mines of the Ophir District. Phyllic alteration haloes appear to be relatively narrow at the Griffin, Stafford, and Steel mines. Phyllic alteration may extend over widths of tens of meters at the Coggins and Sallie Coggins, Riggon Hill, and Russell Mines. A 20 meter thick zone of phyllic alteration is present in the hanging wall of the siliceous 2-3 meter thick Little Lead ore zone at the Russell Mine (**Klein *et al.*, 2007**).

Chloritic alteration is reported for mine dump material at the Steel Mine (**Kerr and Hanna, 1888**), possibly as sub-economic propylitic alteration peripheral to the silicic to phyllic altered ore zones. Increased chlorite and carbonate content in the transition from phyllic alteration to unaltered host rock is reported at the Russell Mine (**Klein *et al.*, 2007**). There is little mention of chloritic alteration in other deposits of the Ophir District, but weakly developed propylitic alteration is difficult to distinguish from the regional greenschist facies metamorphism.

Sulfide mineralogy and occurrence

Auriferous silicic alteration and quartz veins are invariably sulfide-bearing. Pyrite is the dominant sulfide, and occurs as small (≤ 1 to 5 millimeters) randomly disseminated euhedral crystals, as bedding-parallel concentrations of 20-50% fine-grained pyrite, as irregular stringers with or without quartz, as cleavage-parallel seams or veins (often with other sulfides), and as thin coatings (paint) on cleavage surfaces, joints, and fractures (**Kerr and Hanna, 1888**; **Pratt, 1915**; **Klein *et al.*, 2007**).

Pyrite is also present in phyllic and chloritic alteration zones around siliceous mineralization in the Ophir District gold deposits, although the mode of occurrence is seldom described. **Klein *et al.* (2007)** describe the extensive occurrence of fine-grained disseminated pyrite and bedding-parallel pyritic laminae in phyllic alteration hanging wall to the Little Lead ore zone of the Russell Mine. Siliceous phyllic alteration with significant chlorite at the Steel Mine contains fine-grained disseminated pyrite (**Kerr and Hanna, 1888**).

Pyrrhotite is a minor sulfide phase in several deposits, and typically associated with pyrite (**Pardee and Park, 1948**; **Carpenter, 1976**; **Klein *et al.*, 2007**). However, **Carpenter (1976)** reports that pyrrhotite is the dominant sulfide mineral in quartz veins and stringers at the Stafford Mine, with subordinate pyrite and chalcopyrite.

Galena, sphalerite, and minor chalcopyrite are significant ore minerals at the Steel Mine (**Kerr and Hanna, 1888**), Sallie Coggins Mine (**Pardee and Park, 1948**), and Eldorado Mine (**Carpenter, 1976**). Chalcopyrite is a minor accessory at the Stafford Mine (**Pardee and Park, 1948**). These minerals often occur with pyrite in narrow, sulfide-rich, and typically gold-rich stringers or seams parallel to cleavage (**Kerr and Hanna, 1888**, **Pardee and Park, 1948**) or as narrow stringers along fractures in quartz veins (**Carpenter, 1976**). Both occurrences suggest that high Au-grade, base metal sulfide-rich ores in these deposits formed late in the paragenesis, post-dating cleavage development, silicic alteration, and quartz vein formation.

Accessory arsenopyrite is reported at the Coggins (**Pratt, 1915**) and Russell (**Klein *et al.*, 2007**) mines. However, **Klein *et al.* (2007)** report the common occurrence of As-enriched growth bands in pyrite from the Russell Mine, and arsenic may be a common though minor geochemical component of many Ophir District gold deposits. Synkinematic, synmetamorphic ore stage (Stage-2) pyrite at the Russell Mine locally contains inclusions of chalcopyrite and, less commonly, inclusions of aggregated pyrrhotite with arsenopyrite, cobaltite, galena, and sphalerite (**Klein *et al.*, 2007**). Microscopic inclusions of these sulfides may be present in pyrite at other Ophir District gold deposits as well.

Trace to minor molybdenite is present at the Russell Mine, and most abundant in pyritic quartz + carbonate veins footwall to the Little Lead ore zone (**Klein *et al.*, 2007**). Additionally, geochemically anomalous Mo is commonly present in association with auriferous pyritic mineralization in both the Little Lead and Big Cut ore zones (**Klein *et al.*, 2007**). Molybdenite has not been reported from other lodes in the district.

Contrasting shear zone hosted gold deposits oriented 025° and 045°

As previously noted, shear zones that host gold mineralization in the Ophir District typically strike either 025° or 045°. Although there is significant similarity in the style of structural control, alteration assemblages, and mineralization in deposits at both orientations, there are also systematic differences in the geometry and continuity of hosting structures and the volume and distribution of hydrothermal alteration and mineralization.

The Steel Mine is presented as an example of the narrow, single lode style of mineralization hosted by shear zones that trend 025°. The Russell Mine and the Coggins-Sallie Coggins mines are selected to represent the multiple lode deposits that strike around 045°.

The Steel Mine and Saunders extension

The Steel Mine and the Saunders extension were developed along a line-of-lode that was reportedly traced for 1.6 kilometers along a shear zone that strikes 025° and dips 70°NW (**Kerr and Hanna, 1888**). Mining appears to have focused on a section of the shear zone with a strike length of 150-160 meters that was mined to a maximum depth of 67 meters. The mineralized zone is typically 2.7 to 3.7 meters thick, but locally up to 6.0 meters thick (**Kerr and Hanna, 1888**).

Lower-grade mineralization (No. 2 ore) is generally siliceous with 1-3% pyrite and similar to that of the Russell and Coggins mines (**Kerr and Hanna, 1888**). However, this lower-grade mineralization (No. 2 ore) locally encloses a 40-90 centimeter thick zone of high-grade mineralization (No. 1 ore) characterized by free gold associated with thin, cleavage-parallel seams of galena, sphalerite, chalcopyrite, and pyrite (**Kerr and Hanna, 1888**; **Pardee and Park, 1948**). This ore assayed up to several hundred oz/t gold and over a hundred oz/t silver (**Pardee and Park, 1948**). It is possible that the lower-grade silicic mineralized zone extends much farther along strike, but that the Steel deposit was only of economic grade where the higher-grade (No. 1) stringer sulfide ore was present.

There is no information available on the total width and possible zonation of the alteration zone enclosing the ore lodes at the Steel Mine, or the width and kinematics of the host shear zone. **Pardee and Park (1948)** report that waste rock on the mine dumps was largely silicified schistose metasediment with disseminated fine-grained sulfides and stringers of quartz ± carbonate. The schists are typically dark-greenish in color due to the presence of relatively abundant fine-grained chlorite. This material probably represents subeconomic mineralization peripheral to the ore zones, possibly propylitic alteration transitional from silicic and phyllic alteration into unaltered host rocks.

The Russell Mine

Pratt (1915) and **Klein *et al.* (2007)** identify at least six parallel mineralized structures striking approximately 045° and dipping steeply northwest over a 500 meter wide zone at the Russell Mine (**Figure 8, Figure 12**). The mineralized zones are, from NW to SE; the Little Lead, Big Cut Lead, Riggins Hill Lead, Soliague Lead, Walker Lead, and Laurel Hill Lead. The Palmer workings are on a southwest extension of the Riggins Hill Lead.

The Russell Mine gold lodes are 3-21 meters thick (**Pardee and Park, 1948**) and appear to be hosted by silicified shear zones developed along the axes of meso-scale northeast-trending, doubly plunging, asymmetric folds that are appressed and overturned to the southeast (**Maddry *et al.*, 1992**; **Klein *et al.*, 2007**). Additionally, some folds are cut by steeply NW-dipping axial-planar reverse faults (**Klein *et al.*, 2007**). The mineralized structures are characterized by intense cleavage development and strong small-scale folding, faulting, and transposition of primary textures and fabrics (**Klein *et al.*, 2007**). Cleavage and reverse faults are typically axial planar to the meso-scale folds. These shear zones appear to have limited strike continuity, ranging from 90 to 250 meters (**Maddry *et al.*, 1992**).

The Big Cut Lead ore body of the Russell Mine (**Figure 6**) occupies a doubly-plunging anticline that strikes 045° (**Klein *et al.*, 2007**), with the lower limb and ore body truncated against a reverse fault. Similar anticlines are documented in association with the Riggins Hill and Soliague leads and the Laurel Hill Lead (**Klein *et al.*, 2007**). These folds generally appear to have a wavelength of around 100 to 200 meters, unless unmineralized anticlines are also present. **Maddry *et al.* (1992)** describe two additional parallel mineralized structures farther southeast, one at the contact of Tillery metasediments with breccia units associated with the rhyolite cryptodome mapped by **Klein *et al.* (2007)**.

The entire mass of altered rock in each lode is auriferous, but only certain zones had sufficient Au-grade to be mined profitably. Higher-grade zones begin and end abruptly, and ore is difficult to distinguish from waste except by assay (**Pardee and Park, 1948**). The average grade of the ore is around 3.1 g/t (0.1 oz/t) gold with 1.5 g/t (0.05 oz/t) silver (**Pardee and Park, 1948**). Higher-grade ore zones are 100-150 centimeters thick with grades of 0.5-2 oz/t Au, and locally up to 12-16 oz/t (**Nitze and Hanna, 1896**).

The very high-grade ores were collected by hand and brought out of the mine in empty powder kegs (**Nitze and Hanna, 1896**). Much of this higher-grade gold mineralization may have been the result of localized enrichment through supergene oxidation of sulfides with remobilization and recrystallization of gold. Piedmont Minerals encountered maximum vales of 2.68 oz/t Au and 2.92 oz/t Au over 3 meters wide intervals in drill holes below the Big Cut (**Maddry *et al.*, 1992**), suggesting that high-grade gold is present in primary sulfide ore.

The Russell lodes were mined (**Figure 13**) by a combination of surface and underground methods (**Pardee and Park, 1948**). The open pit at the Big Cut measures about 91 meters long, 46 meters wide, and up to 18 meters deep (**Nitze and Hanna, 1896**). A shaft at the northeast end of the Big Cut extends to a depth of 55 meters **(Figure 13**), with upward stoping of the ore zone from the bottom (**Nitze and Hanna, 1896**). The deepest underground workings appear to be at the Riggon Hill workings, where the shaft reached a depth of 87 meters (**Maddry *et al.*, 1992**).

The gold lodes were worked intensively over a strike distance of about 100 meters (**Figure 12**), with most production by surface excavation and underground stoping to depths of around 30 meters (**Pardee and Park, 1948**). The mined portion of each shear zone appears to generally correspond to the apex of a doubly-plunging anticlinal crest. The highly localized nature of ore-grade gold mineralization and lack of strike continuity suggests that structural controls were a dominant factor in the formation of ore-grade gold lodes at the Russell Mine.

The structural character of the Russell Mine contrasts strongly with that of other reverse fault-hosted gold deposits in the Ophir District (**Figure 12**). Most deposits are hosted by single structures that strike 025°, such as the Steel Mine. Although multiple parallel ore-grade lodes are present at the Coggins and Riggon Hill mines, which also strike 045°, they are closely spaced within a single deformation zone. The multiple reverse-faulted meso-scale anticlines of the Russell Mine are part of a deformation zone of unknown character, controls, and strike continuity.

Alteration and mineralization at the Russell Mine, based on the work of **Klein *et al.* (2007)**, are discussed in more detail in a separate section (see below).

The Coggins and Sallie Coggins Mines

The shear zone at the Coggins (Rich Cog, Appalachian) Mine strikes 042°, dips 75°-80° northwest (**Pratt, 1915**), and has been traced for about 300 meters along strike (**Figure 4**). This shear zone has been prospected to the northeast and southwest, but intense hydrothermal alteration and significant gold mineralization are restricted to a central zone about 100 meters long and up 18 meters wide (**Figure 14**) that was mined to a depth of at least 80 meters (**Pratt, 1915**).

Silicification and gold mineralization are generally parallel to a penetrative cleavage that strikes 042° and dips 75°-80°NW, associated with a zone of faults that parallel the cleavage or cut it at a small angle (**Pratt, 1915**). Mineralization includes zones of cleavage-parallel quartz stringers in quartz-sericite-pyrite schist or phyllite, and larger quartz veins or lenses enclosed by variably silicified and pyritic phyllite (**Pratt, 1915**). Silica is the dominant alteration mineral and sulfides are largely pyrite with minor arsenopyrite.

Higher Au-grades appear to be restricted to lenticular shoots with indefinite boundaries that cannot be visually distinguished from the enclosing lower-grade mineralization. Two higher-grade shoots separated by lower-grade ore are present on the 30 meters level of the mine (**Figure 14**). One of the high-grade shoots assayed an average of 0.43 oz/t gold over a width of 6 meters, while the low-grade zone separating the shoots assayed 0.10-0.12 oz/t gold (**Pratt, 1915**). These shoots merge at depth and on the 60 meters level **(Figure 14**) to form a single zone 13 meters thick that averages about 0.29 oz/t gold (**Pratt, 1915**).

The Sallie Coggins Mine is located a short distance west of the Coggins Mine and produced around 124 ounces of gold between 1906 and 1916 (**Pratt, 1915**; **Pardee and Park,**

1948); however, the total historical production is not recorded. Stringers and lenses of rusty quartz carrying sphalerite, galena, and pyrite are present in an intensely foliated shear zone 9 meters wide that strikes 045° and dips 65°NW (**Pardee and Park, 1948**). The major working is an open cut about 23 meters long, 9 meters wide, and up to 20 meters deep with an 18-meter deep shaft at the base of the pit (**Pardee and Park, 1948**).

The shear zone extends for at least 76 meters to the northeast, where stringers and lenses of Fe-strained quartz are exposed in a series of hydraulic pits and open cuts (**Pardee and Park, 1948**). Hydraulic washing of a zone 15 meters wide in 1896 and 1897 exposed stringers of mineralization containing pyrite, sphalerite, and galena (**Pardee and Park, 1948**).

Hydrothermal alteration and sulfide mineralization at the Russell Mine

The most detailed analysis of sulfide mineralization, alteration, and structure in the Ophir District is the work of **Klein *et al.* (2007)** at the Russell Mine. The following discussion is based primarily on their published data and descriptions. Analytical work by **Klein *et al.* (2007)** focused largely on core from vertical core drill hole CYR-5, drilled by Piedmont Minerals through the Little Lead zone of mineralization. This is the western-most of the six historically mined mineralized zones at the Russell Mine, and located about 30 meters northwest of the Big Cut. Additionally, **Klein *et al.* (2007)** analyzed samples from the surface workings of the Big Pit and Little Lead lodes.

The Big Pit is opened along the largest of the mineralized zones of the Russell Mine. The ore body is a zone of intense silicic alteration and gold mineralization located within a shear zone along the axis of a doubly plunging anticline that strikes 045° and dips steeply northwest. The northwestern limb of the anticline dips 50°NW and the southeastern limb dips 80° SE, but is truncated against a steeply NW-dipping reverse fault that also offsets the mineralized zone (**Klein *et al.*, 2007**). The ore body does not continue along the shear zone to the southwest, but appears to continue down-plunge to the northeast (**Pardee and Park, 1948**; **Klein *et al.*, 2007**). Similar controls were noted for the Riggins Hill and Soliague ore bodies (**Figure 8**). Two parallel high-angle reverse faults cut the anticline at Riggins Hill, but show only minor displacement (**Klein *et al.*, 2007**).

Pyrite paragenesis at the Russell Mine

Sulfide mineralogy at the Russell Mine is dominated by pyrite, which occurs in a number of different habits and associations. Two stages of pyrite formation were described in samples analyzed by **Klein *et al.* (2007)**. Earlier Stage-1 pyrite is characterized by fine-grained (10-µm) euhedral grains with a spongy texture due to the presence of 1-µm diameter central cavities. This pyrite occurs in thin “massive sulfide” laminae parallel to bedding and is intergrown with pyrrhotite, chalcopyrite, sphalerite, and trace arsenopyrite (**Klein *et al.*, 2007**). Stage-2 pyrite occurs as massive, euhedral overgrowths on Stage-1 pyrite that has been transposed into cleavage-parallel veinlets; it may contain inclusions of chalcopyrite and locally inclusions of aggregated pyrrhotite with arsenopyrite, cobaltite, galena, and sphalerite (**Klein *et al.*, 2007**).

Stage-1 pyrite generally contains < 0.08 wt% but locally up to 0.49 w% As; with up to 0.02 wt% Ag, 0.06 wt% Au, 0.07 wt% Co, 0.02 wt% Cu, 0.03 wt% Sb, 0.02 wt percent Se, and 0.02 wt% Zn (**Klein *et al.*, 2007**). Anomalous Au-values in Stage-1 pyrite are typically concentrated along the grain margins, and cannot be definitively linked to the genesis of this generation of pyrite (**Klein *et al.*, 2007**). Stage-2 pyrite overgrowths have complex zonation, with As-rich bands averaging 2-3 wt% As (maximum 4.7 wt% As) alternating with As-poor bands, and trace amounts of Co, Ni, Ag, and Zn. Rare molybdenite crystals that occur parallel to cleavage appear to be late in the paragenesis and cut both pyrite stages. Rare veinlets of chalcopyrite and calcite also appear to post-date both stages of pyrite formation.

Higher Au-grades in pyrite-rich mineralized zones are typically associated with strongly anomalous arsenic. A three meter wide zone of cleavage-parallel quartz veins in silicic and sericite altered schists is also auriferous, and appears to be syntectonic. A discordant late syntectonic to post-tectonic quartz-calcite-pyrite vein with accessory REE-rich apatite (**Klein *et al.*, 2007**) contains 1.2 ppm Au and highly anomalous As (1100 ppm) and Mo (3300 ppm).

Klein *et al.* (2007) suggest that formation of Stage-1 pyrite is syngenetic or early diagenetic, synchronous with deposition of the host sedimentary rocks, and possibly nucleated on organic material or bacteria. Formation of Stage-2 pyrite is interpreted as syntectonic, and accompanies formation of the penetrative cleavage (**Klein *et al.*, 2007**). The genetic model proposed by **Klein *et al.* (2007)** suggests late Proterozoic syngenetic gold-rich "massive sulfide" mineralization, possibly associated with localized felsic volcanism, that was remobilized by focused hydrothermal fluid flow into asymmetric anticlinal traps associated with southeast-directed shear zones during the Cherokee Orogeny in the late Ordovician to early Silurian (**Hibbard *et al.*, 2012**).

Phyllic alteration and bedding-parallel pyritic mineralization at the Russell Mine

In core from drill hole CYR-5 through the Little Lead zone, phyllic alteration (quartz + sericite ± pyrite) is present from the surface to a depth of around 92 meters down-hole, and characterized by the development of unfoliated, randomly oriented sericite grains (**Klein *et al.*, 2007**). A spaced S_1 cleavage locally cuts across S_0 in the lower portion of this zone. Pyritic laminae parallel to bedding (S_0) are present from 36-40 meters and from 45.5-50 meters, and intervals of "massive pyrite" 30-100 centimeters thick are present at 70, 73, and 91 meters down-hole.

Pyritic laminae parallel to bedding (S_0) in the hanging wall of the Little Lead mineralized zone are not actually massive but consist of around 20-30 vol% disseminated subhedral to euhedral pyrite grains about 10 μm in diameter, locally associated with textures interpreted as graded bedding (**Klein *et al.*, 2007**). Bedding-parallel disseminated pyrite is not documented in unaltered Tillery metasediments in the area, and first appears in zones of incipient to partial phyllic alteration. **Klein *et al.* (2007)** do not specify the component mineralogy, pyrite content, or texture of "massive sulfide" intervals in the Little Lead core hole, and their character and paragenesis cannot be fully evaluated.

Although **Klein *et al.* (2017)** interpret bedding-parallel disseminated pyrite at the Russell Mine as exhalative in origin; similar textures at the Kennecott Ridgeway Gold Mine in South Carolina (**Figure 15**) are interpreted by the author (**Moye, 2012**) as the product of sulfidation of around 5-10% detrital Fe-Ti oxides along the coarser-grained base of immature turbidite beds (**Figure 16**). This process results in an assemblage of 10-30 vol% pyrite intimately associated with 5-10 vol% very fine-grained rutile in a matrix composed largely of sand-sized quartz grains (**Figure 17**). This first generation of pyrite at the Ridgeway Deposit is anomalous in arsenic but does not contain any gold (**Moye, 2012**).

Klein *et al.* (2007) admit that there is not a strong case for primary Au content in bedding-parallel pyrite from the phyllic alteration zone of the Little Lead deposit. Although they interpret Type-1 pyrite as exhalative or diagenetic in origin and nucleated around organic material or bacteria, **Klein *et al.* (2017)** note that pyrite could have nucleated on a primary detrital mineral that has been dissolved.

Although not part of a zone of reported bedding-parallel pyritic laminae or "massive sulfide" units, samples from drill hole CYR-5 at 67.36 meters and 67.67 meters down-hole (**Klein *et al.*, 2007; page 248, Table 1**) appear to be from pyrite-rich intervals in the phyllic alteration zone. The first sample contains roughly equal proportions of quartz (26 wt% SiO_2) and sericite with abundant pyrite (22.8 wt% Fe_2O_3) and carries 2.80 ppm Au and 5400 ppm As. The second sample is similar in composition with <0.05 ppm Au and 560 ppm As. A sample at 91.44 meters down-hole, presumably the lowermost "massive sulfide" unit of **Klein *et al.* (2007)**, contains 22.6 wt% quartz, 16.1 wt% Al_2O_3, and 28 wt% Fe_2O_3 with 3.4 ppm Au, 1700 ppm As, and 66 ppm Mo. The most pyrite-rich sample listed by **Klein *et al.* (2007)** is from 72.85 meters down-hole and composed of 40 wt% Fe_2O_3, 15.2 wt% quartz, and minor sericite, with 740 ppm As but no detectable Au (<0.05 ppm).

There is no observable consistency in the occurrence or abundance of pyrite and the concentrations of associated gold, arsenic, or molybdenum in the samples from drill-hole CYR-5. **Klein *et al.* (2007)** provide no adequate definition or terminology regarding the character of bedding-parallel occurrences of pyrite to distinguish disseminated sulfides from truly massive or sub-massive sulfide mineralization. Documentation of stratigraphic and structural context, sulfide abundance, gangue mineral associations, and non-sulfide mineral paragenesis by **Klein *et al.* (2007)** is inadequate to fully evaluate their geochemical data and interpretations.

Silicic alteration zones at the Russell Mine

Intense, dark gray silica + pyrite ± sericite alteration with an SiO_2 content of 80-90 wt% is present from 92-112 meters down-hole in core from drill hole CYR-5 through the Little Lead zone, associated with strong development of a penetrative S_1 foliation and local S-C fabric (**Klein *et al.*, 2007**). The position of this zone in core hole CYR-5 is consistent with the down-dip projection of the 2-3 meter thick Little Lead ore body from the surface at a dip of around 78°NW.

Bedding, bedding-parallel pyritic laminae, and earlier-formed quartz and carbonate veins are strongly deformed, dismembered, and transposed into the S_1 tectonic fabric (**Klein *et al.*, 2007**) approaching the silicic zone. In the footwall of the silicic zone, the color of the rock changes to light gray from 112-125 meters down-hole, with lower silica content and coarser-grained sericite. This lithology is gradational down-hole into increasingly chlorite-rich phyllic alteration with carbonate veins and less intense S_1 cleavage development, forming the footwall of the shear zone (**Klein *et al.*, 2007**).

With increasing development of the penetrative S_1 cleavage in the mineralized Big Cut and Little Lead zones of the Russell Mine, bedding-parallel pyritic laminae are asymmetrically folded at millimeter to centimeter scales, dismembered, and transposed into the cleavage fabric (**Klein *et al.*, 2007**). Stockwork veinlets of quartz ± carbonate also post-date formation of bedding-parallel pyritic laminae, but pre-date S_1-parallel shearing (**Klein *et al.*, 2007**). At the Kennecott Ridgeway Deposit in South Carolina, similar transposition of bedding and pyritic laminae within zones of penetrative cleavage, shearing, and intense silicic-potassic alteration (**Figure 18**) results in the incorporation of early stage pyrite into cleavage-parallel quartz veins and the addition of gold + silver and a suite of associated pathfinder elements that include As, Pb, Bi, Te, Se, and Mo (**Moye, 2012**).

However, at the Kennecott Ridgeway Mine gold deposits in South Carolina, the earlier phyllic and silicic alteration events with low-grade gold mineralization are locally overprinted by higher-grade epithermal gold mineralization accompanied by Kspar-stable potassic alteration (adularia + microcline), formation of hydrothermal breccias, and emplacement of aplite dikes (**Moye, 2012**). The earlier phyllic-silicic phase of alteration at the Ridgeway Mine and the overprinting potassic epithermal event with aplite magmatism are both part of a single mineralizing event dated to circa 550 Ma (**Moye, 2012**). This high-grade Au epithermal overprint, the association with felsic magmatism, and highly anomalous F and Mo distinguish the Kennecott Ridgeway Mine gold deposits from the Russell and Coggins mines in the Ophir District.

The gold concentration in both stages of pyrite in the Big Cut lode at the Russell Mine is typically below detection limit, but locally up to 600 g/t or 17.5 oz/t (**Klein *et al.*, 2007**). However, there is no information as to which generation of pyrite contains these higher gold values. According to **Klein *et al.* (2007)**, the highest Au values are associated with high As concentrations and with units of "massive sulfide". Ten bulk samples of sulfide-rich zones (**Klein *et al.*, 2007**) contained Au values of 0.5-4 g/t (0.015-0.117 oz/t); however, there is no discrimination among pyrite types or paragenetic associations. Elevated Au values are also associated with a zone of syntectonic S_1-parallel quartz veins intersected between 95 and 98 meters down-hole in the Little Lead silicic alteration zone (**Klein *et al.*, 2007**). Formation of these veins is considered synchronous with the growth of Stage-2 pyrite (**Klein *et al.*, 2007**).

Core sample analyses taken between 110 and 113.4 meters down-hole, in the transition from the intensely silicic altered gold ore zone to the less-altered footwall rocks, have Mo in excess of 100 ppm with a high value of 476 ppm (**Klein *et al.*, 2007**). **Klein *et al.* (2007)**

describe a discordant syntectonic to post-tectonic pyrite + calcite vein at 124.4 meters that contains 1.2 ppm Au, 1100 ppm As, and 3300 ppm Mo. However, their analysis indicates that this sample is composed of 59 wt% SiO_2 and less than 2 wt% CaO; suggesting that the vein is largely composed of quartz with abundant pyrite and subordinate carbonates other than calcite.

Critique of the work of Klein *et al.* (2007) on the Russell Deposit

The work of **Klein *et al.* (2007)** on the Russell Mine gold deposit is the most detailed published analytical study of a gold deposit in the Ophir District in the Carolina Terrane of central North Carolina, and an invaluable resource for those seeking to better understand this interesting and enigmatic style of mineralization. However, this study is in some respects geologically incomplete with many unanswered questions. There is an unfortunate absence of detailed petrographic analyses and supporting imagery, especially of gangue mineralogy associated with both generations of pyrite. Additionally, there is a strong bias towards an exhalative "massive sulfide" model for the Russell Mine gold deposit despite strong ambiguity in the inferences, correlations, and conclusions in the text that support that model.

An exhalative origin or precursor for Carolina Terrane gold deposits has been a focus of USGS publications since 1997 (**Ayuso *et al.*, 1997**: **Foley *et al.*, 2001**; **Ayuso *et al.*, 2005**; **Foley and Ayuso 2012**). A major failing of this model is the attempt to group widely diverse ore deposit types (VMS, epithermal, mesothermal) into a single ore deposit model and metallogenic event, despite the obvious differences in the age of host rocks and mineralization, diverse structural controls and tectonic settings, differing alteration styles and associations, and dissimilar ore mineral and trace element characterization.

The VMS precursor problem

Klein *et al.* (2007) present no evidence for the existence of widespread, stratabound sulfide mineralization or "potassium metasomatism" in the form of phyllic (sericite) alteration in the Russell Mine area. Sulfide mineralization and hydrothermal alteration are only known to be present within and immediately peripheral to the structurally-controlled silicic gold-bearing lodes at the Russell Mine. Additionally, the suggestion that sulfide mineralization that averages around 5% by volume represents a "massive sulfide deposit" is incongruous.

The suggestion of **Klein *et al.* (2007)** that the small Russell Dome rhyolite located northeast of the Russell Mine, deep within the stratigraphic footwall in the homoclinal Tillery Formation sequence, is the source of heat or fluids involved in the formation of the Russell Mine mineralization, is without any geologic foundation. There is no evidence of syn-emplacement mineralization associated with this rhyolite dome or cryptodome. Sulfide-bearing veins occur in conjugate brittle tension fractures within the rhyolite body (**Klein *et al.*, 2007**) and veinlets and alteration with low Au-values are associated with shearing along the contacts (**Maddry *et al.*, 1992**); both clearly products of late Ordovician tectonism.

Klein *et al.* (2007) suggest that the host Tillery Formation metasediments for the Russell Mine gold deposit are "similar in age" to those hosting volcanogenic massive sulfide (VMS) deposits in the Cid District (Silver Hill and Silver Valley mines) and Gold Hill District (Union Copper and Silver Shaft mines) of North Carolina and the Barite Hill VMS deposit in the Lincolnton-McCormick District in South Carolina and Georgia.

However, the VMS deposits of the Gold Hill and Silver Hill districts in North Carolina are hosted by the Flat Swamp Member of the Cid Formation (**Moye *et al.*, 2017**), dated to between 540 and 547 Ma (**Ingle *et al.*, 2003**; **Hibbard *et al.*, 2008**; **Hibbard *et al.*, 2012**). The VMS deposits of the Gold Hill and Silver Hill districts are around 10 Ma younger and 4000 meters stratigraphically above the Tillery Formation host of the Russell Mine deposit. The Barite Hill VMS deposit is hosted by volcaniclastic facies associated with the Lincolnton Metadacite rhyolitic magmatic complex, dated to 566 Ma (**Carpenter *et al.*, 1982**), around 10 Ma older than the Tillery Formation host for the Russell Mine deposit.

Mixed and missing ore deposit models

Klein *et al.* (2007) briefly introduce some of the different styles of hydrothermal alteration and mineralization in the Carolina Terrane, including VMS deposits, advanced argillic alteration centers (Brewer Mine in South Carolina and Pilot Mountain and Robbins in North Carolina), and low-sulfidation orogenic gold-bearing quartz veins and silicic alteration zones along the Gold Hill Fault Zone. However, they fail to mention or discuss the gold deposits in the Carolina Terrane that are most similar to the Russell Mine; those of the Sawyer-Keystone Trend in northwestern Randolph County, North Carolina.

These are broad, often multiple zones of low total sulfide, base metal poor Au-Ag-As mineralization associated with pyritic silicic and phyllic alteration hosted by shear zones and meso-scale folds along a 065° alignment that extends for 21 kilometers across northwest Randolph County, North Carolina. They include the Jones-Keystone, Lofflin, Parrish-Kindley, Sawyer, and New Sawyer deposits. The mineralized trend and the host structures cut across the stratigraphy of the Albemarle Group and major regional-scale folds associated with the early stages of the Cherokee Orogeny (**Hibbard *et al.*, 2012**). The style of structural control, the composition and distribution of hydrothermal alteration, and the character and grade of gold mineralization in many of these deposits is very similar to that at the Russell Mine. The character and source of the causal hydrothermal fluids in both areas is unclear, and may include both metamorphic and igneous components.

The Russell Mine deposits of the Ophir District are also compared to the Ridgeway and Haile deposits of the Carolina Terrane in central South Carolina (**Klein *et al.*, 2007**). Although there are similarities in the style and structural controls of alteration and mineralization, the Ridgeway and Haile hydrothermal gold deposits are 1-2 orders of magnitude larger, include epithermal potassium feldspar as a stable alteration phase in higher-grade mineralization, are strongly anomalous in Mo and F, well constrained to a late Proterozoic age (circa 550 Ma), and appear to be associated with localized felsic magmatism associated with late Proterozoic collision of the Carolina and Charlotte terranes (**Moye, 2012**).

The gold deposits of the Ophir District, including the Russell Mine, as well as similar deposits of the Sawyer-Keystone Trend, are interpreted to be late Ordovician to early Silurian in age. This would suggest that the Sawyer-Keystone Trend and Russell-type Ophir District deposits formed during a tectonic-metallogenic event separate and distinct from that responsible for the Haile and Ridgeway deposits.

The character, origin, and timing of sulfide formation and gold mineralization

Klein *et al.* (2007) admit the difficulty in demonstrating primary gold content for their Stage-1 pyrite, presumed to be "syngenetic", and no mechanism is offered for dramatically enriching gold and trace element content in Stage-2 pyrite. Although **Klein *et al.* (2007)** propose remobilization and recrystallization of Stage-1 pyrite accompanied by silicic alteration by hydrothermal fluids during the Cherokee Orogeny, there is no indication of the character and composition of these fluids and whether they may have been responsible for the introduction of part of the deposit gold budget as well as Mo and REE-rich apatite in late stage quartz-carbonate-pyrite veins. It is asserted that these hydrothermal fluids are responsible for the intense silicification of the ore lodes and that this silicification post-dates peripheral phyllic alteration assemblages, despite the obvious genetic association of both alteration assemblages in all Ophir District gold deposits.

Finally, **Klein *et al.* (2007)** provide little detailed contextual stratigraphic, structural, or mineralogical studies for the occurrence, habit, and paragenesis of pyrite in the Russell Deposit. No detailed mineralogy, pyrite paragenesis, or imagery is provided for intervals of "massive sulfide" observed in core. Microscopic imaging is selectively limited and data for the electron-microprobe (EMP) analyses of pyrite types discussed in the text are not provided. The reliance on unpublished electron microprobe data and the absence of ICP-MS analyses of Russell Mine pyrite samples is puzzling, and limits the utility and reliability of the work by **Klein *et al.* (2007)**.

The felsic volcanic-sedimentary sequence contact association myth

Klein *et al.* (2007) repeat the often cited misconception that there is a strong spatial association between gold deposits in the Carolina Terrane and the stratigraphic contact between host metasedimentary sequences and underlying felsic metavolcanic sequences (**Worthington and Kiff, 1970**; **Spence *et al.*, 1980**; **Feiss and Wesolowski, 1986**; **Feiss and Wesolowski, 1990**; **Feiss *et al.*, 1993**; **Gillon *et al.*, 1998**; **Ayuso *et al.*, 2005**). A number of authors (**Klein *et al.*, 2007**; **Gillon *et al.*, 1998**; **Ayuso *et al.*, 2005**) further suggest that gold mineralization in the Ridgeway, Haile, and Russell deposits originated as stratabound exhalative mineralization deposited synchronously with their host rocks and remobilized into shear zones during subsequent tectonic events.

The Russell Mine deposit is located near the top of the Tillery Formation; over a thousand meters stratigraphically above the conformable contact with the felsic volcanic dominated Uwharrie Formation. There is no evidence of any significant gold or base metal mineralization localized along or immediately above or below the contact of the Uwharrie and Tillery formations.

At the Kennecott Ridgeway Mine in South Carolina, only the Ridgeway North ore body is located adjacent to the structurally imbricated contact between the felsic to intermediate volcanic rocks of the Persimmon Fork Formation and the basal sedimentary sequence of the Richtex Formation. The Ridgeway South ore body is located around 1500 meters stratigraphically above this boundary, near the contact between the immature sandstone-siltstone turbidites and mafic flows and volcaniclastic units of the basal sequence of the Richtex Formation and the thinly-bedded siltstone-mudstone sediments of the upper Richtex Formation (**Gillon *et al.*, 1995**). Neither ore body is stratabound, but hosted within gently to moderately north-dipping reverse shear zones that cross-cut the subvertical stratigraphy (**Gillon *et al.*, 1995**; **Moye, 2012**). Additionally, ore-grade gold mineralization in both ore bodies is characterized by F-rich, Kspar-stable potassic epithermal alteration and hydrothermal breccias and intimately associated with small volumes of aplite magma in the form of dikes and dikelets (**Martin, 1985**; **Moye, 2012**).

The Haile Mine gold deposit is hosted entirely within the volcanic Persimmon Fork Formation (**Oceanagold, 2017**). The contact with the overlying sedimentary Richtex Formation is located 500 meters southeast of the Haile Mine. The contact dips moderately to the southeast, suggesting that the Haile deposits may be located 200-300 meters below the contact projected into the Haile Mine area.

Discussion

There does not appear to be any geologically valid evidence for precursor late Proterozoic syngenetic exhalative sulfide or gold mineralization in the Ophir District, as proposed by **Klein *et al.* (2007)**. There is no compelling evidence for two separate and distinct gold mineralization events in the district; however, there are two separate and distinct styles of gold mineralization that appear to have formed under similar P-T conditions during a single tectonic event. Variations between these two styles of gold mineralization may be largely related to the character of structural controls and the scale of rock-fluid interactions.

All of the larger Ophir District gold occurrences are hosted by the relatively uniform and homogenous metasedimentary rocks of the Tillery Formation. The host structures and causal hydrothermal fluids for all deposits appear to be associated with the Cherokee Orogeny in the late Ordovician or early Silurian (**Hibbard *et al.*, 2012**). The two styles of gold deposit present in the Ophir District are distinguished by the character and orientation of the host structures and the volume and distribution of hydrothermal alteration and gold mineralization. Differences between deposit types may largely reflect variations in structural controls, hydrothermal fluid composition and volume, and the character of fluid interactions with host rocks.

In all deposits of the Ophir District, where detailed geologic descriptions are available, gold mineralization appears to be synkinematic and synmetamorphic and occurs within reverse faults or shear zones. Mineralization is associated with silicic and phyllic alteration that overprint, and is synkinematic with, a strong penetrative cleavage or foliation. Pyrite is the dominant sulfide and occurs as disseminated grains and cleavage-parallel veins or stringers with or without quartz. The mineralization may be cut and offset by late reverse faults subparallel to the cleavage fabric.

Gold deposits on 025°-trending shear zones

All Ophir District gold deposits appear to be hosted by ductile-brittle reverse faults that dip steeply northwest but strike either 025° or 045°. The 025° oriented structures are typically narrow and occur as single strands (Steel and Eldorado mines) or possibly *en echelon* segments (Griffin and Stafford prospects). Some structures appear to have relatively short strike lengths (Eldorado-Russell Prospect) but the Steel Mine shear zone was reportedly traced for over 1.6 kilometers (**Kerr and Hanna, 1888**). The silicic mineralized zones in these deposits are typically only 2-3 meters thick (**Pardee and Park, 1948**), but at the Steel Mine the lode was locally up to 6 meters thick (**Kerr and Hanna, 1888**). The width of enclosing phyllic and/or chloritic alteration zones is uncertain, but unlikely to have exceeded a few meters.

These gold deposits have characteristics consistent with low-sulfidation orogenic gold deposits that are widespread within the Gold Hill Fault Zone to the west (**LaPoint and Moye, 2012**; **Moye, 2017**). The ore-grade lodes are characterized by tabular or lens-shaped zones of silicic alteration, single or multiple large quartz veins, and swarms or stockworks of quartz + sulfide veins and veinlets. Mineralization is low-sulfide, generally base metal poor, and pyrite-dominated, with gold and silver as the only economic commodities. Like those of the Gold Hill Fault Zone, the lodes of the Ophir District that strike 025° are parallel to the locally developed tectonic fabric and subparallel to the strike of bedding in the adjacent metasedimentary units.

Gold deposits on 045°-trending shear zones

Gold deposits that strike 045° appear to be characterized by multiple parallel siliceous lodes in a zone ranging from 30 meters to 500 meters wide (**Pratt, 1915**; **Pardee and Park, 1948**; **Maddry *et al.*, 1992**). The individual silicic altered ore bodies typically range from 3 meters up to 20 meters thick and may be enclosed within zones of phyllic alteration measuring tens of meters thick with 5% fine-grained pyrite as disseminated grains, bedding-parallel pyritic laminae, and in quartz ± carbonate veins and stringers.

Discussion of structural fabric development and kinematics for Ophir District gold deposits that trend 045° is largely predicated on features documented at the Russell Mine by **Klein *et al.* (2007)**. However, similarities in the relationships among structural fabrics, alteration, and mineralization at similar mines in the district (**Kerr and Hanna, 1888**; **Pratt, 1915**; **Pardee and Park, 1948**) suggest that documented Russell Mine structure (**Pratt, 1915**; **Maddry *et al.*, 1992**; **Klein *et al.*, 2007**) is broadly applicable.

At the Russell Mine, wide zones of pervasive sulfidation and phyllic alteration appear to form at relatively low ductile-brittle strain within the deformation zones, probably synkinematic with initial meso-scale folding. Phyllic alteration is characterized by randomly oriented sericite grains and fine-grained pyrite as random disseminations and as localized, narrow intervals of 20-30 vol% to over 50 vol% fine-grained pyrite parallel to S_0 (**Klein *et al.*, 2007**). These pyritic laminae are described from the hanging wall of the Little Lead and Big Cut ore zones at the Russell Mine (**Klein *et al.*, 2007**), but have not been documented in other deposits.

With increasing reverse shear strain, a spaced cleavage develops along anticlinal axes and intersects bedding (S_0) at angles that vary from acute on the limbs of the anticlines to around 90° near the axes. As anticlines become increasingly appressed at higher strain, a zone of intense penetrative cleavage, characterized by the alignment of sericite and quartz grains (**Klein *et al.*, 2007**), develops within the axial region of the fold. Bedding and conformable pyritic laminae are progressively folded at small scales, offset and dismembered, and transposed into the cleavage fabric (**Klein *et al.*, 2007**). Formation of this penetrative fabric may provide the pathway for ore-grade mineralizing fluids.

The earlier phyllic alteration assemblage is progressively silicified, possibly through hydrothermal leaching, pressure solution, and volume loss, accompanied by formation of numerous cleavage-parallel quartz ± sulfide veinlets (**Klein *et al.*, 2007**). Gold, arsenic, base metals, and molybdenum may be introduced with overgrowth or recrystallization of earlier Type-1 pyrite as Type-2. A late phase of brittle failure results in the formation of reverse faults sub-parallel to the anticline axis that cut across the earlier fabrics, structures, alteration assemblages, and ore bodies (**Klein *et al.*, 2007**). **Klein *et al.* (2007)** suggest a kinematic evolution from dominantly ductile to increasingly brittle strain. The paragenesis of hydrothermal alteration mineral assemblages and gold mineralization is synkinematic with deformation and greenschist facies metamorphism.

Ore grade mineralization in Russell Mine lodes typically extends no more than 100 meters along strike and the host shear zones and anticlines have been traced no more than 100 to 300 meters (**Pratt, 1915**; **Maddry *et al.*, 1992**). Similar multiple ore zones with limited strike length appear to characterize the Coggins-Sallie Coggins Mine area (**Pratt, 1915**; **Pardee and Park, 1948**) and the Riggon Hill Mine (**Maddry *et al.*, 1992**). The character of the deformation zone hosting gold mineralized structures at the Russell Mine is poorly constrained. It is characterized by multiple SE-verging, meso-scale folds and reverse faults within a zone 500 meters wide that has only been traced along strike for 300 meters.

The Coggins Mine deformation zone has a similarly limited strike length of around 300 meters. The mineralized portion of the zone is about 100 meters long and up to 20 meters wide, but narrows rapidly to 1-2 meters wide to the northeast and southwest. Both the Russell and Coggins deformation zones appear to be distinctly discontinuous and lensoidal.

Comparing and contrasting the two styles of Au mineralization

A significant difference between the 045° oriented gold lodes (Russell-type) and 025° oriented deposits (Steel-type) of the Ophir District is the volume of rock that has been hydrothermally altered and sulfidized; typically 3-6 meters wide in the Steel-type deposits, but tens of meters wide and often in multiple parallel zones in Russell-type deposits.

In Russell type deposits, the presence of a more complex reverse shear structure consisting of multiple shear strands with associated appressed anticlines, combined with their orientation at a 20° angle to the dominant strike and tectonic fabric of the host rocks, may result in development of a much larger ductile-brittle damage zone with more pervasive fluid-rock interactions.

The often voluminous phyllic assemblage of quartz + sericite + pyrite in Russell-type deposits forms by pervasive sulfidation and low-pH hydrothermal leaching of the host Tillery Formation metasediments, composed of quartz + feldspar + sericite + chlorite + carbonate (**Stromquist and Sundelius, 1969**). Feldspar and chlorite are altered to sericite, apparently with the introduction of K^+, while Ca, Na, and Mg are largely removed. Available Fe (in chlorite, carbonate, and detrital Fe-Ti oxides) is converted to sulfides, largely pyrite (Type-1). Minor carbonate may remain as a component of the phyllic assemblage, both as disseminated grains and in early-formed quartz veins.

The 045° orientation of Russell type deposits in the Ophir District is similar to the orientation of 2nd and 3rd order parasitic folds to the north and south of the area (**Conley, 1962**, Seiders 1981, **Stromquist and Henderson, 1985**). This suggests the possibility of localized structural inheritance, with Russell-type reverse shear zones developed as modifications of existing 2nd or 3rd order anticlines through reverse shear compression during the later phases of the Cherokee Orogeny (**Hibbard *et al.*, 2012**). This may be synchronous with overprinting, dismembering, and transposing of 1st and lower-order folds in the Albemarle Sequence by development of the Gold Hill Fault Zone to the west (**Hibbard *et al.*, 2012**).

Comparison with similar gold deposits of the Carolina Terrane

The nature of structural controls, the character and volume of hydrothermal alteration, and the style of gold mineralization at the Russell Mine and Coggins Mine are similar to those of the Au-Ag-As deposits of the Sawyer-Keystone alignment to the northwestern Randolph County, North Carolina (**LaPoint and Moye, 2012**). These include the historic Lofflin, Jones-Keystone, Sawyer, and New Sawyer deposits. This low sulfide, base metal poor, disseminated and stringer pyrite-dominated mineralization occurs in multiple intervals of silicic alteration enclosed by phyllic alteration in zones tens to hundreds of meters wide.

The deposits are hosted by discontinuous deformation zones characterized by reverse or oblique shear zones and meso-scale folds along a 21 kilometers long zone that trends 065°. **Pratt (1907)** noted the similarity of silicic alteration of the Miller Vein of the Sawyer Mine to the ore zone in the Big Cut at the Russell Mine. The Sawyer-Keystone structural trend cuts across the stratigraphy of the Albemarle Group and large-scale first-order folds formed during the early phases of the Cherokee Orogeny (**Hibbard *et al.*, 2012**) and may be associated with a younger generation of 2nd or 3rd order anticlines and synclines.

The gold deposits of the Sawyer-Keystone Trend are distinctly different from the low-sulfidation orogenic gold lodes present along the Gold Hill Fault Zone to the west. However, both appear to be associated with deformation and metallogeny in the late Ordovician to early

Silurian. The same appears to be true for both the Russell-type and Steel-type gold deposits of the Ophir District.

How many ore fluids?

There is evidence that multiple ore-forming fluids may have been involved in formation of the gold deposits of the Ophir District. Some orogenic lode gold deposits (Steel-type) show possible evidence of at least two separate and distinct mineralizing fluids.

Fracture-controlled, gold-rich stringer veins of galena, sphalerite, chalcopyrite, and pyrite appear to post-date silicic-phyllic alteration and quartz vein formation at the Steel Mine (**Kerr and Hanna, 1888**; **Pardee and Park, 1948**), the Sallie Coggins Mine (**Pardee and Park, 1948**), and the Henderson (Eldorado) Prospect (**Carpenter, 1976**). This may suggest the presence of two mineralizing fluids. The earlier dominant, more voluminous fluid, associated with formation of phyllic and silicic alteration and lower-grade gold mineralization, may be low-salinity, near-neutral pH, H_2O-$CO_2 \pm CH_4$ fluids typical of orogenic gold mineralization (**Groves *et al.*, 1998**). A second fluid, associated with the formation of gold + base metal sulfide veins and stringers, could be low-volume saline brines strongly enriched in these elements. However, there is no published data available to support this suggestion.

Klein *et al.* (2007) report the presence of pyrrhotite, chalcopyrite, sphalerite, and trace arsenopyrite intergrown with Stage-1 pyrite at the Russell Mine; and chalcopyrite and, less commonly, aggregated pyrrhotite with arsenopyrite, cobaltite, galena, and sphalerite occur as inclusions in ore stage (Stage-2) pyrite. This suggests that a single mineralizing fluid was involved with no separate base metal sulfide-rich phase.

The ore-forming fluids involved in the formation of Russell-type gold deposits may be distinct from those responsible for typical orogenic gold deposits. They may be more highly enriched in sulfur (H_2S), resulting in lower pH conditions of alteration, and contain geochemically significant arsenic in addition to minor base metals and rare Mo. The character, composition, and source of these fluids in both the Ophir District and the Sawyer-Keystone Trend to the north are poorly constrained.

Conclusions

Like the low-grade, large tonnage, phyllic-silicic alteration dominated Au-Ag-As deposits of the Sawyer-Keystone Trend in northwest Randolph County, the Russell-type Au-Ag-As deposits of the Ophir District appear to have formed synkinematic and synmetamorphic with the later phases of deformation associated with the Cherokee Orogeny in the late Ordovician to early Silurian (**Hibbard *et al.*, 2012**). The Russell and Coggins deposits appear to have formed under similar P-T conditions to typical low-sulfidation orogenic gold deposits such as the Steel Mine. Both deposit types appear to fit within the diverse spectrum of orogenic gold deposits (**Groves *et al.*, 1998**; **Geoscience Australia, 2018**).

The absence of features indicative of formation at shallow crustal depths suggests that both Russell-type and Steel-type orogenic gold deposits can be classified within the mesozonal subtype of orogenic gold deposits proposed by **Groves *et al.* (1998)**, formed at depths of 6-12 kilometers and at temperatures of 300°-475°C. The Russell-type and Steel-type gold deposits of the Ophir District appear to have formed at the lower P-T end of this range under lower greenschist facies metamorphic conditions.

The distinctive character of the Russell and Sawyer-type orogenic gold deposits of the Carolina Terrane in North Carolina may be related to the development, under reverse shear strain, of broad zones of penetrative cleavage axial to appressed meso-scale anticlines. The cleavage provides stockwork pathways for hydrothermal fluids that distribute heterogeneous fluid flow across a large volume of host lithology, maximizing fluid-rock interaction and resulting in pervasive sulfidation and phyllic and silicic alteration over intervals tens to hundreds of meters wide.

Pyrite formation through sulfidation may be an important mechanism in gold deposition, and much of the gold budget in Russell-type primary sulfide ore may be contained in pyrite, either in stoichiometric content or as microscopic inclusions. The dominant Fe-bearing minerals available for sulfidation in the Tillery Formation are chlorite, Fe-bearing carbonate species, and possibly detrital Fe-Ti oxides in the coarser-grained basal portion of graded turbidite beds.

If formation of bedding-parallel pyritic laminae in phyllic alteration zones at the Russell Mine was similar to that in the North and South ore bodies of the Kennecott Ridgeway Au-Ag-As-Mo deposit in South Carolina (**Moye, 2012**), then this generation of pyrite (Type-1) should be intimately associated with fine-grained rutile. Adequate petrographic analysis to test this hypothesis is not available in the work of **Klein *et al.* (2007)**. This initial phase of pyrite formation in complex paragenesis of the Ridgeway ore bodies precedes the gold mineralizing event (**Moye, 2012**). Gold mineralization associated with early Type-1 pyrite at the Russell Mine deposit cannot be demonstrated from available data.

Initial phyllic alteration, sulfidation, and pyrite formation at both the Russell Mine (**Klein *et al.*, 2007**) and the North and South ore bodies of the Kennecott Ridgeway deposit (**Moye, 2012**) occurred at relatively low initial ductile-brittle strain. In both the Russell and Kennecott Ridgeway deposits, development of a heterogeneous spaced cleavage fabric axial to meso-scale folds provided a stockwork of fluid pathways while largely preserving bedding and protolith textures in the host metasedimentary rocks.

The siliceous gold ore bodies of the Russell and Coggins deposits formed in zones of progressively intense penetrative cleavage and reverse shear development that overprinted phyllic alteration assemblages accompanying increasingly brittle-dominated strain. These shear zones are typically axial to increasingly appressed asymmetric meso-scale anticlines in the Russell Mine lodes. Swarms or stockworks of minor reverse displacement structures provided higher volume fluid pathways, distinguished by more intense silicic alteration, destruction of protolith textures, and higher-grade gold mineralization.

Pyrite in bedding-parallel laminae and early quartz-carbonate veins is deformed, transposed, and remobilized into the cleavage fabric, providing a platform for the deposition of gold and associated pathfinder elements from the hydrothermal fluids. The same structural evolution and progression of hydrothermal alteration and mineralization is observed in the Kennecott Ridgeway North and South ore bodies in South Carolina (**Moye, 2012**)

The large volumes of auriferous phyllic and silicic alteration in Russell/Sawyer-type gold deposits contrasts strongly with the narrow zones of dominantly silicic alteration in Gold Hill-type low-sulfidation orogenic gold deposits. Because a large volume of host lithology is pervasively sulfidized in Russell/Sawyer-type orogenic gold deposits, total contained sulfur (as sulfide, dominantly pyrite), may be 1-2 orders of magnitude higher than in typical orogenic gold deposits. This abundance of sulfur may indicate a more strongly S-enriched fluid, higher sulfur activity, or possibly more sustained fluid flow through a large volume of rock at a high fluid/rock ratio.

The combination of intense fabric development over broad intervals and ~5% fine-grained disseminated pyrite makes Sawyer-Russell type gold deposits highly susceptible to supergene oxidation and weathering enhanced by acid leaching to the depth of the local water table. This process, combined with the long history weathering under temperate climatic conditions in the Southeaster Piedmont of the USA, has resulted in the formation of large volumes of generally low-grade but easily mined and free-milling gold ore.

Additionally, broad intervals (10-30 meters) of moderate to low Au grade (0.05-0.20 oz/t) primary sulfide ore in the Big Cut lode locally contains narrow (3-meters) high-grade intervals (>2.5 oz/t Au) that add significantly to the Au resource total (**Maddry *et al.*, 1992**). The distribution of these lensoidal high-grade shoots, the focus of underground stoping below the open cut workings at the Russell Mine, is unpredictable and unlikely to be effectively defined by widely-spaced drill holes.

The total gold resource of around 350,000 oz Au quoted by **Maddry *et al.* (1992)** for the Russell Mine is largely based on drill holes through the Big Cut and Little Lead ore bodies to a depth of 150 meters, but there appears to be no significant exploration of the possible down-plunge extension of the ore bodies to the northeast (**Figure 11**). The Lower Zone of the Big Cut ore body remains open in all directions (**Maddry *et al.*, 1992**) and the remaining Russell Mine leads to the southeast are under-explored. The total Au resource of the combined Russell Mine ore bodies may approach 500,000 ounces.

Finally, narrow zones of bonanza-grade mineralization (>100 oz/t Au) are present at the Steel Mine (**Kerr and Hanna, 1888**; **Pardee and Park, 1948**) and reported from the lowest level of the Coggins Mine (**Pratt, 1915**), suggesting the possible presence of very high-grade feeder zones that could represent viable underground targets.

Understanding the character, controls, and economic potential of Russell-type deposits in the Ophir District and similar gold deposits of the Sawyer-Keystone Trend in Randolph County provides a better defined ore deposit model to aid effective exploration and evaluation strategies for precious metal exploration in central North Carolina and other parts of the Carolina Terrane.

The Henty Gold Deposit, Tasmania – a distant relation?

The Russell-Sawyer type Au-Ag-As deposits of the Carolina Terrane in North Carolina may be part of a diverse group of shallow mesozonal to deep epizonal gold deposits that combine features of orogenic and high- and low-sulfidation epithermal styles of mineralization. Orogenic features include strong structural controls and mineralization synkinematic and synmetamorphic with compressive tectonism under ductile-brittle to brittle conditions.

High-sulfidation epithermal features (**White and Hedenquist, 1995**) include:

- Large volumes of intense phyllic-silicic alteration (low pH fluids).
- Dominantly disseminated and replacement styles of mineralization with well-defined veins subordinate.
- No evidence of boiling.
- Trace elements often include Au-Ag-Mo-As-Pb-Cu-Bi-Te-Se.

Low-sulfidation epithermal features (**White and Hedenquist, 1995**) include:

- Absence of advanced argillic and vuggy quartz alteration.
- No typical high sulfidation indicator minerals (enargite).
- Carbonate gangue association.

Studies of these deposits commonly engender widely divergent theories of genesis, often divided between structurally modified syngenetic and structurally controlled epigenetic variations. Examples of these enigmatic deposits include the giant Hemlo gold deposits of Ontario, Canada; the Ridgeway and Haile deposits of South Carolina in the USA; the enormous Sukhoi Log deposit of Siberia, Russia; and the Henty Gold Mine deposit in Tasmania, Australia.

The Henty gold deposit in western Tasmania is hosted by the Cambrian-age Mount Read Volcanics (**Figure 19**). The Mount Read Volcanic Belt is an arcuate domain, 20 kilometers wide and approximately 200 kilometers long, of extension-related submarine and subaerial rhyolitic to basaltic lavas, intrusions, and volcaniclastic and epiclastic units (**Figure 19**). The Mount Read Volcanics host four major VMS deposits; including Hellyer (Cu-Pb-Zn), Que River (Cu-Pb-Zn-Au), Rosebery (Zn-Au-Cu), and Hercules (Zn-Au-Cu), in addition to numerous small prospects. The belt also hosts the large Mount Lyell (Cu-Au) high-sulfidation epithermal deposit and the Henty Gold deposit (**Figure 19**).

The Henty Mine ore bodies are a series of small tonnage (<500,000 t) high-grade (10-30 g/t or 0.29-0.88 oz/t Au), subvertical flattened lenses of often intensely silicic mineralization that each contain <15,000 to 300,000 ounces of gold (**Figure 20, Figure 21**). The ore bodies typically measure around 200-500 meters along strike, 100-150 meters down dip, and are 2-20 meters thick. The distribution of these lenses may be *en echelon* along strike and in the plane of dip.

The silicic ore bodies are enclosed by a subvertical, tabular zone of phyllic altered volcaniclastic and epiclastic sedimentary rocks 10-100 meters thick (**Figure 20**) with a strike length of over 3000 meters (**Callaghan, 2001**). The alteration zone has a strongly developed penetrative cleavage and distinctly asymmetric alteration zonation, with contrasting hanging wall and footwall mineral assemblages (**Callaghan, 2001**). The silicic to siliceous-phyllic ore zones are variably sheared, mylonitic, and brecciated with sulfides often remobilized into cross-cutting veins and stringers, possibly the result of deformation during the Devonian (**Callaghan, 2001**). Footwall alteration is dominated by sericite + quartz ± pyrite ± carbonate assemblages, and hanging wall alteration is pervasive albite-quartz and albite-quartz-chlorite (**Lintner, 2006**).

The Henty alteration zone cross-cuts stratigraphy in the Cambrian age Mount Read Volcanics at an acute angle, and is adjacent to the regional scale, large-offset Henty Fault (**Callaghan, 2001**). The Henty Fault originated as an east-directed accretion-related thrust in the Cambro-Ordovician, with reverse and sinistral strike-slip reactivation during the Devonian (**Berry, 1989**). Formation of the Henty gold deposit appears to be associated with proximity to the major fault zone, the contact between two lithologic sequences (the Central Volcanic Complex and the Tyndall Group), and a meso-scale bend in stratigraphy where it is dragged into the orientation of the Henty Fault. Individual ore bodies are of limited extent along strike and dip, the structural-stratigraphic corridor hosting the Henty Mine ore bodies has a limited vertical extent, and the corridor plunges to the south. Deeper ore bodies cannot be predicted from surface structure and geochemistry.

Sulfide mineralization in the silicic and silicic-phyllic ore zones consists of pyrite and chalcopyrite, subordinate galena and sphalerite, and minor gold, electrum, galeno-bismuth, and native bismuth. Sulfide in the peripheral quartz-sericite-chlorite alteration halo is dominantly pyrite. Sericite-rich ore zone and footwall alteration are strongly enriched in K^+. Ore bodies are composed of 30-70% quartz, 5-20% carbonate, 1-10% sericite, and 0.1-1.0% sulfides (**Callaghan, 2001**). Phyllic alteration consists of 30-40% quartz, 15-20% sericite, 1-5% carbonate, and 0.1-5% sulfides.

LA-ICPMS pyrite analyses (**Sebastian Meffre, 2013, personal communication**) suggest that formation of the Henty gold mineralization is the result of an early Paleozoic hydrothermal event with little remobilization or overprinting at the deposit scale during subsequent tectonic events. However, individual ore bodies were structurally modified during Devonian tectonism and reactivation of the Henty Fault (**Sebastian Meffre, 2013, personal communication**). The trace element association for the ore-grade mineralization is Au-Ag-As-Bi-Te-Tl-Se.

The presence of elevated P in whole-rock analyses of the ore zone (**Meffre, 2013, personal communication**), combined with the presence of fine-grained apatite and quartz-pyrite-apatite veinlets on fractures (**Lintner, 2006**) and fluorite on Devonian shears cutting the ore zone, suggest the presence of geochemically elevated fluorine as disseminated fluorapatite in the primary hydrothermal assemblage. Other F-bearing phases, especially micas, may also be present.

Callaghan (2001) suggests the interaction of two fluids in the formation of the Henty gold deposit; a higher temperature (350°C) fluid of magmatic hydrothermal origin (δ13C =–5‰ and δ18O = 5.5‰) and a lower temperature fluid (100° to 250°C). Although **Callaghan (2001)** suggests modified seawater for the second fluid, a metamorphogenic fluid formed under greenschist facies PT conditions is a more likely candidate.

While many published research papers suggest a structurally modified syngenetic exhalative origin for the Henty Mine gold mineralization (**Findlay, 1998**; **Callaghan, 2001**; **Lintner, 2006**), the Henty Gold Mine geology staff interprets the deposit as shear zone hosted epigenetic mineralization (**Lorrigan, 2013**) associated with accretion-related Cambrian tectonism and subsequently heterogeneously modified structurally during Devonian tectonism.

The general structural controls, alteration assemblages, and metallic ore and trace element character of the Russell and Sawyer-type Au-Ag-As deposits of the Carolina Terrane in North Carolina are similar to those for the Henty Gold Mine deposit in Tasmania, Australia. This deposit type is not well represented in the literature and is commonly misinterpreted as some form of fortuitous structural modification of stratabound exhalative gold mineralization. Like the Russell and Sawyer-type deposits of the Carolina Terrane, the Henty Gold Mine deposit in the Mount Reed Volcanic Belt occurs in a volcanic-sedimentary sequence that also hosts VMS deposits, similar to those of the Gold Hill and Silver Hill districts of North Carolina, and the large Mount Lyell (Cu-Au) high-sulfidation epithermal deposit, possibly similar to the Brewer Mine deposit in South Carolina.

A better understanding of the character and genesis of the Russell-Sawyer type gold deposits of the Carolina Terrane, especially in the context of associated tectonism, may help to clarify and better define the extensive global catalogue of idiosyncratic syntectonic gold deposits that do not neatly fit into existing models. Major differences among these deposits may relate to the relative proportion of fluids in their genesis sourced from felsic magmatic reservoirs and from metamorphogenic fluids. Higher igneous fluid contributions may be indicated by higher-temperatures of formation relative to their host rocks and significant concentrations of trace elements that include F, Mo, Bi, and Te. This end of the spectrum may overlap or be continuous with Intrusion (Granite)-Related gold deposits. The Russell-Sawyer type deposits of the Carolina Terrane may have formed from on the other end of the spectrum from dominantly dilute metamorphogenic fluids with little or no igneous contribution.

The important point is that all of these diverse deposits appear to have formed under compressional synkinematic strain under shallow mesozonal to deep epizonal conditions. They appear to be typically associated with reverse or thrust faults and are characterized by strongly zoned pervasive phyllic and silicic alteration of large volumes of typically epiclastic host rocks; deposit-scale enrichment in silica, alumina, titanium (as rutile), and potassium; and are typically low total sulfide with pyrite dominant. Mineralization is typically disseminated to stockwork veining with ore-grade gold present as indefinite shoots and lenses in a larger volume of low-grade mineralization. Gold is typically stoichiometric in sulfides or very fine-grained.

It is worth noting that the limited strike and dip extent of the Russell Mine ore bodies and host structures could be analogous to the narrow, plunging structural corridor hosting the individual ore bodies of the Henty Mine Deposits (**Figure 21**). Continuity of the Russell structures down-plunge along a corridor of limited width and vertical height would be difficult to confirm from surface structural or geochemical data. Additional *en echelon* ore bodies at the Russell deposit may exist at depth to the northeast, but an extensive deep drilling program would be required to confirm that possibility. The same potential may exist for the similar gold deposits of the Sawyer-Keystone Trend in northwest Randolph County, North Carolina.

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Figure 1. Location and regional geologic setting of the Ophir District within the Albemarle Sequence of the Carolina Terrane in central North Carolina.

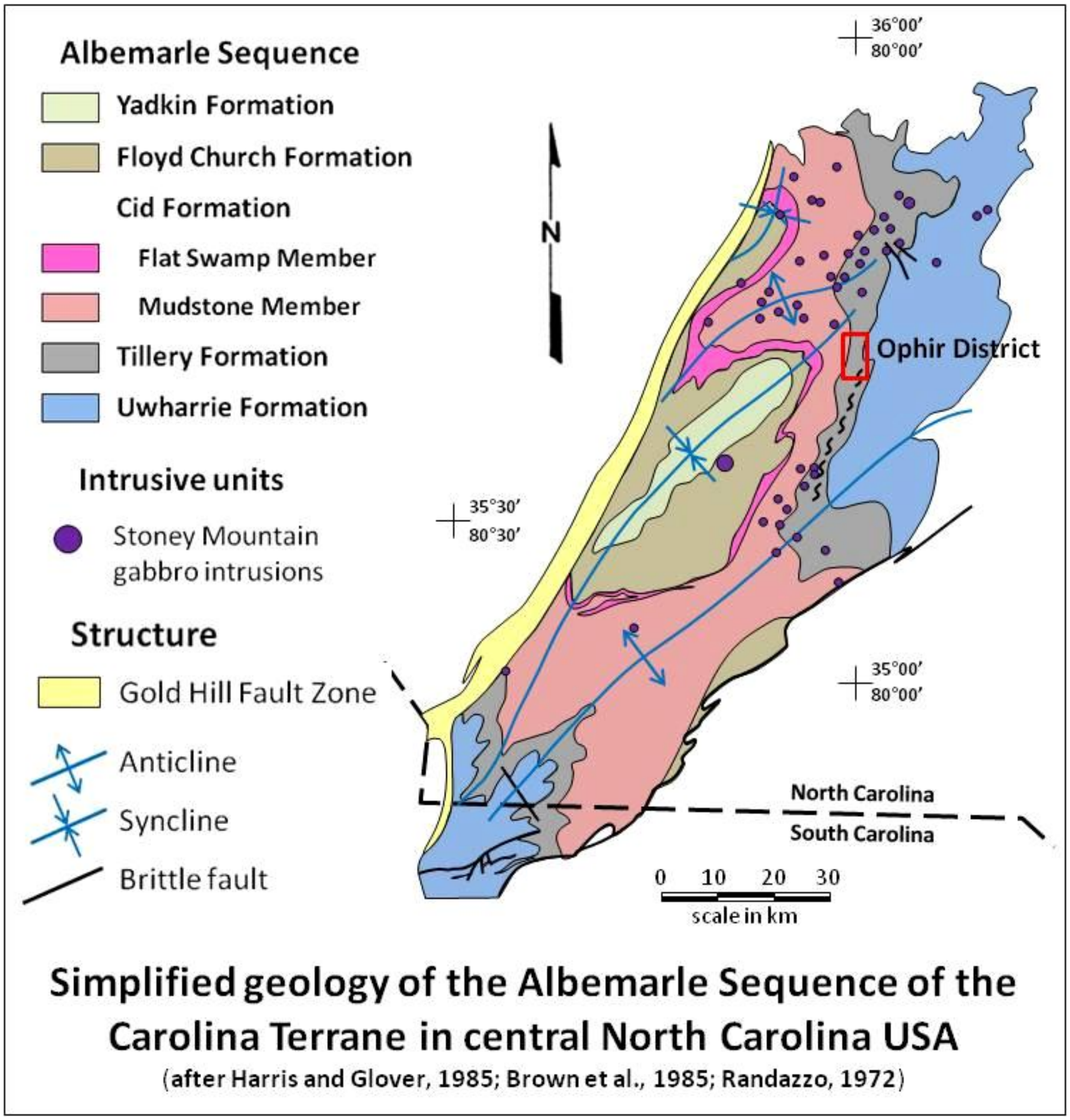


Figure 2. Location and local geologic setting of the Ophir District in northwest Montgomery and southern Randolph counties, North Carolina.

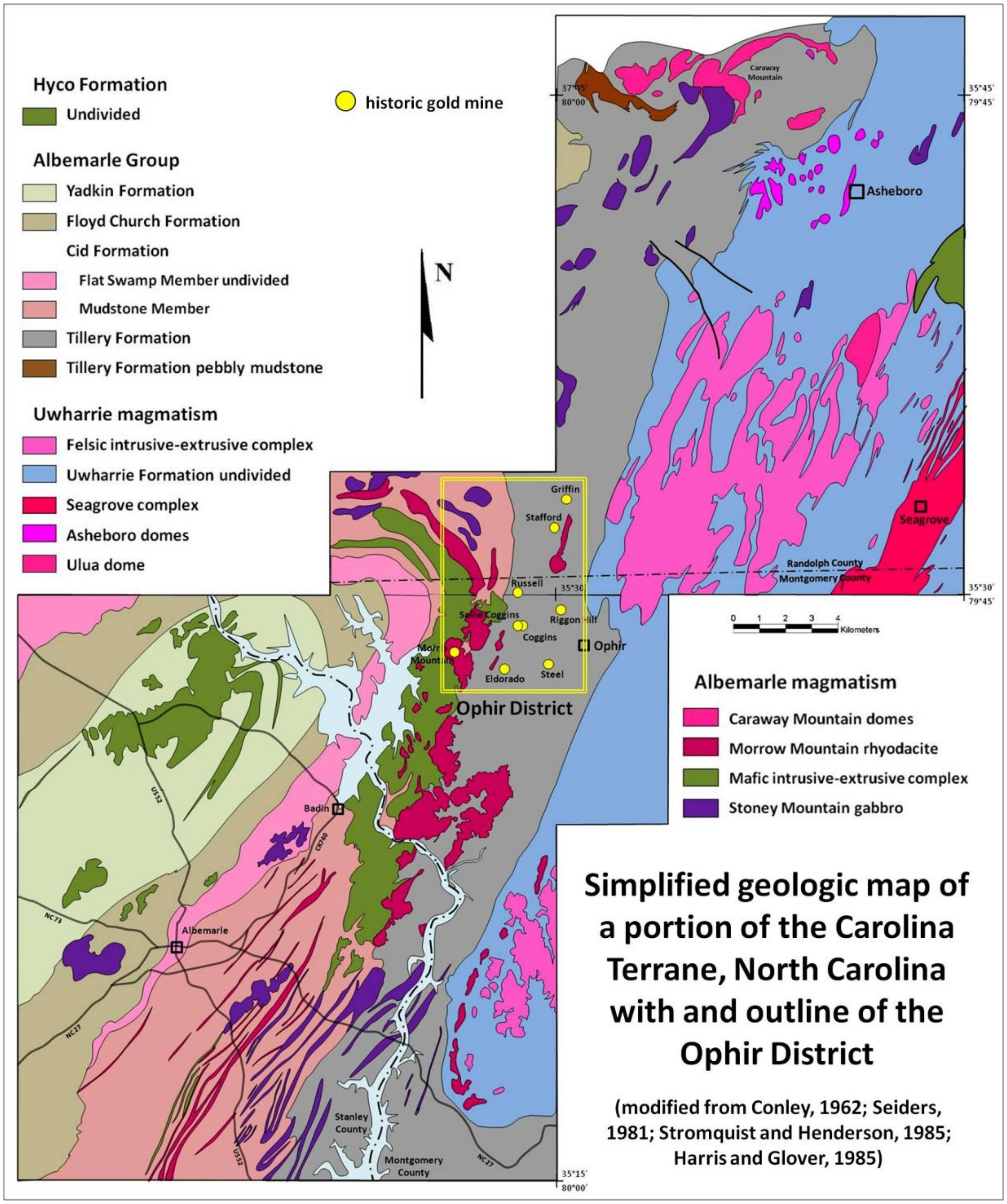


Figure 3. Historic gold mines of the Ophir District.

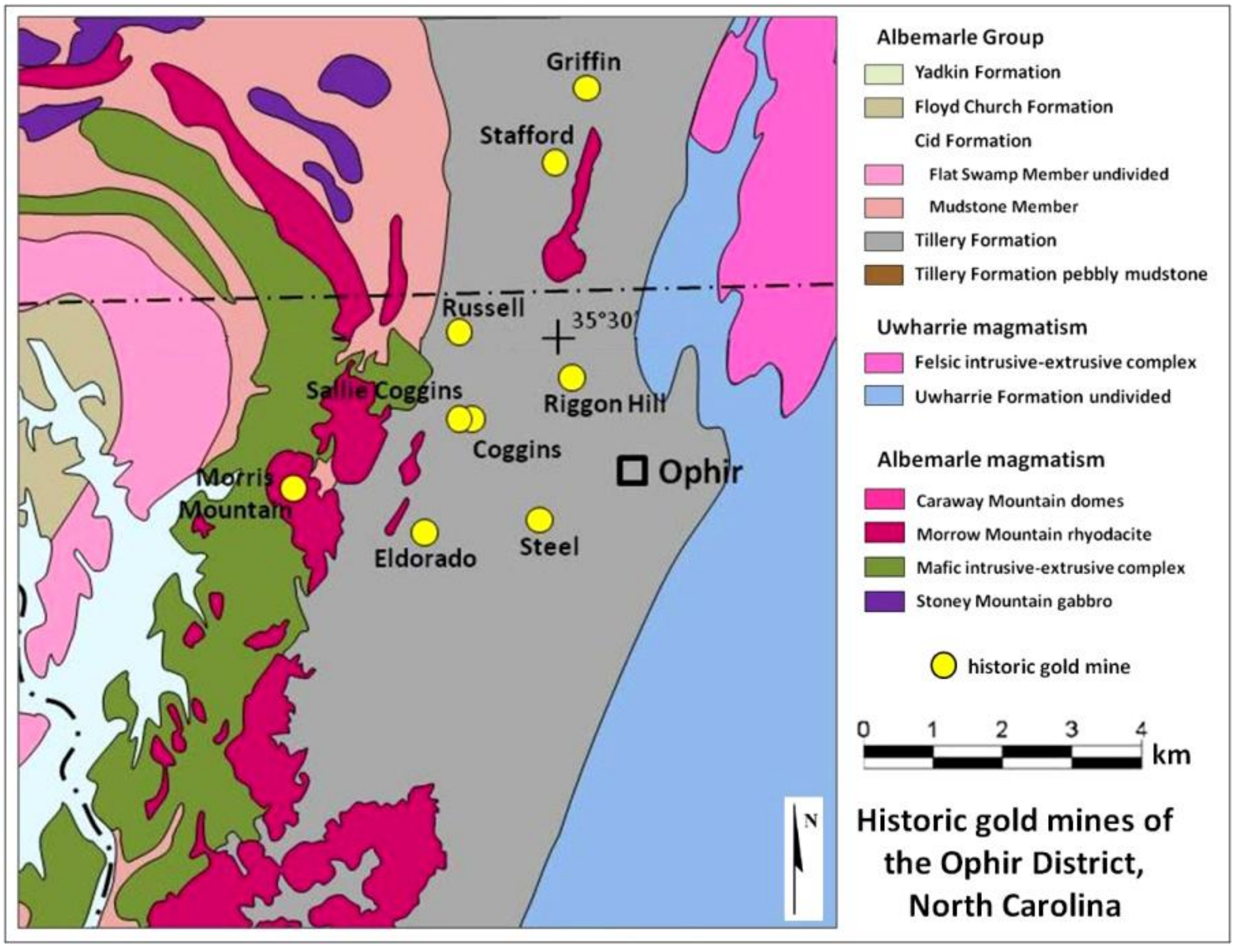


Figure 4. Structural elements present in the Ophir District area of the Carolina Terrane in central North Carolina. The dominant elements are NNE-striking shear zones and NE-striking meso-scale folds. Note a possible step-over in the contact between the Albemarle and Tillery formations just north of the town of Ophir.

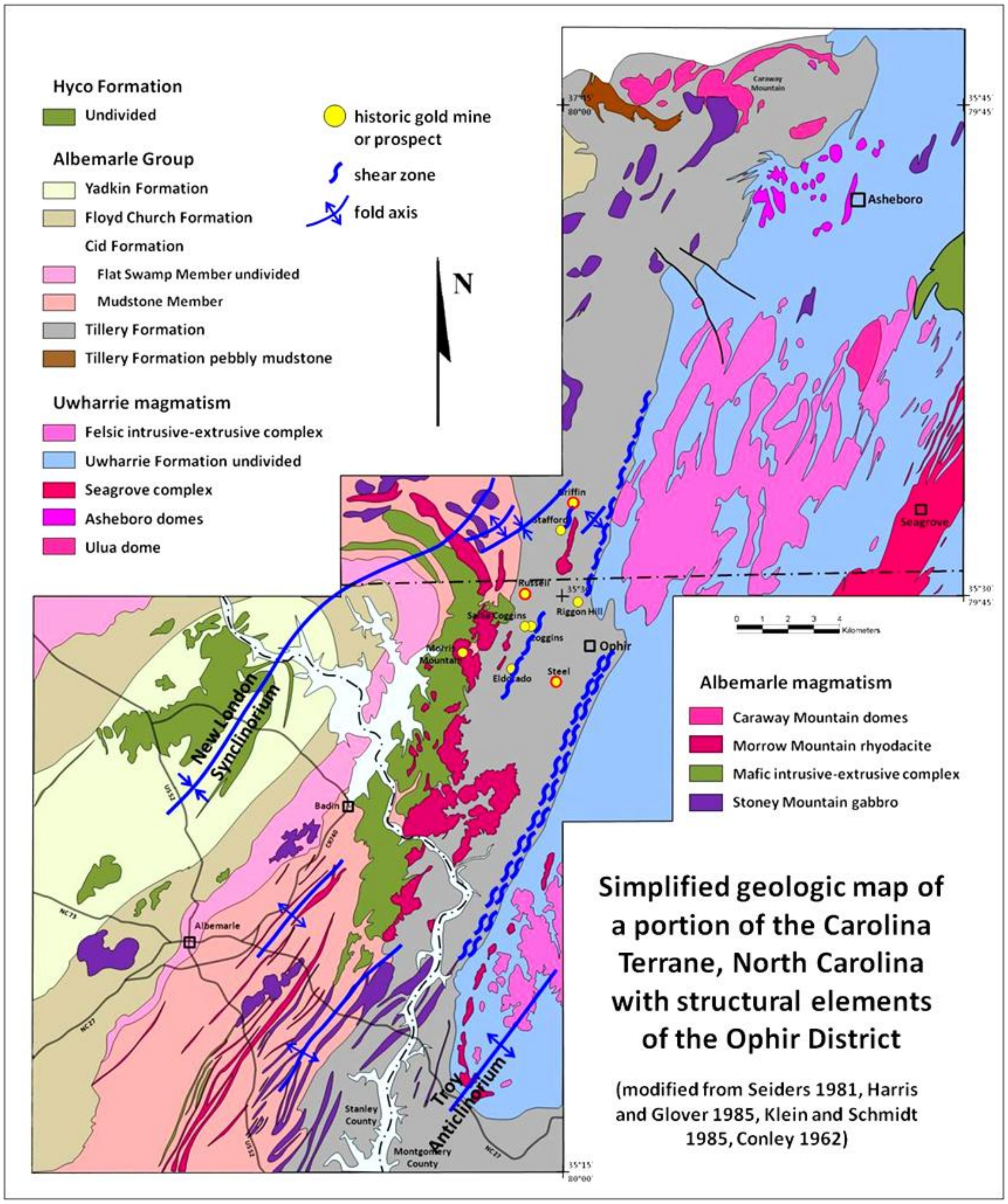


Figure 5. Possible boundaries of Ophir deformation zone, which appears largely restricted to the Tillery Formation on the western limb of the Troy Anticlinorium.

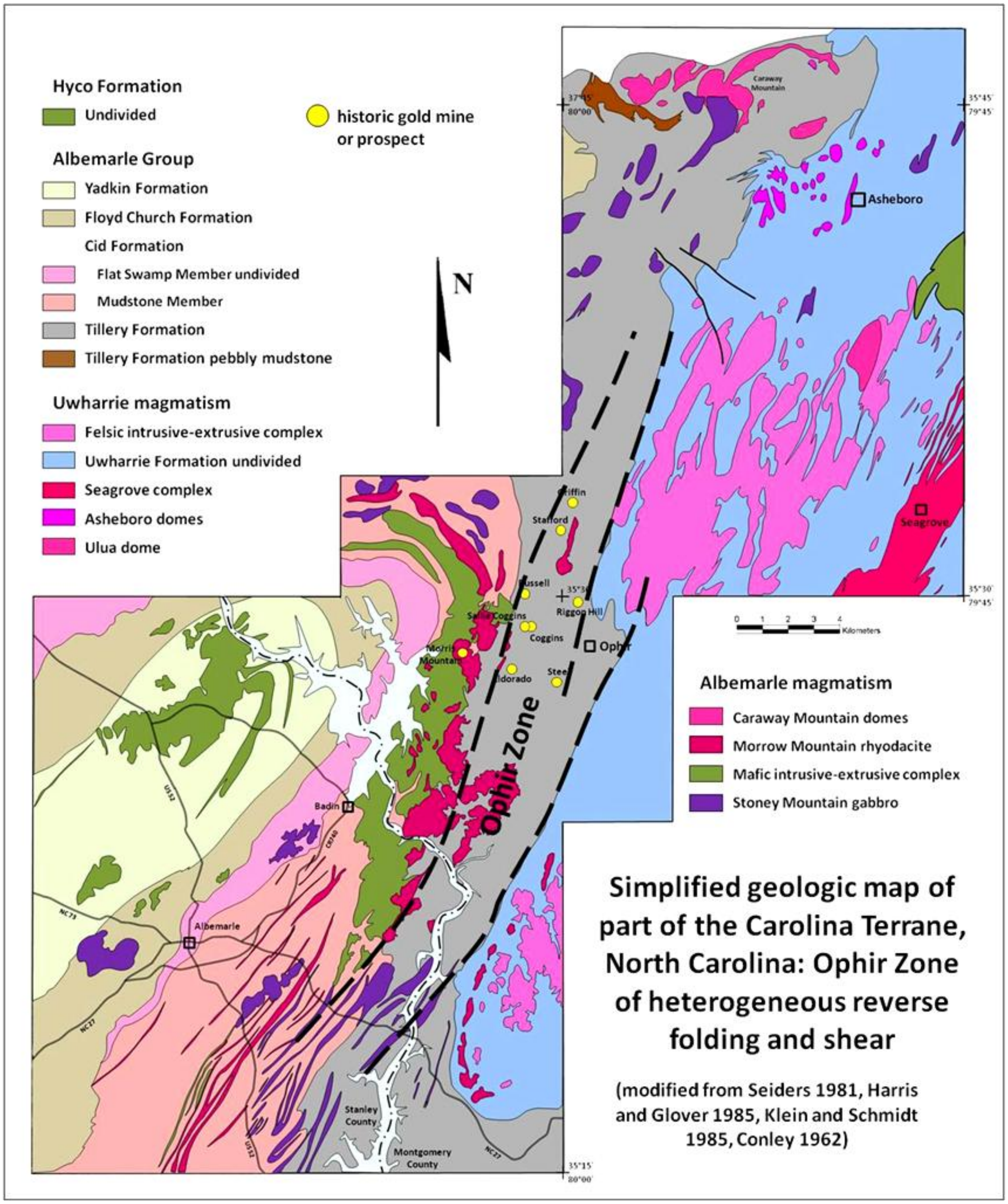
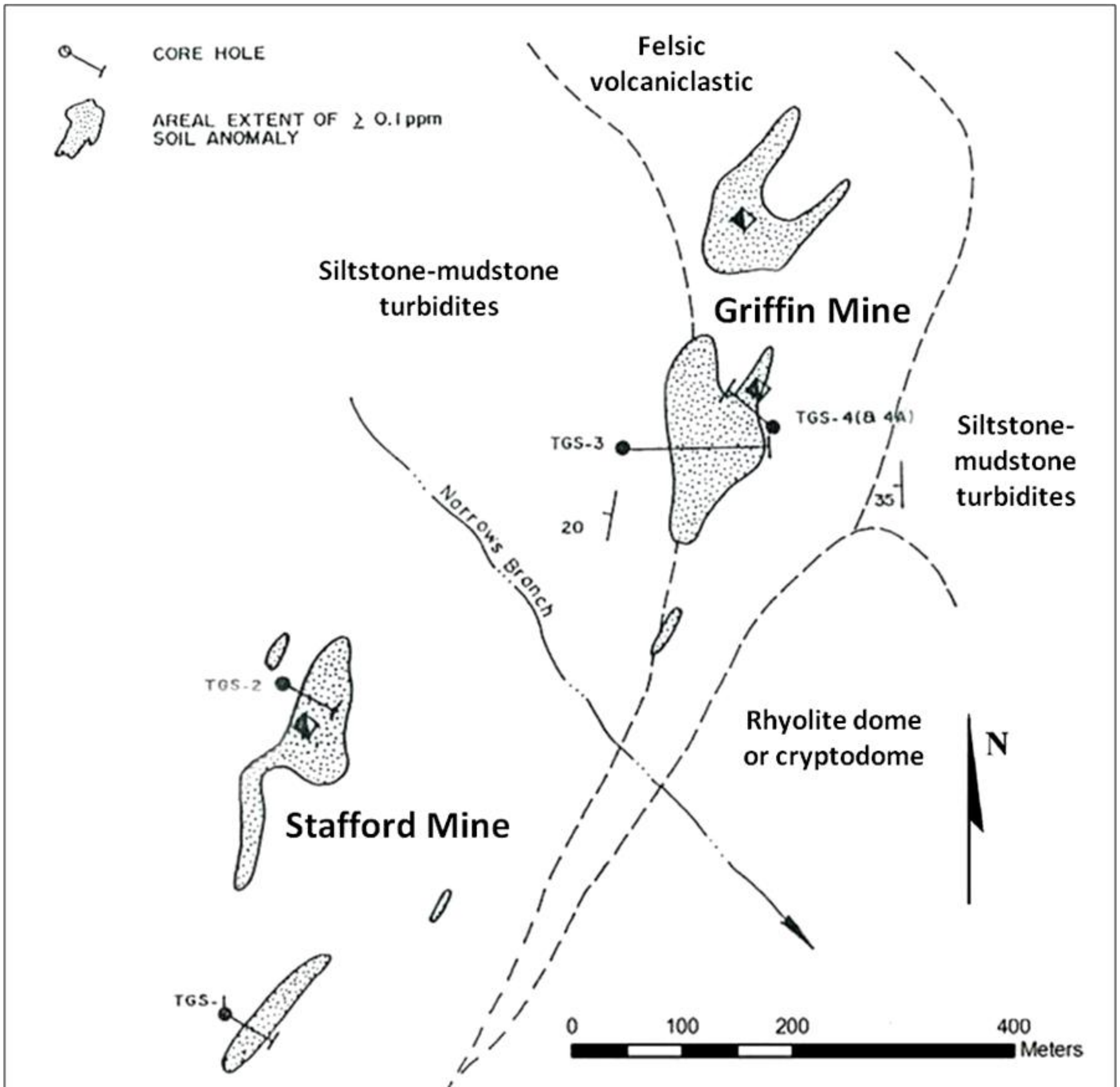


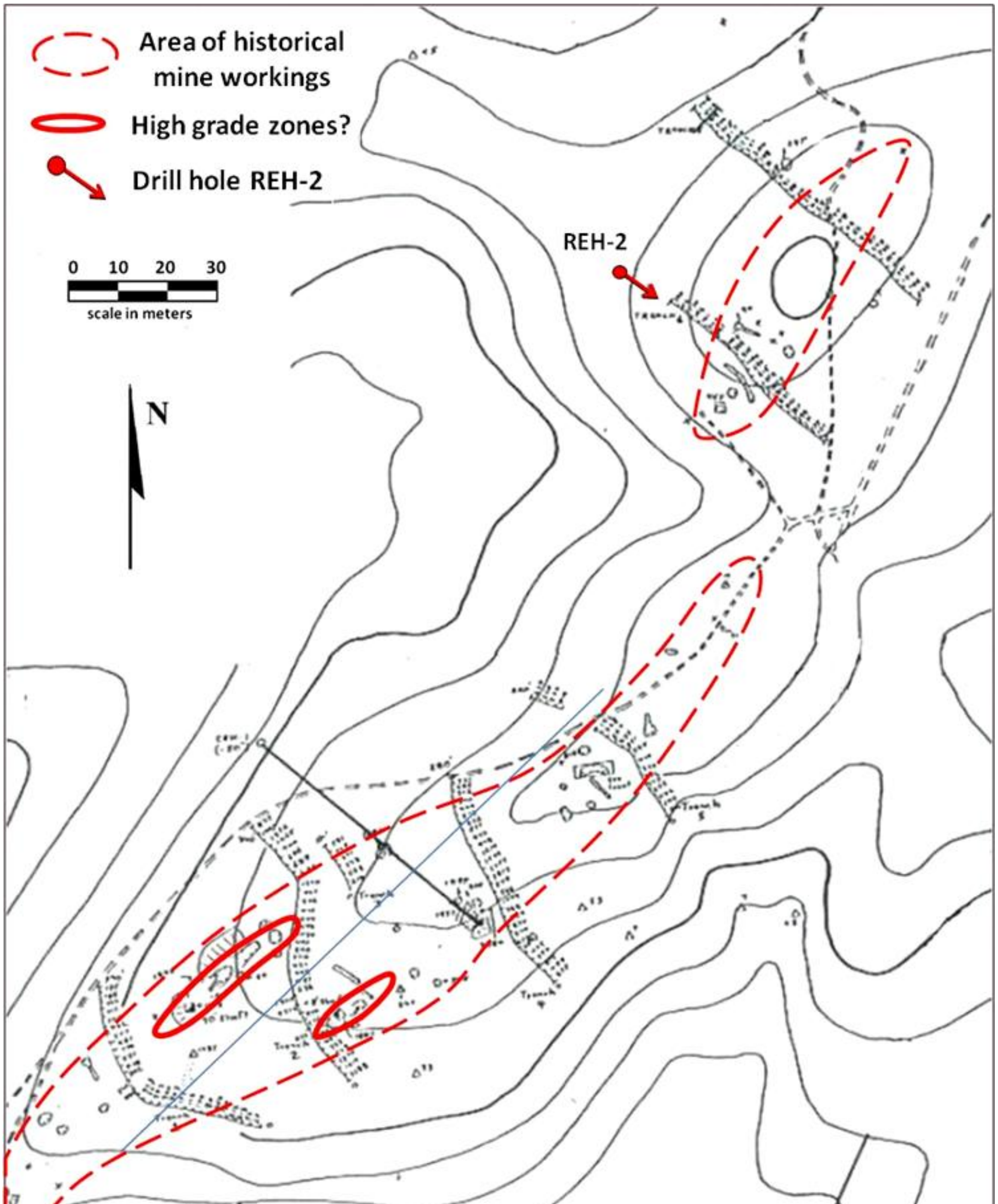
Figure 6. Griffin and Stafford prospects in the Ophir District (modified from **Maddry *et al.*, 1992**). Although possibly formed along *en echelon* shear zones, the two prospects are hosted by very different rock types.



Griffin and Stafford prospects, Randolph County, NC geology, soil gold anomalies, and core holes

(modified from Maddry *et al.*, 1992 after Tenneco Minerals)

Figure 7. East Riggon Hill Mine in the Ophir District (modified from **Maddry *et al.*, 1992**). Historical workings suggest the presence of discrete lenses of higher-grade gold within the broader zone of mineralization.



Riggon Hill East, Ophir District, Montgomery County, NC
Historic workings, exploration trenches, and core holes
(modified from Maddry *et al.*, 1992)

Figure 8. Mineralized lodes at the Russell Mine (modified from **Klein *et al.*, 2007**), typically located along the axis of a reverse faulted appressed meso-scale anticline overturned to the southeast. Work by **Klein *et al.* (2007)** suggests that an unmineralized anticline is present north of the Palmer Workings.

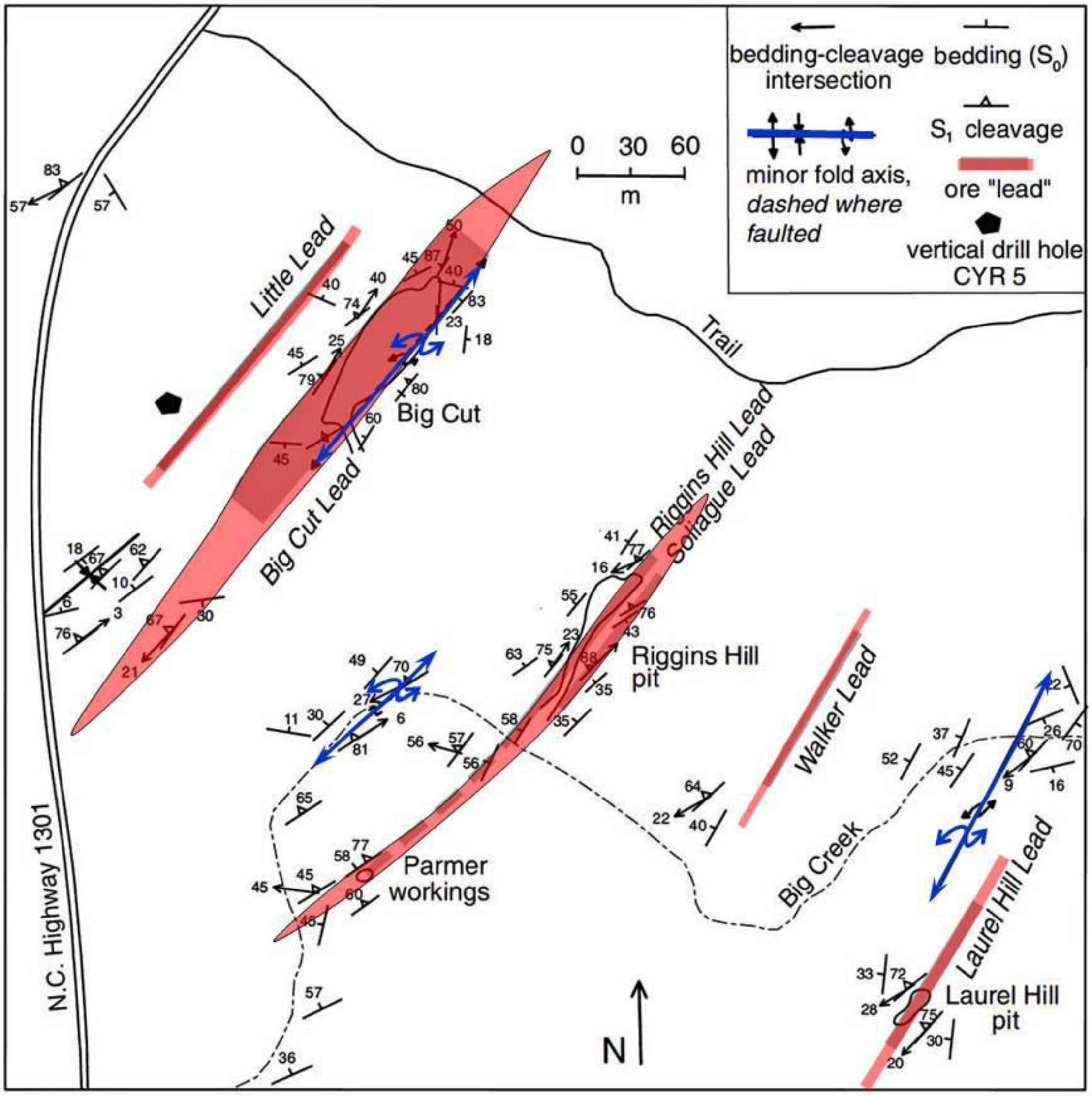


Figure 9. Mine workings at the Russell Mine (**Pratt, 1915**), illustrating the limited area of ore-grade gold relative to the extent of the mineralized zone.

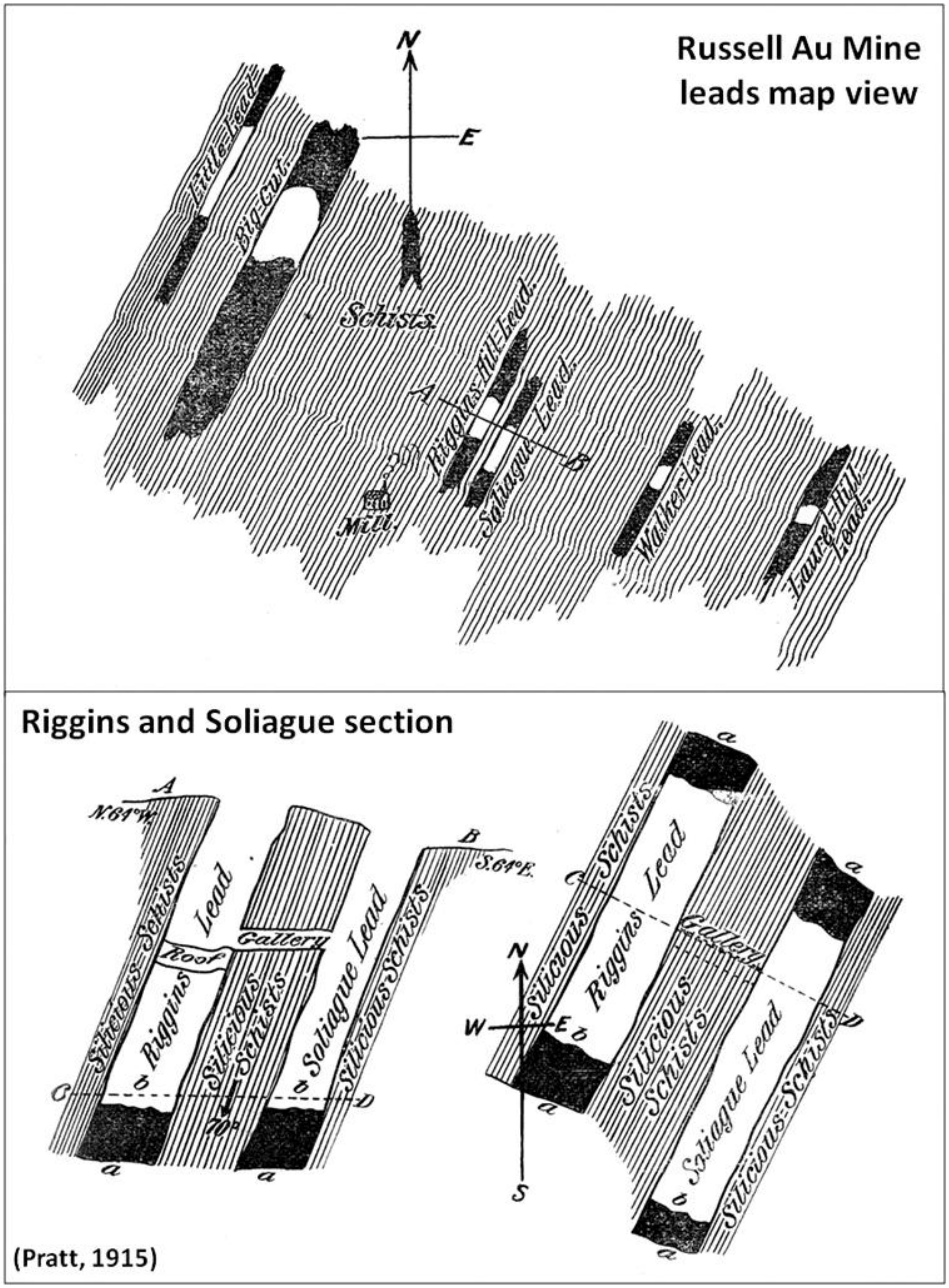


Figure 10. Coggins Mine long section. The section is oriented 042° parallel to the strike of the lode and details shafts, levels, and stopes of the mine workings (modified from **Pratt, 1915**). A cross-section through the inclined shaft appears on the right side of the section. Stope geometry suggests steeply NE-plunging lenses of ore-grade mineralization within the plane of the lower-grade mineralized lode.

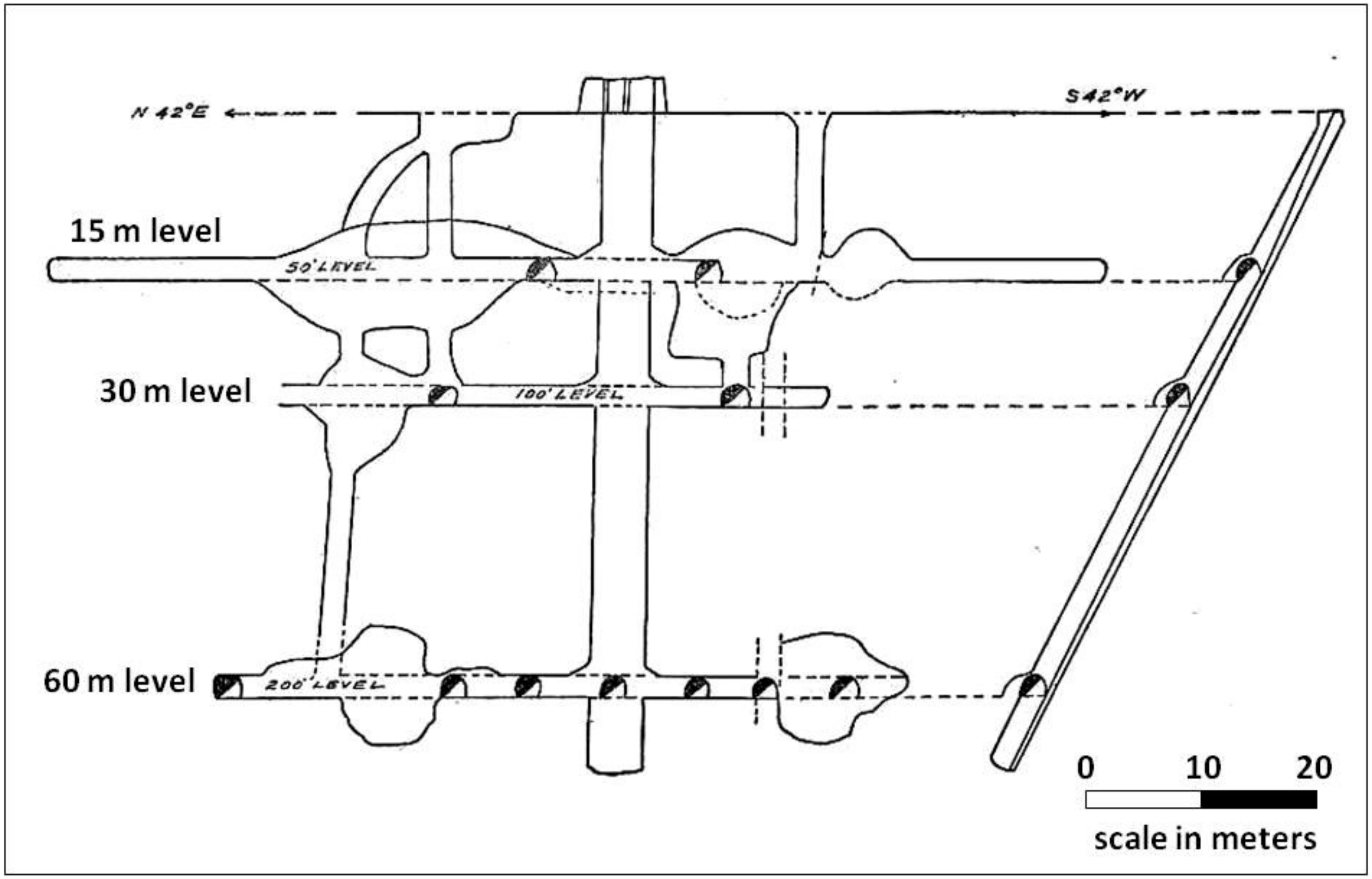


Figure 11. Russell Mine drill-hole locations and chronology; with collar locations and traces projected to the surface and a chronology of drilling activity on the property (modified from **Maddry *et al.*, 1992**). The Big Cut lode was the focus of most drilling efforts.

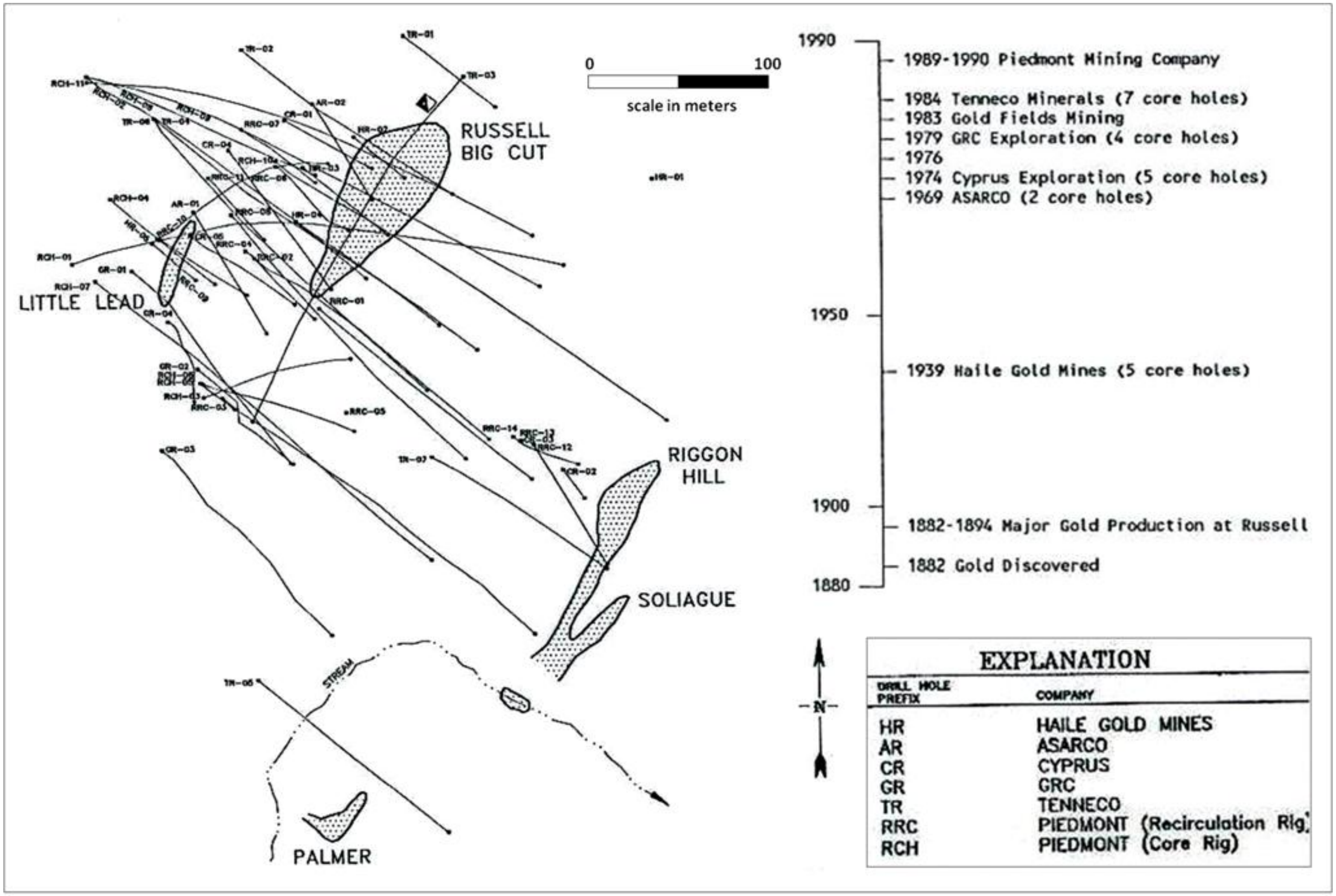


Figure 12. Structural controls of mineralization in the Russell Mine area (modified from **Klein *et al.*, 2007**). Most of the gold mineralization in the area occurs on individual reverse shear zones, although the Griffin and Stafford prospects may be on *en echelon* shear zones. The multiple reverse faulted appressed meso-scale anticlines that host the gold lodes of the Russell Mine are apparently unique in the district and the specific character, geometry, and strike extent of the associated deformation zone is unknown.

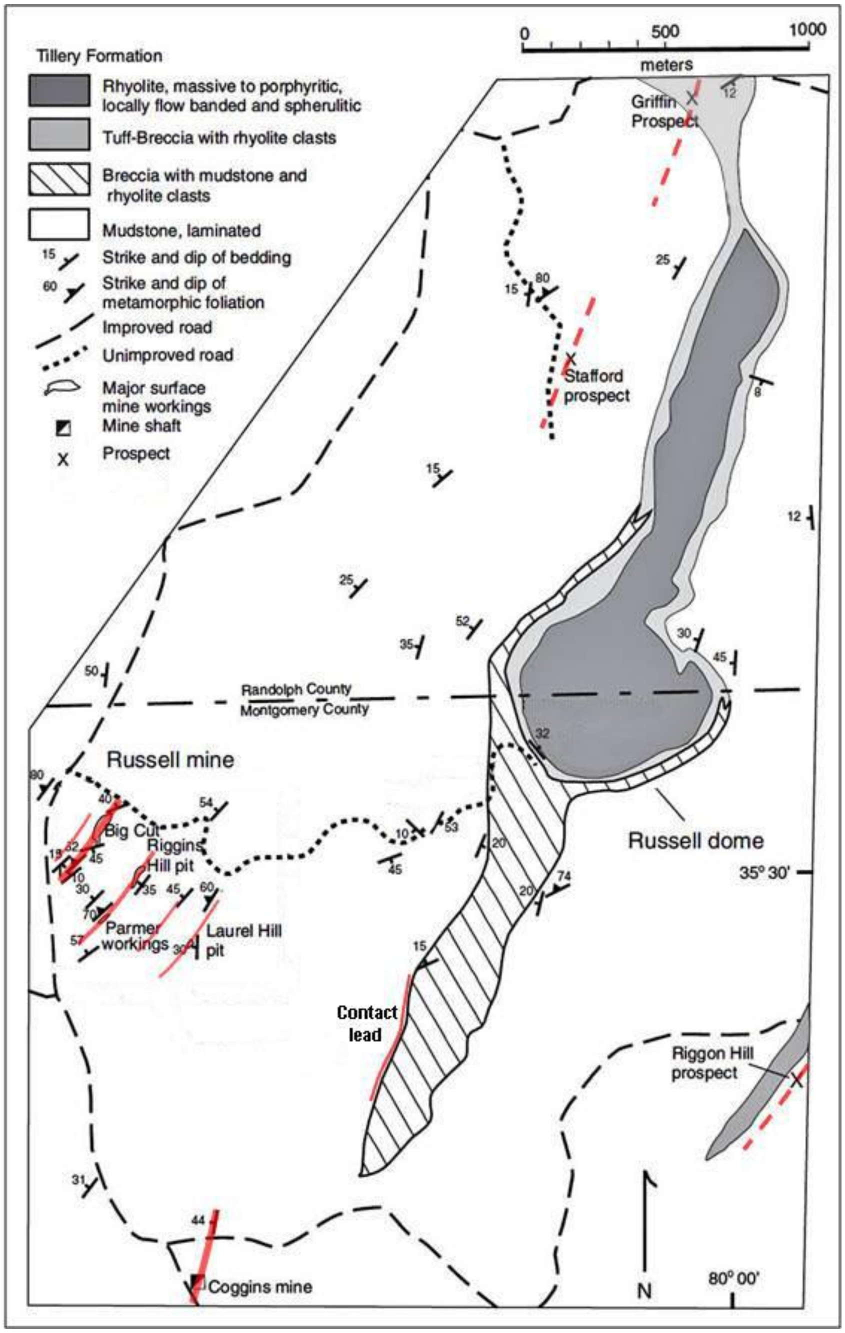


Figure 13. Long sections of lode workings at the Russell Mine, view to the southeast (from **Pardee and Park, 1948**). The ore bodies appear to plunge steeply to the northeast along the axes of the host meso-scale anticlines. Ore grade mineralization was followed down-plunge by underground methods at the Big Cut, Riggon Hill, and Lauren Hill workings.

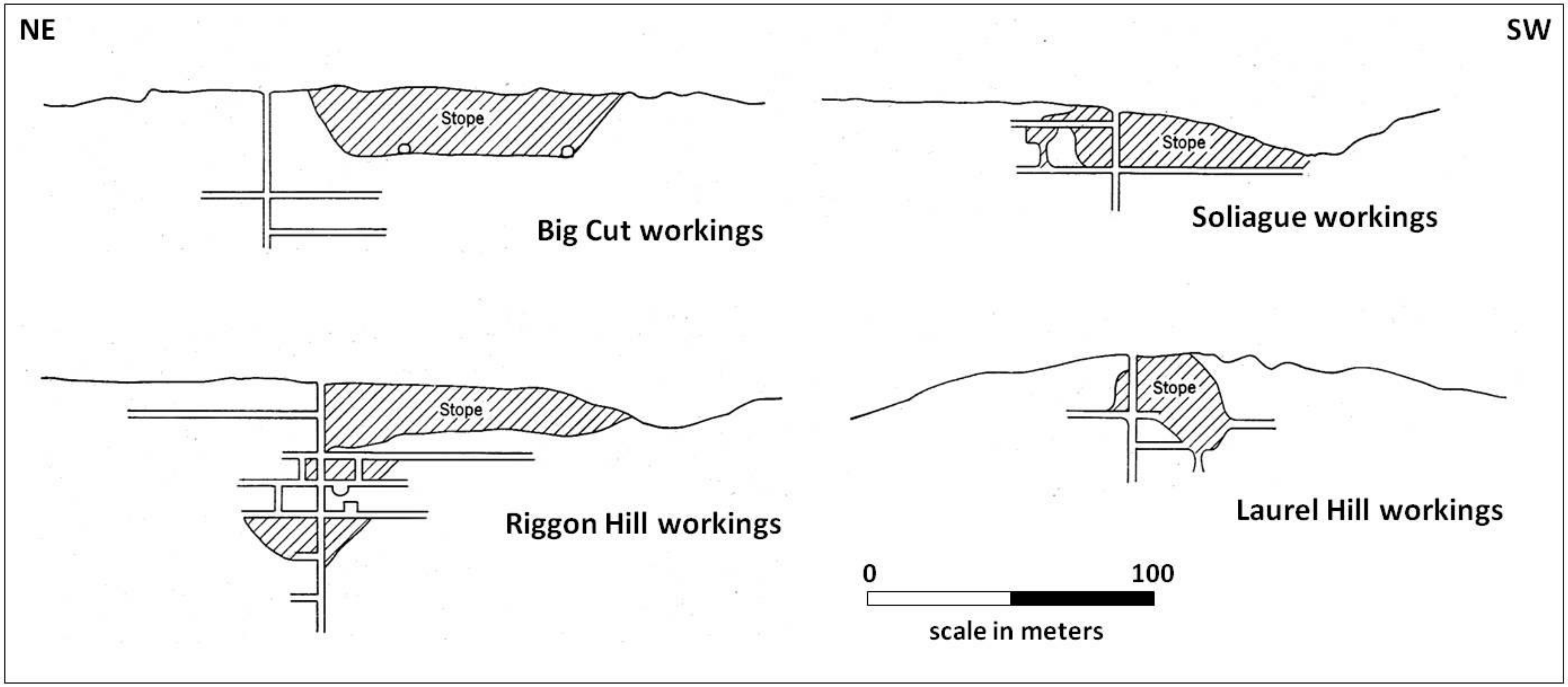


Figure 14. (a) Coggins Mine workings longitudinal section projected onto vertical plane, with cross-section of the inclined shaft showing dip (right side). (**b)** Coggins Mine level plans with ore-grade shoots and stopes highlighted. Both figures modified from **Pratt, 1915**.

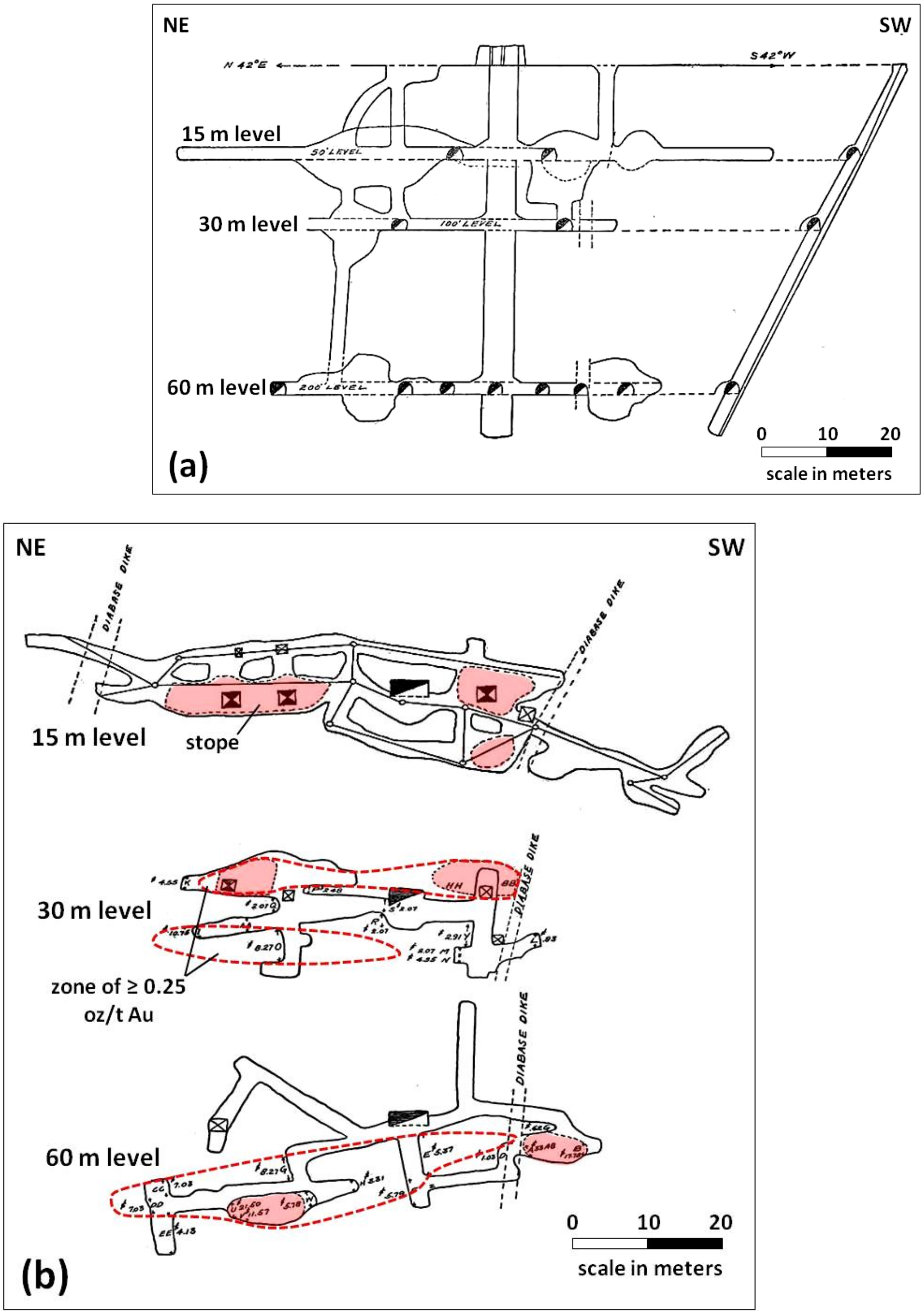


Figure 15. Bedding-parallel pyritic laminae at Ridgeway North. Centimeter-thick pyritic laminae on S_0 in phyllic altered siltstone on the north edge of the Kennecott Ridgeway North Pit. The laminae are partially transposed into the S_2 cleavage, axial planar to recumbent F_2 folds. This weakly mineralized interval is waste rock on the periphery of the ore body.

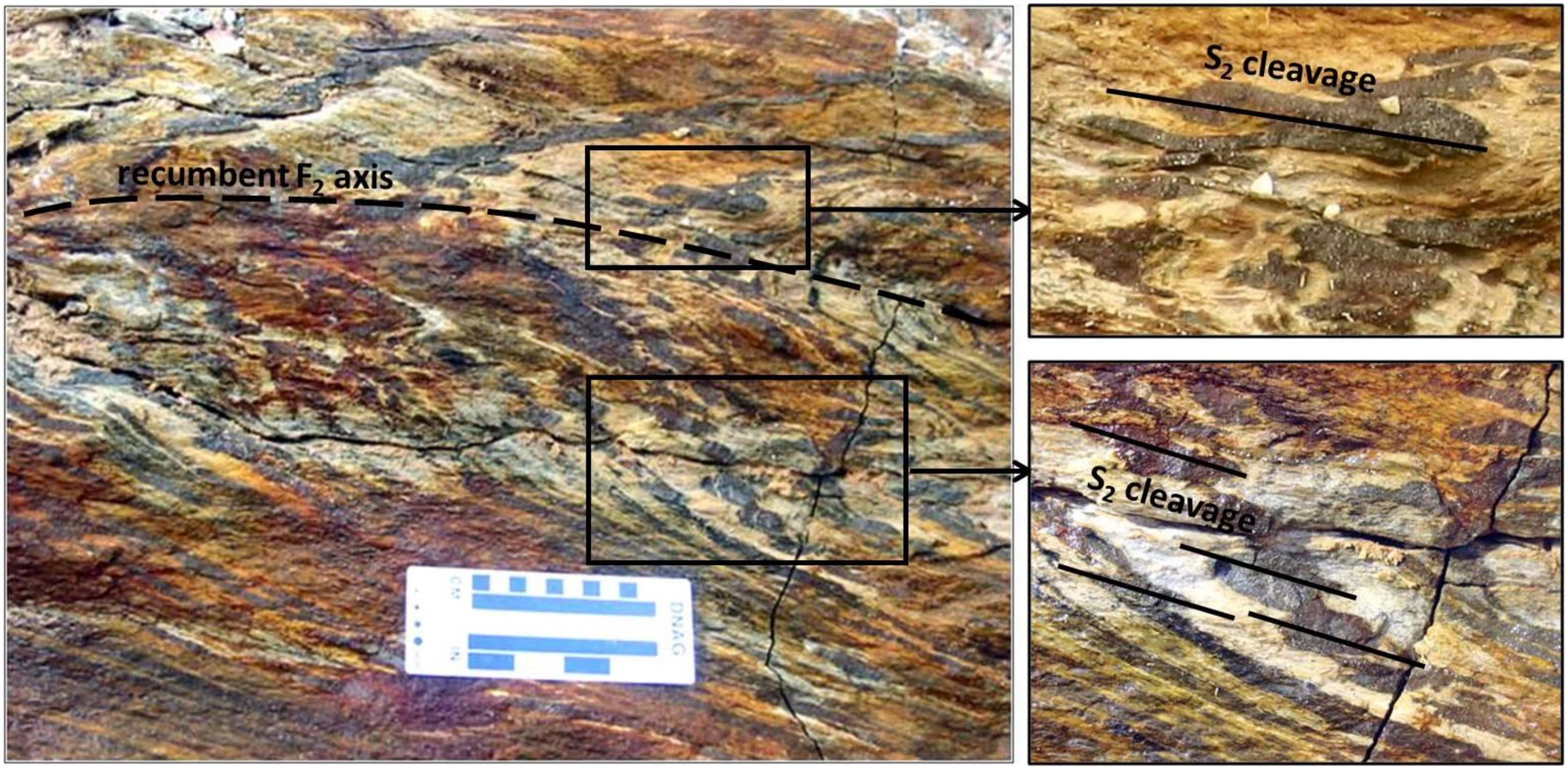


Figure 16. Origin of pyritic laminae at Ridgeway Mine SC deposit by sulfidation; **(a)** plain light image of fine-sand base of graded turbidite bed in sample JMRC5.1 (hanging wall of Ridgeway South ore body), **(b)** same image in reflected light with 5-10 vol% detrital Fe-Ti oxides in basal portion of turbidite bed, **(c)** plain light image of fine-sand base of graded turbidite bed in sample JMRC2.4 (hanging wall of Ridgeway North ore body), **(d)** same image in reflected light with 20 vol % disseminated pyrite in basal portion of turbidite bed.

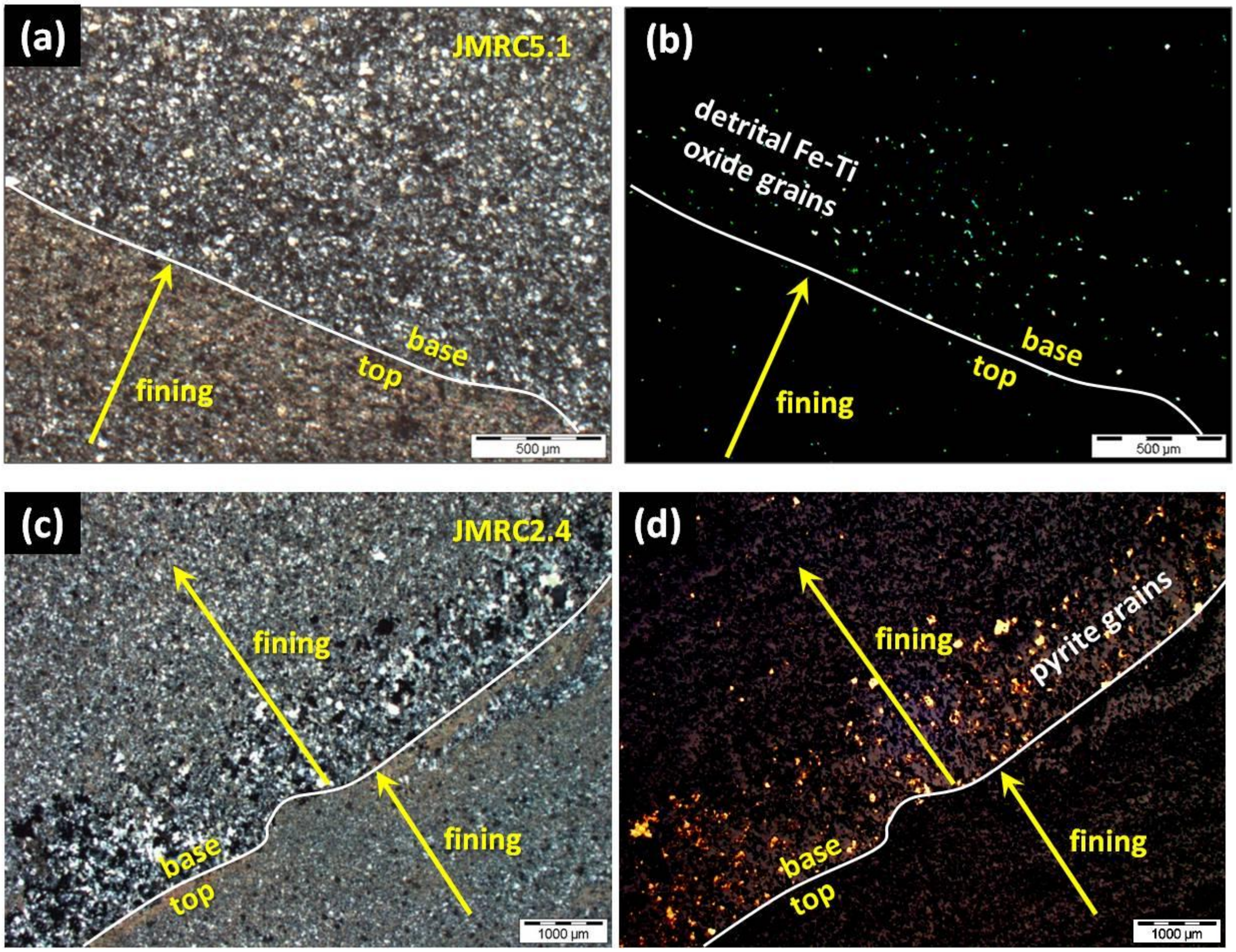


Figure 17. Association of bedding-parallel pyrite with rutile as by-product of sulfidation; **(a)** bedding parallel pyritic laminae folded by small-scale F_2 in sample JMRC2.4 from drill-hole APD17 in the hanging wall of the Kennecott Ridgeway North ore body, **(b)** plain light photo of pyritic laminae in thin section JMRC2.4, locally dismembered by a spaced S_2 cleavage, **(c)** plain/polarized image of pyritic laminae in base of graded turbidite bed, **(d)** same image in reflected light, **(e)** reflected light image of small area in image (d) showing association of pyrite with rutile as products of sulfidation of Fe-Ti oxides.

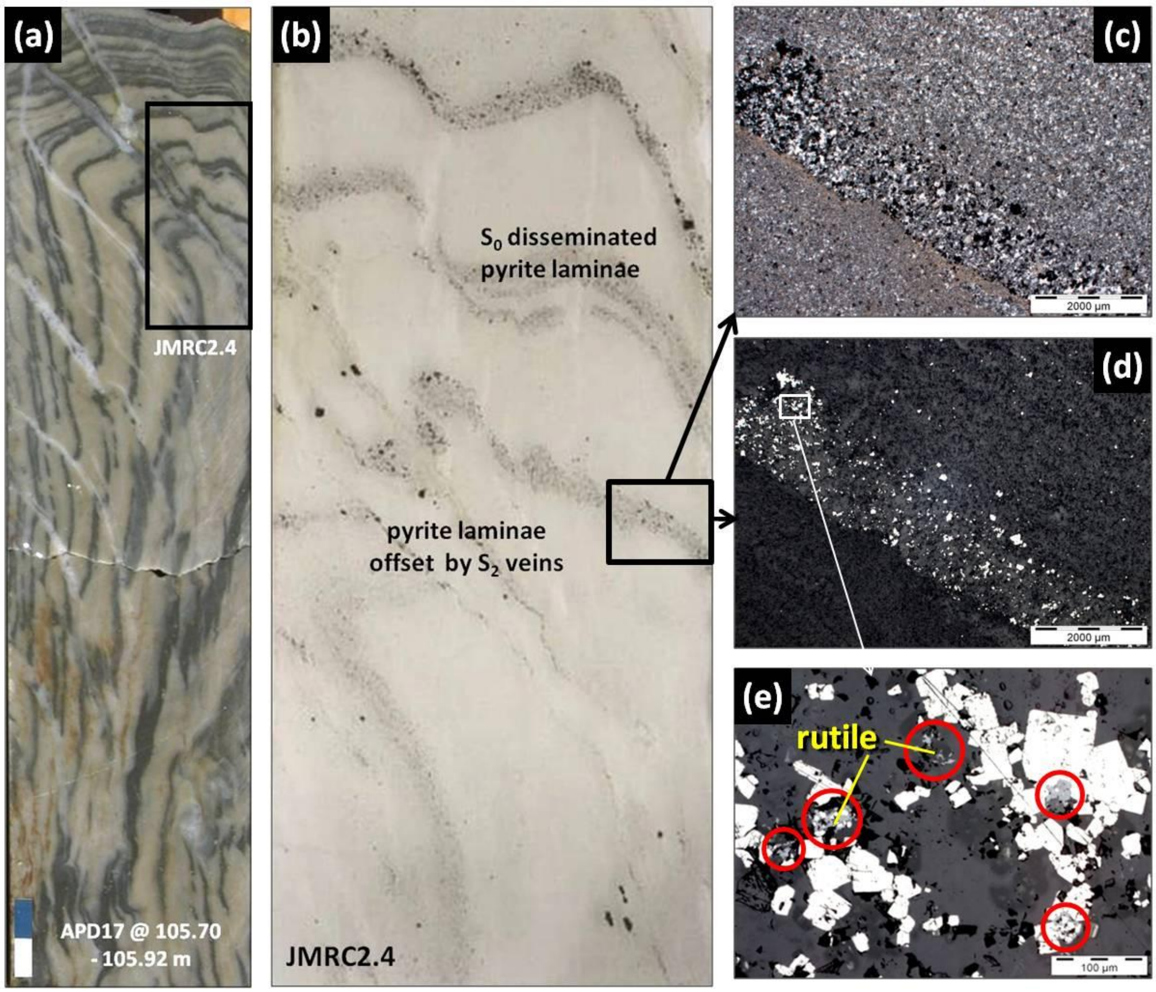


Figure 18. Cleavage-parallel D_2 silicic-potassic alteration cross-cutting, transposing, and mineralizing bedding-parallel pyritic laminae (close-up to right) on the sheared limb of a meso-scale F_2 fold in the South Pit of the Kennecott Ridgeway Gold Mine. Phyllic altered siltstone turbidite with S_0-parallel pyritic laminae in the footwall (detail of boxed area), located in the axial portion of a recumbent F_2 fold, is unmineralized.

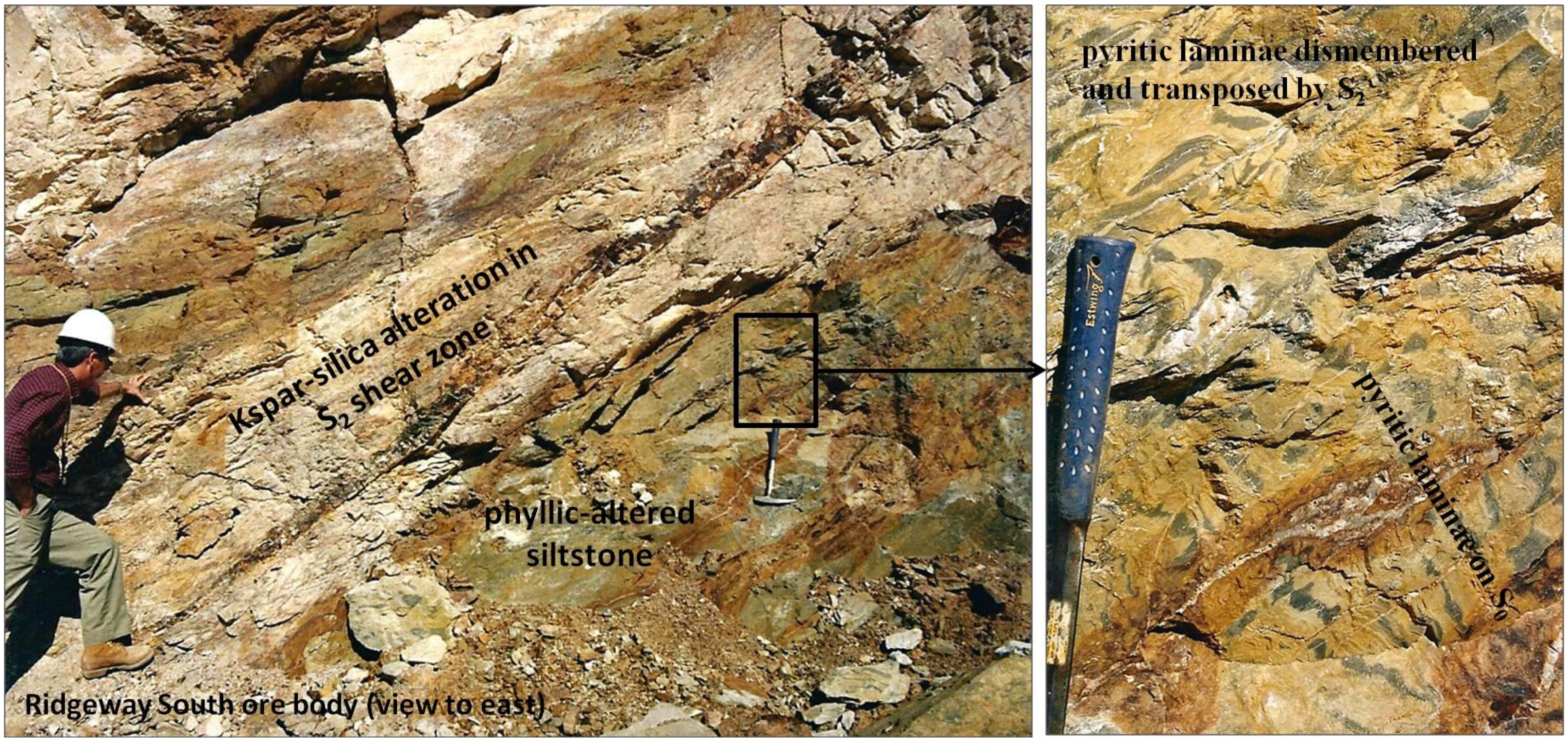


Figure 19. (a) Location of the Mount Read Volcanic Belt (left) in northwest Tasmania, Australia. **(b)** Simplified geologic map of the Mount Read Volcanic Belt (modified from **Bottrill, 2001**) with locations for associated mineral deposit types.

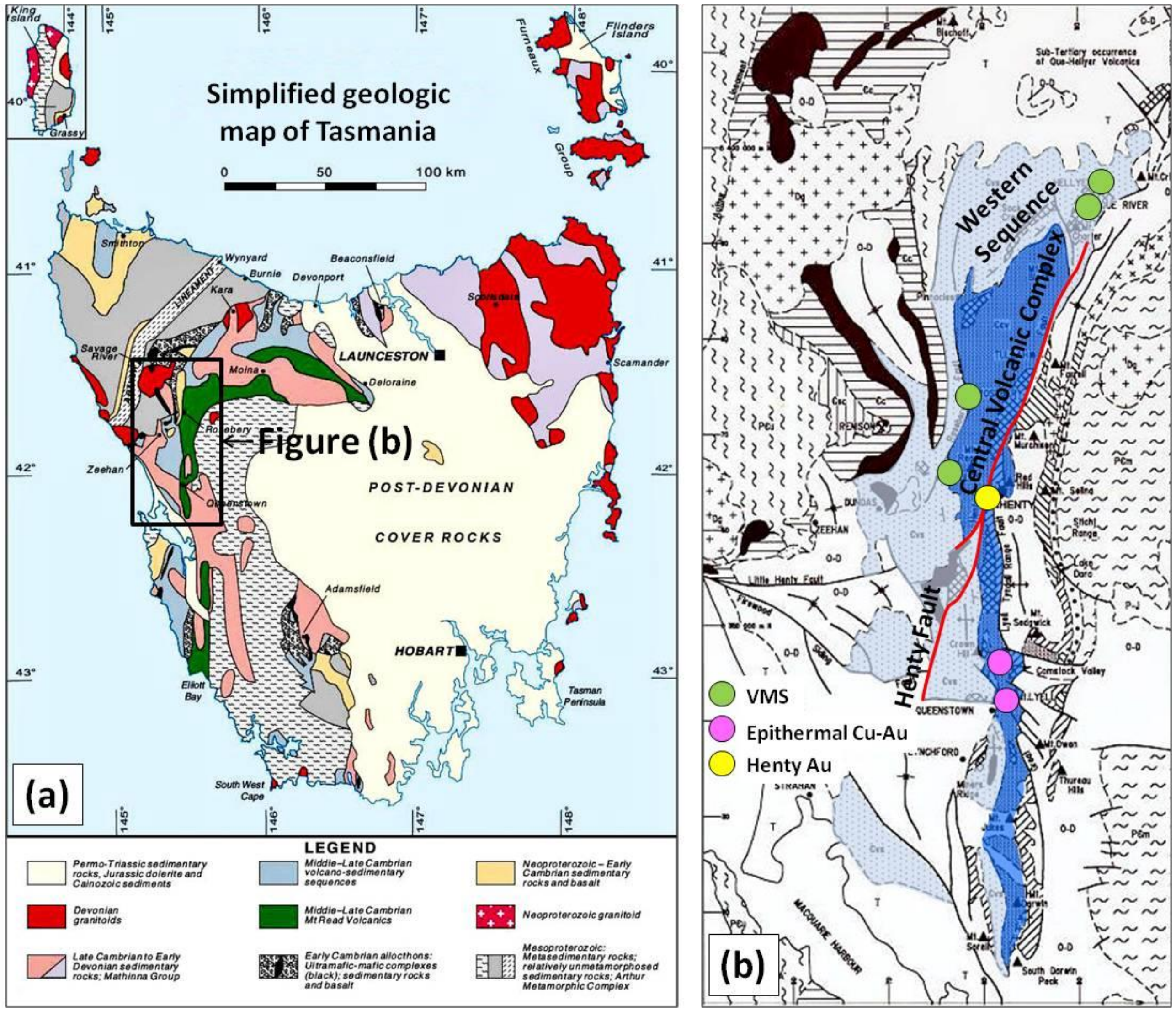


Figure 20. (a) Henty Mine mineralized zone map in the footwall of the Henty Fault Zone (modified from **Lorrigan, 2011**); **(b)** Cross-section of lithology and alteration associated with the Henty Mine mineralized zone (modified from **Beckton, 1999**).

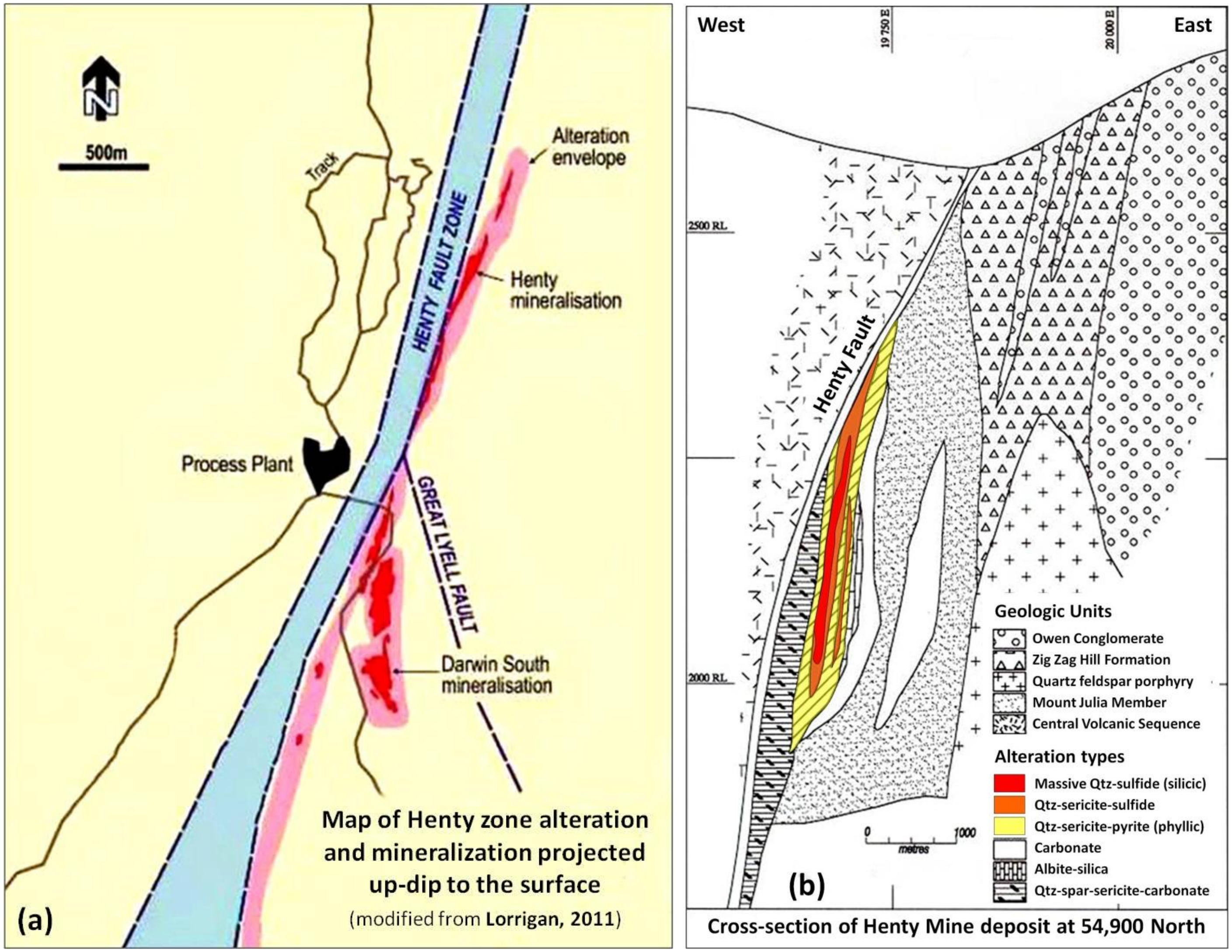
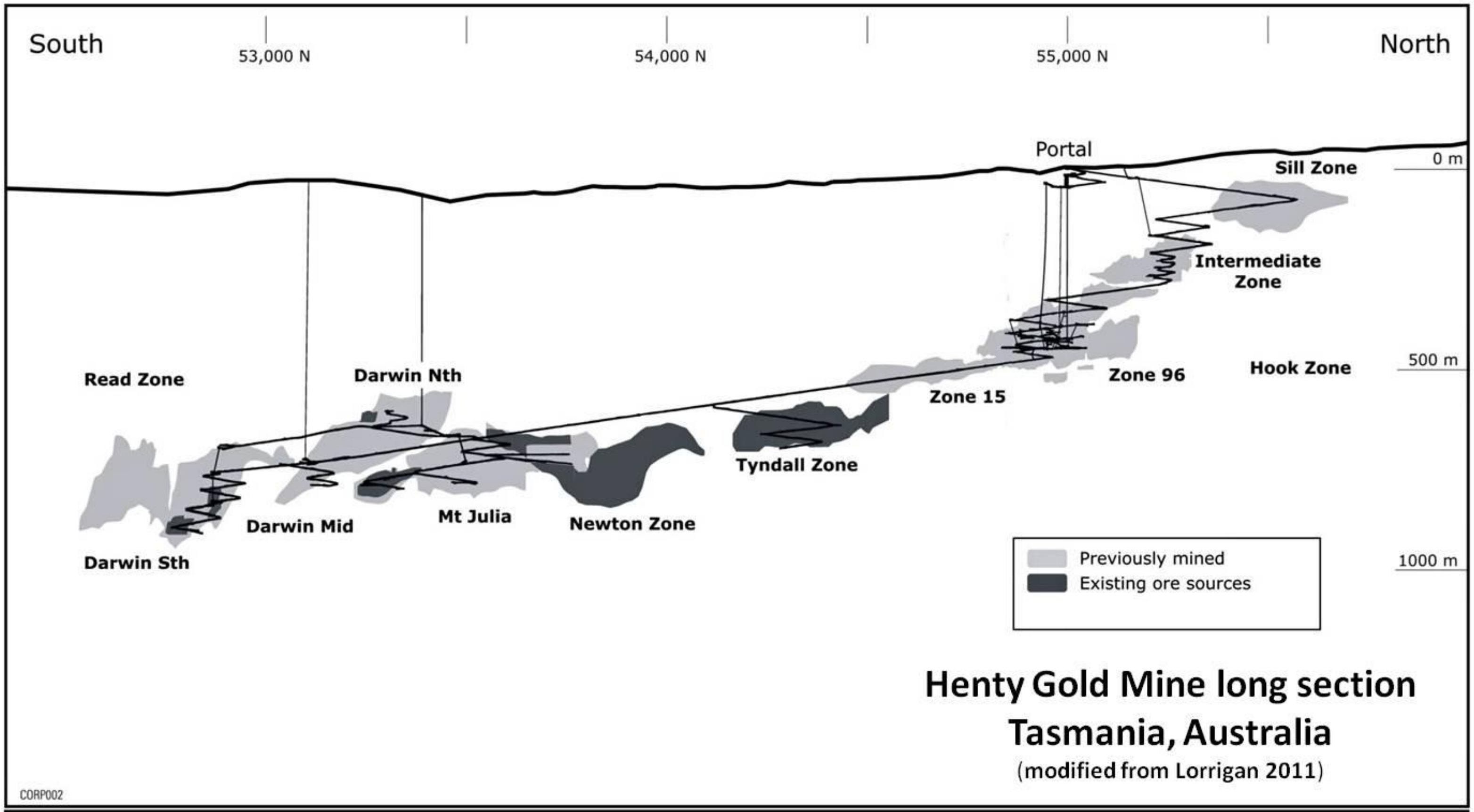


Figure 21. Distribution of Henty Mine ore bodies within the Henty alteration zone corridor (modified from **Lorrigan, 2011**). Although the ore lenses and enclosing alteration zone are subvertical, note that the corridor has limited vertical extent (~250 meters) compared to the strike extent. This may reflect the combination of structural and stratigraphic controls in the channelling of hydrothermal fluids.



	Darwin Sth	Darwin Mid	Darwin Nth	Mt Julia	Tyndall	Zone 15	Zone 96	Intermediate Zone	Sill Zone
Historic production	*300,300 oz*	*72,500 oz*	*44,200 oz*	*68,500 oz*	*12,700 oz*	*76,400 oz*	*285,300 oz*	*90,500 oz*	*218,900 oz*
Grade	*11.5 g/t gold*	*7.1 g/t gold*	*6.1 g/t gold*	*8.1 g/t gold*	*5.2 g/t gold*	*11.1 g/t gold*	*18.9 g/t gold*	*15.9 g/t gold*	*22.6 g/t gold*

Table 1. Russell Mine drilling 1939-1984 by various companies, with drill-hole information and assays for mineralized intervals (from **Maddry *et al.*, 1992**).

COMPANY	DRILL HOLE	INCLINATION/BEARING	T.D.	TARGET	FOOTAGE	GOLD(IN OPT)
HAILE GOLD MINES, INC.	R-1	-90	225'	E. OF BIG CUT	65- 75'(10')	0.01
	R-2	-45 /S50 E	160'	BIG CUT	105-160'(55')	0.04
	R-3	-45 /S50 E	265'	BIG CUT	90-170'(85')	0.06
	R-4	-45 /S50 E	220'	BIG CUT	100-160'(60')	0.09
	R-5	-45 /S55 E	180'	LITTLE LEAD	25- 65'(40')	0.01
ASARCO	R-1	-45 /S30 E	352'	LITTLE LEAD +	24- 51'(27')	0.003
	R-2	-45 /S30 E	284'	BIG CUT	29- 64'(35')	0.011
					168-243'(75')	0.070
CYPRUS	R-1	-60 /S60 E	347'	BIG CUT	160-200'(40')	0.037
	R-2	-90	127'	RIGGON HILL	STOP @ 100'	(NO ASSAYS)
	R-3	-90	458'	RIGGON HILL	NIL	NIL
	R-4	-45 /S35 E	430'	BIG CUT	185-305'(120')	0.066
	R-5	-90	448'	BIG CUT	300-448'(148')	0.038
GRC	G-1	-60 /S50 E	608.5'	BIG CUT(LOWER)	575-608.5'(33.5)	0.04
	G-2	-40 /S50 E	329'	BIG CUT	NIL	NIL
	G-3	-60 /S50 E	663'	BIG CUT	NIL	NIL
	G-4	-90	563'	BIG CUT(LOWER)	470-550'(80')	0.022
	G-C1	-45 /S54 E	498'	NE COGGINS	454-479'	TRACE
TENNECO	TR-1	-45 /S50 E	305'	BIG CUT	NIL	NIL
	TR-2	-45 /S50 E	604'	BIG CUT	NIL	NIL
	TR-3	-45 /S40 W	1005'	BIG CUT (LOWER)	615-695'(80')	0.064
	TR-4	-45 /S50 E	920'	LITTLE LEAD	115-220'(105')	0.008
				BIG CUT (MAIN)	320-455'(135')	0.053*
				BIG CUT (LOWER)	685-765'(80')	0.011
	TR-5	-45 /S50 E	585'	PALMER	345-405'(60')	0.052
	TR-6	-55 /S30 E	942'	LITTLE LEAD	150-245'(95')	0.009
				BIG CUT (MAIN)	315-475'(160')	0.044
				BIG CUT (LOWER)	580-655'(75')	0.111
					655-845'(180')	0.009
					845-910'(65')	0.060
	TR-7	-60 /S60 E	681'	RIGGON HILL	455-520'(65')	0.013
	TGS-1	-45 /S60 E	204'	STAFFORD	NIL	NIL
	TGS-2	-45 /S60 E	215'	STAFFORD	70 -105'(35')	0.11-1.33 (.67 ppm or 0.02 opt)
					145-160'(15')	0.69-1.20 0.02 opt
					180-215'(35')	<.02-1.52 (.599 ppm or 0.015 opt)
	TGS-3	-45 /N90 E	600'	GRIFFIN	NONE	(FEW ASSAYS AVAILABLE)
	TGS-4*	-45 /N55 W	214'	GRIFFIN	0-120'(120')	<.02-1.34 ppm
	TGS-4A**	-60 /N55 W	60'	GRIFFIN		

* AVERAGE FOR TR-4 DOES NOT INCLUDE 2.03 OPT AU ASSAY
** ROTARY- DRILL CUTTINGS ONLY, NO CORE.

Table 2. Russell Mine drilling 1989-1990; Piedmont Minerals core and reverse circulation drill-hole information and assays for mineralized intervals (from **Maddry *et al.*, 1992**).

COMPANY	DRILL HOLE	INCLINATION/BEARING	T.D.	TARGET	FOOTAGE	
PIEDMONT CORE HOLES	RCH-1	-50 /N80 E	1205'	BIG CUT	190-520'(330')	0.045
				BIG CUT (LOWER)	590-910'(320')	0.109
				(INCLUDES	710-790'(80')	0.329)
				BIG CUT (LOWER)	930-1080'(150')	0.015
	RCH-2	-70 /S50 E	1200'	BIG CUT	564-640'(76')	0.036
				BIG CUT (LOWER)	670-890'(220')	0.039
				?	940-1010'(70')	0.022
	RCH-3	-60 /N70 E	505'	BIG CUT (LOWER)	380-480'(100')	0.015
	RCH-4	-90	1001'	BIG CUT	290-570'(280')	0.046
				BIG CUT (LOWER)	600-760'(160')	0.037
	RCH-5	-60 /S70 E	500'	BIG CUT (LOWER)	NIL	NIL
	RCH-6	-70 /S50 E	539'	BIG CUT ?	450-520'(70')	0.014
	RCH-7	-70 /S50 E	1229'	BIG CUT ?	710-210'(10')	0.032
	RCH-8	-90	1481'	BIG CUT (LOWER)	910-970'(60')	0.018
	RCH-9	-52 /S71 E	1255'	BIG CUT	480-560'(80')	0.053
				BIG CUT (LOWER)	670-900'(230')	0.199
				(INCLUDES	740-750'(10')	2.680)
				?	920-1030'(110')	0.018
	RCH-10	-40 /S50 E	1005'	BIG CUT	130-200'(70')	0.151
				BIG CUT	400-410'(10')	0.021
	RCH-11	-60 /S85 E	1241'	BIG CUT ?	710-990'(280')	0.132
				(INCLUDES	930-940'(10')	2.917)
				BIG CUT (LOWER)	1020-1150'(130'	0.021
	CCH-1	-45 /S45 E	503'	COGGINS	330-340'(10')	0.009
	CCH-2	-80 /S45 E	945'	COGGINS	510-540'(30')	0.018
					630-720'(90')	0.015
PIEDMONT RC HOLES	RRC-1	-45 /S49.8 E	975'	BIG CUT	NIL	NIL
	RRC-2	-70 /S50 E	980'	BIG CUT	150-190'(40')	0.066
				BIG CUT (LOWER)	360-380'(20')	0.010
				BIG CUT (LOWER)	490-510'(20')	0.012
				BIG CUT (LOWER)	910-930'(20')	0.018
	RRC-3	-60 /S50 E	980'	LOWER ?	NIL	NIL
	RRC-4	-90	540'	BIG CUT	220-290'(70')	0.038
				BIG CUT (LOWER)	480-530'(50')	0.043
	RRC-5	-90	480'	LOWER ?	NIL	NIL
	RRC-6	-90	500'	BIG CUT	220-360'(140')	0.043
	RRC-7	-90	500'	BIG CUT	340-450'(110')	0.048
	RRC-8	-90	1060'	LITTLE LEAD	110-150'(40')	0.023
				BIG CUT	220-370'(150')	0.046
				BIG CUT (LOWER)	490-610'(120')	0.084
				BIG CUT (LOWER)	660-680'(20')	0.011
				BIG CUT (LOWER)	750-770'(20')	0.014
				BIG CUT (LOWER)	800-860'(60')	0.038
	RRC-9	-90	570'	LITTLE LEAD	30-230' (200')	0.118
					530-570'(40')	0.016
	RRC-10	45 /N60 E	500'	LITTLE LEAD	40-60' (20')	0.044
				LITTLE LEAD	380-470'(90')	0.032
	RRC-11	-90	500'	LITTLE LEAD	150-170'(20')	0.014
				BIG CUT	310-450'(130')	0.036
	RRC-12	60 /S30 E	500'	RIGGON HILL	180-230'(50')	0.030
	RRC-13	-90	73'	RIGGON HILL	HIT WORKINGS	
	RRC-14	-90	500'	RIGGON HILL	NIL	NIL