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Geological Mapping of the Oak Ridge K-25 Site, Oak Ridge, Tennessee

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Environmental Restoration Program Division
K-25 Environmental Restoration Program

Geological Mapping of the Oak Ridge K-25 Site,
Oak Ridge, Tennessee

P. J. Lemiszki

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EXECUTIVE SUMMARY

The Oak Ridge K-25 Site (formerly known as the Oak Ridge Gaseous Diffusion Plant) is located in the southern Appalachian Valley and Ridge province of east Tennessee and overlies an area of folded and faulted Cambrian through Ordovician sedimentary rocks in the footwall of the Whiteoak Mountain fault. Environmental restoration plans for the area require that the geology of the site be well understood because various aspects of the groundwater system are directly influenced by stratigraphic and structural characteristics of the bedrock. This study involved mapping the bedrock geology of an 18-square mile area in and around the plant site. Field mapping focused on: (1) checking the accuracy of previously mapped stratigraphic and fault contacts, (2) dividing the bedrock into distinct stratigraphic units based on field criteria, (3) determining the geometry of map-scale folds and faults, and (4) documenting various aspects of the local fracture system.

Besides accomplishing all of the above tasks, results from this study have led to a number of new hypotheses regarding various aspects of the site geology. First, faulting and folding within carbonates of the Chickamauga Supergroup in the plant area has repeated certain rock units, which requires that there be a thrust fault in the subsurface below them. This thrust fault may project to the surface with the Carters Limestone. Second, thrust slices of the Rome Formation that overlie the Chickamauga carbonates may be extremely thin and have a limited aerial extent. Third, part of the Knox Group on McKinney Ridge is folded into an anticline. Evaluating the above hypotheses will require information about the subsurface that can only be acquired through drilling and surface geophysical surveys. The geologic map produced from this study can be used to evaluate the location of coreholes that will more effectively intersect a combination of stratigraphic, structural, and hydrologic targets.

1. INTRODUCTION

The Oak Ridge K-25 Site (formerly known as the Oak Ridge Gaseous Diffusion Plant) was constructed in the 1940s and was used for the enrichment of UF_6 until 1985. As a result of activities at the site, nonhazardous, hazardous, radioactive, and mixed wastes have been stored, treated, and disposed of at various locations (Poling et al. 1992). The site is located in the southern Appalachian Valley and Ridge province and overlies an area of folded and faulted Paleozoic sedimentary rocks (Fig. 1). The complex geology of the site needs to be well defined because various aspects of the groundwater system are directly influenced by stratigraphic and structural characteristics of the bedrock. For example, underlying the site is a sequence of carbonate and noncarbonate sedimentary rock types. Throughout the area, carbonate rock units have developed a karst groundwater system, and noncarbonate rocks have groundwater flow through fractures (Solomon et al. 1992). Because groundwater flow rates in karst conduits are faster than in fractures, it is important to determine the location and characteristics of karstified carbonate rock units and the geologic factors that control their development.

The purpose of this study was to produce a 1:12,000-scale bedrock geologic map of the K-25 Site and surrounding area. Field mapping covered ~ 18 square miles and was completed during the winter and spring of 1992–1993. Stratigraphic and structural data were recorded from over 250 outcrops and are included in Appendix A. The geologic map of the K-25 Site area generated by this study is included as Appendix B. Field mapping focused on: (1) checking the accuracy of previously mapped stratigraphic and fault contacts; (2) dividing the bedrock into distinct stratigraphic units based on field criteria; (3) determining the geometry of map-scale folds and faults; and (4) characterizing various aspects of the local fracture system. Furthermore, since most of the area is underlain by carbonate rock, various karst landforms and features were mapped, including: seeps and springs, sinkholes, a sinking stream, pinnacles, and open cavities. The results from this study will be used as a framework in which to interpret old bedrock well logs and groundwater data. The results will also be used as the groundwork for developing a drilling strategy to investigate the geologic factors that control the development of groundwater flow pathways.

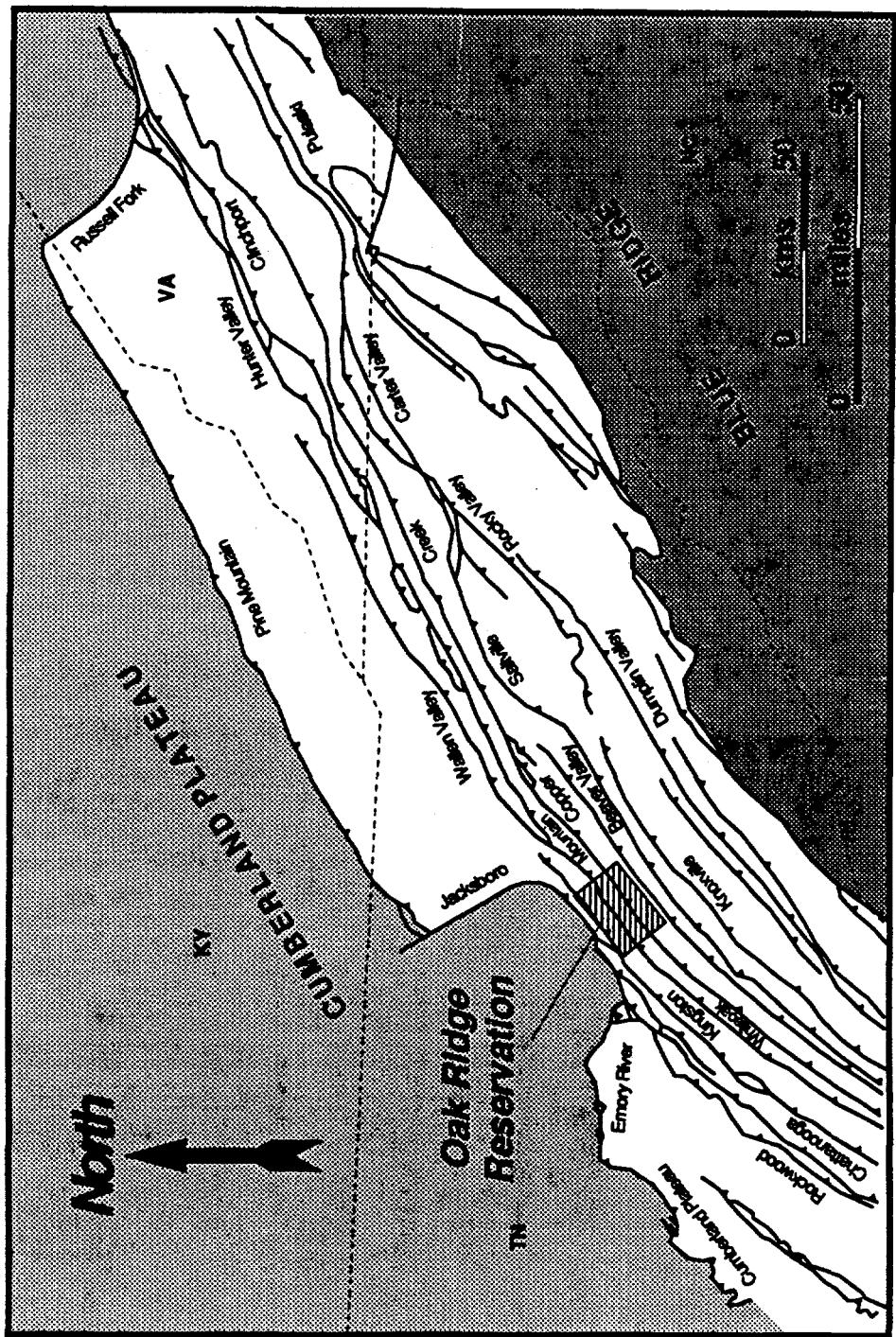


Fig. 1. Location of the Oak Ridge Reservation in the southern Appalachian foreland fold-thrust belt of east Tennessee.

2. GEOLOGIC SETTING AND PREVIOUS WORK

The Oak Ridge Reservation (ORR) is located in the western portion of the Appalachian Valley and Ridge physiographic province in east Tennessee. The Valley and Ridge topography is related to the differential resistance to erosion of folded and thrust-faulted Cambrian through Pennsylvanian sedimentary rocks (Fenneman 1938). The deformational event that caused the development of the southern Appalachian fold-thrust belt was the Late Paleozoic Alleghanian orogeny (Hatcher 1987). The three regional thrust faults that are responsible for the bedrock structures present on the ORR are the Copper Creek, Whiteoak Mountain (WM), and Kingston faults (Fig. 2). These faults strike northeast, dip southeast, and cause the Paleozoic stratigraphic units to be repeated three times (Fig. 3). See Hatcher et al. (1992) for a detailed discussion of the geology of the ORR.

The K-25 Site area is located on the trailing edge of the Kingston thrust sheet, adjacent to the WM fault (Hardeman 1966). Bedrock structure in the area is closely related to the development of the East Fork Ridge syncline and WM fault. The major stratigraphic units involved in the deformation are the Rome Formation, underlying Pine Ridge and parts of the valley to the northwest; the Knox Group, underlying Blackoak Ridge and McKinney Ridge; and the Chickamauga Supergroup, which underlies the low-lying areas between the foregoing ridges. The Conasauga Group underlies Sugar Grove Valley to the northwest and Bear Creek Valley to the southeast of the plant area. Neither shales nor carbonates of the Conasauga Group were found exposed in the plant area, but it is possible that fault slices may exist at depth.

The interpretation of the bedrock geology in the K-25 Site area has changed little since the early work of Rodgers (1953). Reconnaissance field maps by McMaster (1962) and later by R. H. Ketelle (personal communication 1992), however, better defined the location of the major stratigraphic contacts and hinted at the complex bedrock structures in the area (Fig. 4). The geology southwest of the Clinch River between Blackoak Ridge and Pine Ridge was mapped by Jones (1963), and Ossi (1979) mapped part of the Chickamauga Supergroup during construction of the proposed Synfuels site. More recent hydrogeologic studies have proposed slight changes to the site geologic map (e.g., Geraghty & Miller 1989). The changes involved (1) having a continuous section from the Knox Group on the south side of McKinney Ridge down to the upper part of the Conasauga Group under Blair Road; and (2) having a portion of the Shady Dolomite underlying the Rome Formation in the WM thrust sheet. Although present mapping covered these areas, the validity of these changes could not be confirmed because of the lack of bedrock exposure. The present map does not include these new interpretations because the available reports do not convincingly document them.

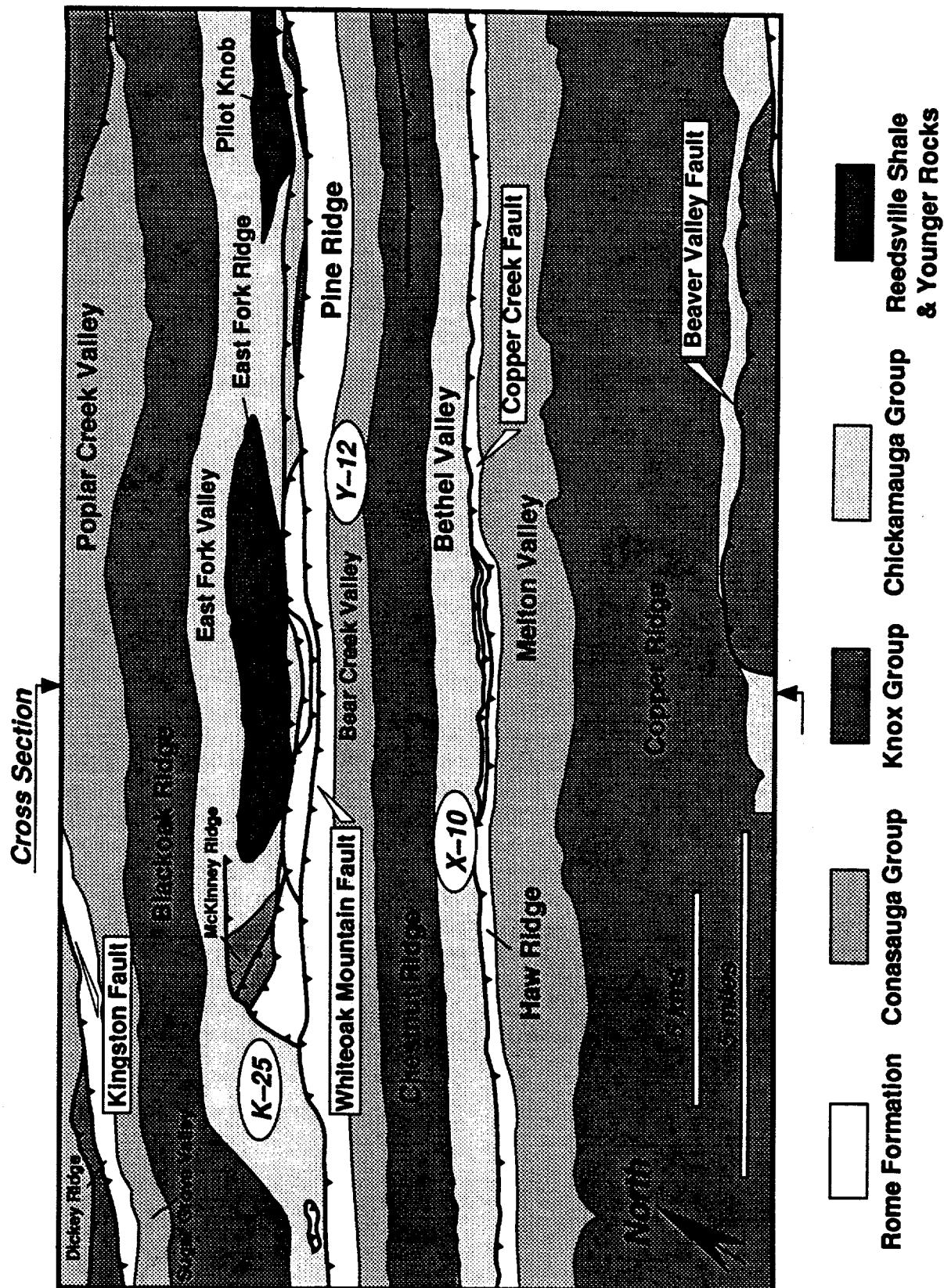


Fig. 2. Geologic map of the Oak Ridge Reservation.

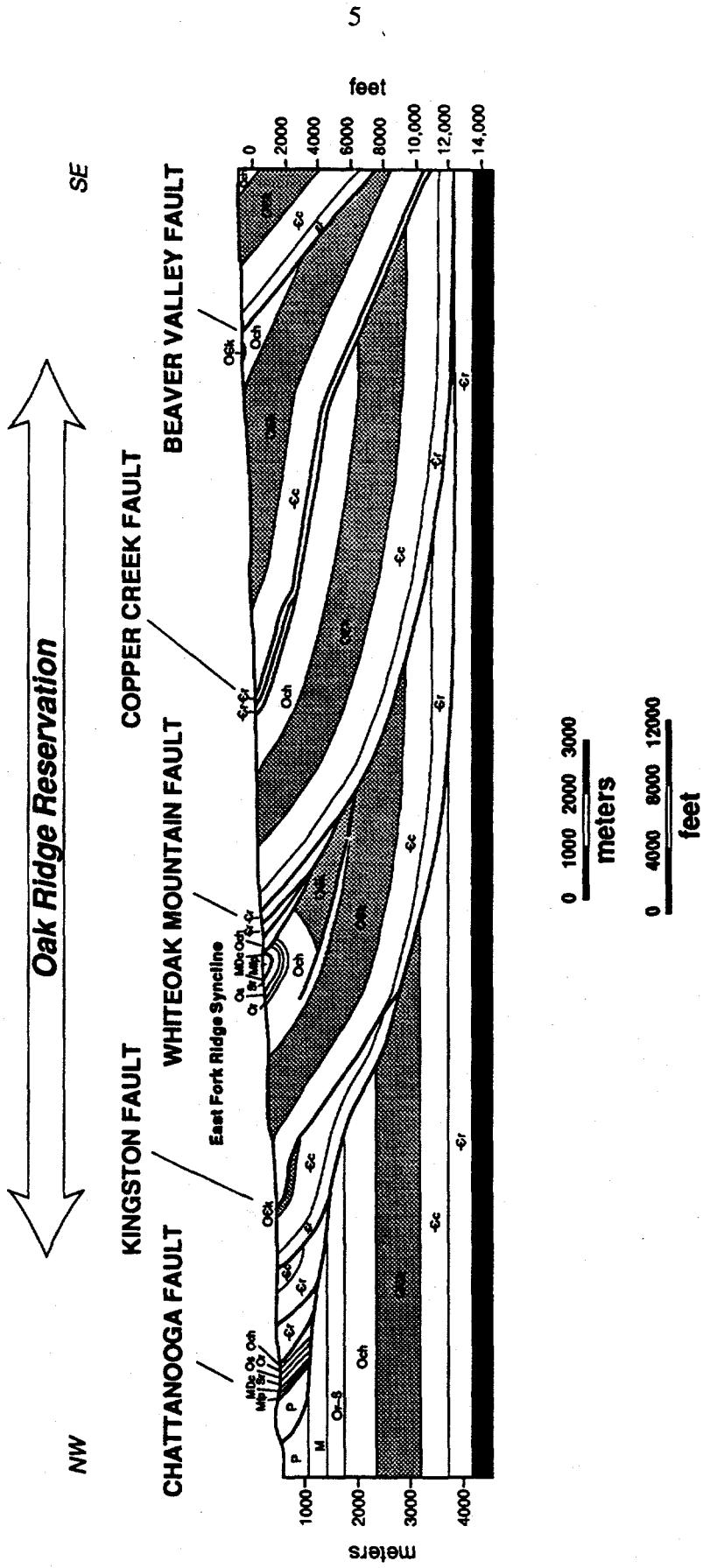


Fig. 3. Balanced cross section from the undeformed foreland of the Cumberland Plateau province through the Oak Ridge area to the Beaver Valley fault in the Valley and Ridge province. P = Pennsylvanian; M = Mississippian; S = Silurian; Or = Reedsville Shale; Os = Sequatchie Formation; Sr = Rockwood Formation; MDc = Chattanooga Shale; Mfp = Fort Payne Formation. See Fig. 5 for explanation of other stratigraphic formation symbols.

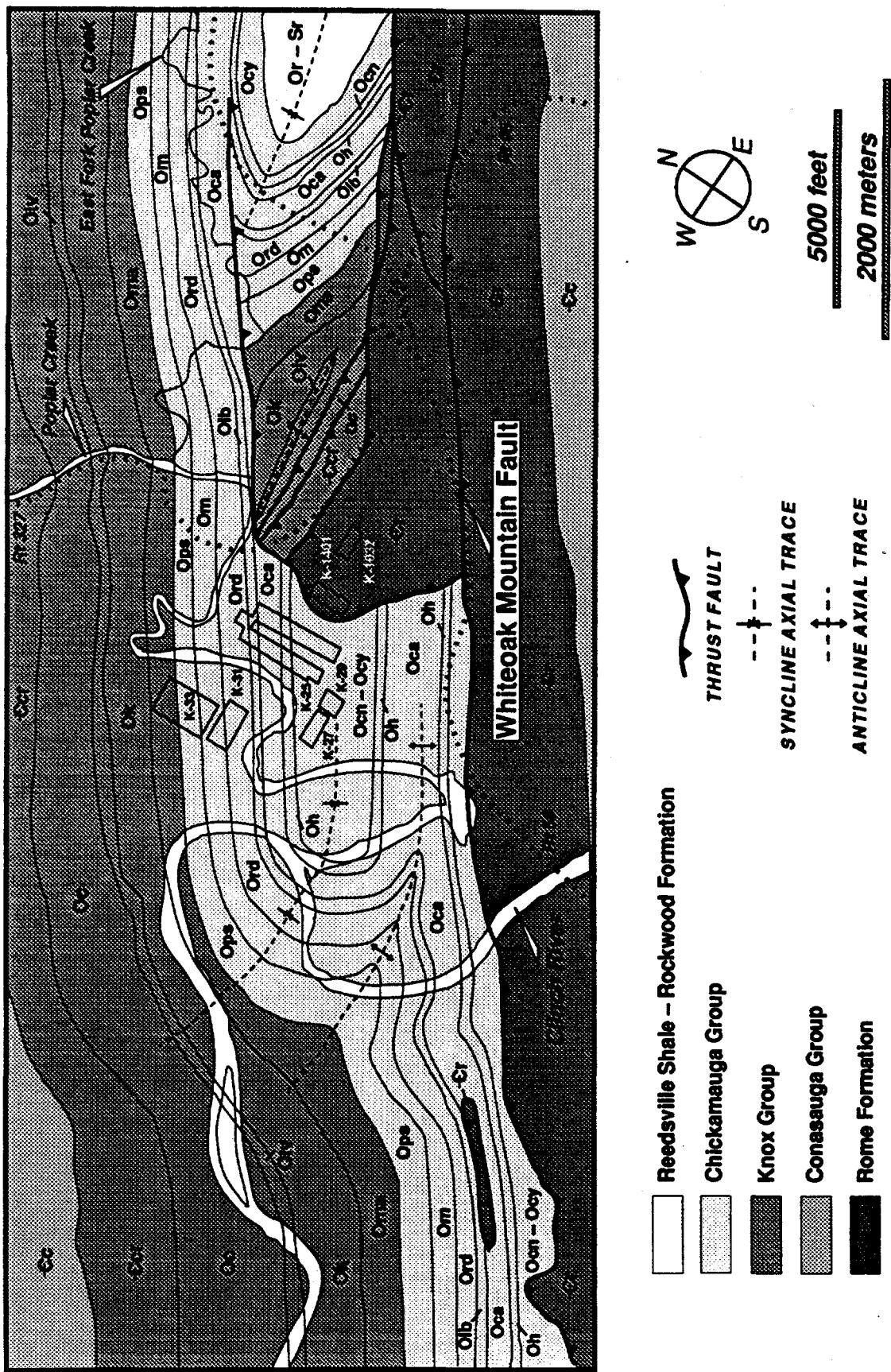


Fig. 4. Bedrock geologic map of the K-25 Site area. See Fig. 5 for key to stratigraphic unit symbols.

3. DESCRIPTIONS OF STRATIGRAPHIC UNITS

The bedrock stratigraphic units on the ORR and vicinity range in age from Early Cambrian to the Early Mississippian (Fig. 5). The sedimentary deposits record the evolution of the southern Appalachian basin from a passive margin to a foredeep basin during the lower Paleozoic, and ultimately to a foreland basin for the remainder of Paleozoic time (Rankin et al. 1989). The Rome Formation, Knox Group, and Chickamauga Supergroup are present in the K-25 Site area. Parts of the Conasauga Group may occur in thrust slices on the south side of McKinney Ridge, but no exposures were found, and therefore the unit is not described below. See Hatcher et al. (1992) for a discussion of the geology of the Conasauga Group on the ORR.

Every effort was made to correlate rock units based on criteria previously used throughout the rest of the ORR, as well as to correlate distinctive lithologic intervals within each rock unit. Exposures of the Rome Formation are rare and commonly deformed, which precluded efforts to correlate specific stratigraphic intervals. The Knox Group was divided into five formations by using characteristic chert and sandstone lithologies. These marker units have been found elsewhere on the reservation and were previously mapped towards the northeast on Blackoak Ridge, near the city of Oak Ridge (Hatcher et al. 1992). In the K-25 Site area, division of the Chickamauga Supergroup into seven formations was accomplished by using lithologic criteria originally recognized in middle Tennessee (Wilson 1949) that was later extended to Georgia and the Sequatchie Valley in east Tennessee (Milici and Smith 1969). These criteria have been used with slight modifications to divide the Chickamauga Supergroup, northeast of the K-25 Site area in East Fork Valley (Hatcher et al. 1992).

3.1 ROME FORMATION

The Rome Formation is the oldest rock unit exposed in the area and was named by Hayes (1891) for exposures at Rome, Floyd County, Georgia. The unit underlies Pine Ridge and parts of the valley and hilly topography to the northwest. Sandstones in the upper Rome are the ridge formers and shales in the lower Rome floor the valley. The lower contact of the Rome Formation is the WM fault. Displacement along the WM fault is responsible for transporting the Rome to its present location and leaving behind the lower contact with the Lower Cambrian Shady Dolomite. Because the lower contact has not been found anywhere in east Tennessee, and because the unit has been internally thickened and thinned by mesoscopic folding and faulting, the true thickness of the Rome Formation is poorly constrained. The upper contact of the Rome Formation is located on the southeast side of Pine Ridge and is placed at the top of the last prominent sandstone bed below characteristic shales and siltstones of the Pumpkin Valley Shale. Sedimentological studies of the Rome Formation conclude that it was deposited in a peritidal environment on the Early Paleozoic North American passive margin (Spigai 1963, Samman 1975, McReynolds 1988).

		Lithology	Average Thickness (m)	Map Symbol	Rock Unit Name											
CAMBRIAN	MIDDLE		120	Ocy	CATHEYS FORMATION											
			27	Ocn	CANNON LIMESTONE											
			35	Oh	HERMITAGE LIMESTONE											
			137	Oca	CARTERS LIMESTONE											
			40	Olb	LEBANON LIMESTONE											
			73	Ord	RIDLEY LIMESTONE											
			99	Orn	MURFREESBORO LIMESTONE											
			116	Ops	POND SPRING FORMATION											
			122	Oma	MASCOT DOLOMITE											
			174	Ok	KINGSPORT FORMATION											
ORDOVICIAN	LOWER		35	Olv	LONGVIEW DOLOMITE											
			227	Oc	CHEPULTEPEC DOLOMITE											
			279	Ecr	COPPER RIDGE DOLOMITE											
		CONASAUGA GROUP (Ec) NOT IN MAP AREA														
			400?	Er	ROME FORMATION											
NASHVILLE STONES RIVER GROUP																
CHICKAMAUGA SUPERGROUP (Och)																
KNOX GROUP (Ock)																

Fig. 5. Stratigraphic section of rock units in the K-25 Site area.

Exposures of the lower part of the Rome Formation in the WM thrust sheet are sparse, and therefore a complete description of the unit cannot be made. Most exposures contain thin-bedded shale and siltstone with abundant mica flakes. These lithologies have the characteristic variegated maroon, green, and yellow-brown colors and may represent the Apison Shale Member of the Rome Formation (Hayes 1894, Wilson 1986). Thin-bedded maroon, brown, and gray sandstones are also present. A few small exposures of a weathered carbonate have been found in the lower Rome shales, but not enough to trace across the map area. Towards the northeast, an apparently more extensive carbonate unit has been mapped in the Rome and was considered the contact between the lower and upper parts (Beets 1985). The unit weathers into soil containing shale and siltstone chips and small sandstone blocks. Fragments of bluish-white, tan-brown, and chalcedonic chert are derived from carbonate beds.

The upper Rome Formation consists predominantly of maroon sandstone, siltstone, and shale. Shales in the upper Rome are thin bedded and come in a variety of colors, such as olive-green, light brown, green-gray, and maroon. Greenish-gray, yellowish-gray, light-brown, and olive-gray siltstones and sandstones are interbedded with maroon sandstones. The sandstones are silica and hematite cemented, mostly fine- to medium-grained, quartzose and occasionally glauconitic. Ripple bedforms, small-scale crossbedding, flaser bedding, bioturbation, and mud cracks are common sedimentary structures. The erosional resistance of the sandstones is responsible for the development of Pine Ridge. The same sandstone weathering blocks that occur on the crest of Pine Ridge are found on the top of the hills located on the north side of Grid D5. (See Appendix B.) This observation suggests that the WM fault is located in the valley between them and has repeated the upper Rome section.

3.2 KNOX GROUP

The Knox Group is a major carbonate sequence that is the only designated aquifer on the ORR (Solomon et al. 1992). The Knox Group has been divided into five formations based primarily on the characteristics of chert and sandstone blocks preserved in the residuum. The thickness of the Knox Group ranges from 800 to 1000 m. The Knox Group was deposited in a peritidal environment on the Late Cambrian-Early Ordovician North American passive margin (Harris 1973, Rankin et al. 1989).

3.2.1 Copper Ridge Dolomite

The Upper Cambrian Copper Ridge Dolomite was named for exposures on Copper Ridge in northeast Tennessee and southwest Virginia (Ulrich 1911) and is ~ 280 m thick.

The lower part of the Copper Ridge is characterized by dark gray and brown, massively-bedded, medium-to-coarse crystalline dolomite. Saccharoidal (sugary) texture is a common feature that consists of large, nearly equidimensional crystals of dolomite. Freshly broken pieces commonly yield a strong petroliferous odor, which is probably the most distinctive feature of the lower dark gray dolomites. Massive beds in the lower part weather to rough, pitted, irregular surfaces that can obscure bedding. Light-gray, medium crystalline dolomite, typical of the upper part of the Copper Ridge, is interbedded throughout the lower part.

Beds and zones of dolomitized oolite are common in the lower part, but the ooids are difficult to identify in unweathered rock. Oolitic beds that have been replaced by chert,

however, are very distinctive. Most silicified ooids are spherical, but oval or tabular shapes were also observed. Some silicified ooids have concentric color bands, whereas others are of uniform color throughout but show an onion-like structure. The ooids are gray or white and occur in a matrix of white chert. Cobbles of oolitic chert are abundant in soil derived from the Copper Ridge Dolomite, as well as another variety of white and gray chert with internal laminations, probably inherited from original depositional structures. In addition, dark gray, cryptozoon (algal) chert is common in float and was the only fossil found in the unit. The lower part usually produces a deep-red soil but may also produce a light-tan soil where cherty.

The upper part of the Copper Ridge Dolomite consists primarily of light-gray dolomite that tends to occur as more evenly stratified medium to thick beds. The dolomite varies from fine- to coarse-grained. Interbedded with the dolomite are the dark gray dolomite beds with a petroliferous odor that are characteristic of the lower part. Chert is very common in the upper part and has similar characteristics as the chert in the lower part. In particular, a coarse-grained, white and gray, oolitic chert bed occurs slightly below the upper contact. Scattered sandstone lenses and dolomite with quartz grains are present in the upper part but are not as abundant as in the overlying Chepultepec Dolomite.

3.2.2 Chepultepec Dolomite

The Lower Ordovician Chepultepec Dolomite conformably overlies the Copper Ridge Dolomite and is ~230 m thick. The Chepultepec Dolomite was named for exposures near Chepultepec, Blount County, Alabama (Ulrich 1911). The unit commonly forms a valley between ridges underlain by the more siliceous Copper Ridge Dolomite and Longview Dolomite. Exposures of the Chepultepec are rare, but chert float is conspicuous and distinctive. The lower contact with the Copper Ridge Dolomite is marked by a change from a red clay soil with gray oolitic chert blocks to an orange sandy soil with either silica-cemented or dolomite cemented sandstone blocks and white oolitic chert blocks. The contact with the overlying Longview Dolomite is determined based on the presence of large float blocks of white, porcelaneous chert. Weathering of the main body of the Chepultepec Dolomite produces orange to red clay soil that contains sandy streaks and scattered masses of oolitic chert with white to light-gray centers and rims.

The Chepultepec consists of fine to medium-grained dolomite that is commonly medium- to thick-bedded and light-gray or tan colored. Although other types of dolomite are present, they are less abundant than the light-colored varieties. Oolitic chert in the Chepultepec is generally a lighter color than in the Copper Ridge Dolomite. Much of the chert found in float is light gray, cream, tan, and white. The chert is commonly deeply weathered with black stains and contains rhombohedral shaped molds of weathered dolomite crystals.

3.2.3 Longview Dolomite

The Lower Ordovician Longview Dolomite was named by Butts (1926) for exposures near the town of Longview, Shelby County, Alabama. The Lower Ordovician Longview Dolomite commonly forms a prominent narrow ridge near the center of the broad ridge developed by the Knox Group. The Longview is ~35 m thick.

The Longview is composed of interbedded light- to medium-gray, thin- to thick-bedded, fine- to coarse-grained dolomite. The dolomite commonly contains light-gray to white,

concentrically banded chert nodules, lenses, and large masses. Weathering of the Longview Dolomite produces a clay soil that contains abundant blocks of massive, milky white, chalcedonic chert that are occasionally dolomoldic and oolitic. In addition, nodules of black, red, blue, and tan chert occur.

3.2.4 Kingsport Formation

The Lower Ordovician Kingsport Formation is ~175 m thick. On a map of the Copper Ridge zinc district, Rodgers (1943) named the Kingsport Formation for the city of Kingsport, Sullivan County, Tennessee. In general, less chert is produced from weathering of the Kingsport than the other formations of the Knox Group. The Kingsport usually underlies gentle slopes or valleys located downdip from ridges developed by the Longview Dolomite. The contact with the Longview Dolomite is marked where jasperoidal chert diminishes in float and milky white chert becomes more abundant.

Dolomites in the Kingsport Formation range from light to dark gray, medium- to massively-bedded, and fine to coarsely crystalline. Some dolomites have an oolitic texture. Near the top of the formation the gray color of the dolomite may contain pink streaks or have a pinkish hue. Thick to massive limestones are commonly interbedded with the dolomites. The limestones are light to medium gray and fine-grained, with various forms of chert. Jasperoidal chert is fairly common in the unit and ranges from irregular pods and lenses to well-defined thick beds. The jasperoidal chert can be fine-grained crystalline and may have a sandy texture. Gastropods have been found in various varieties of chert throughout the unit but are found mostly in milky-white-colored cherts near the contact with the overlying Mascot Dolomite.

3.2.5 Mascot Dolomite

The Lower Ordovician Mascot Dolomite was named by Rodgers (1943) on a map of the Copper Ridge zinc district, but the type area of the unit is the Mascot-Jefferson City zinc district, northeast of Knoxville, Tennessee. The Mascot Dolomite has the greatest range in thickness because the top of the unit is an unconformity. The unconformity represents erosion of the Mascot prior to deposition of the overlying carbonate sequence. The basal contact of the Mascot with the Kingsport Formation consists of thick-bedded dolomites that contain a zone of jasperoidal, chert matrix sandstone. In the K-25 Site area the average thickness of the Mascot Dolomite is 122 m.

The Mascot is primarily composed of thick- to massively-bedded light-gray dolomite with pinkish streaks and hues. The dolomite is commonly fine grained, but occasional thick beds of coarse-grained dolomite with scattered quartz sand grains also occur in the unit. Rare limestone beds in the unit are thick to massive, light gray, and fine grained. Limestones contain some silicified gastropods, irregular dolomitic patches, and black chert pods. Near the base of the unit is a jasperoidal and flinty chert zone that commonly has cabbage-head-shaped stromatolitic (algal) laminations. Near the middle of the unit is a medium- to thick-bedded white porcelaneous chert. Both of these chert layers were easily traced in the residuum.

3.3 CHICKAMAUGA SUPERGROUP—STONES RIVER AND NASHVILLE GROUPS

The entire Middle and Upper Ordovician carbonate sequence is preserved in the Kingston thrust sheet and is ~575 m thick. Previous work in the area divided the Ordovician Chickamauga Supergroup based on lithologic characteristics (McMaster 1957, Kemp 1954, Borowski 1982), but no formal stratigraphic nomenclature was prescribed to the mapped units. These studies, however, did locate some of the distinctive features that are characteristic of particular formations mapped elsewhere in Tennessee. For example, Borowski (1982) described the metabentonites, which are characteristic of the Carters Formation. Ghazizadeh (1987) applied middle Tennessee formation names to four Chickamauga sections southwest of the K-25 Site. Ghazizadeh, however, did not describe the criteria that distinguish each formation, and, more importantly, his section descriptions do not identify some of the primary marker beds, such as the metabentonites, that are needed to identify particular units properly. Milici (1991, personal communication) mapped the Chickamauga in the Kingston thrust sheet along the shoreface of the Watts Bar Reservoir and was able to use middle Tennessee stratigraphic characteristics and marker beds to identify the formations of the Stones River and Nashville Groups. Similar field criteria as Milici's were successfully used to identify and divide the Chickamauga Supergroup in East Fork Valley to the northeast of the K-25 Site (Hatcher et al. 1992). Lithofacies analysis indicates that the carbonate sequence represents a tidal flat and subtidal-lagoonal environment on a gently sloping platform (Ghazizadeh 1987).

3.3.1 Stones River Group—Pond Spring Formation

The Pond Spring Formation was named by Milici and Smith (1969) for exposures in northwestern Georgia. The Pond Spring was deposited on the irregular erosion surface of the Knox disconformity and occupies a topographic low between the southeastern side of Blackoak Ridge and a small rise in elevation near the contact with the overlying Murfreesboro Limestone. The Pond Spring is a distinctive mudstone-rich formation at the base of the Chickamauga Supergroup and should be an excellent unit for subsurface correlations in this part of the stratigraphic section. The thickness of the Pond Spring is fairly constant across the map area, at ~120 m.

Basal exposures of the Pond Spring have been reported to range from a conglomerate of light-greenish-red, fine-grained dolomite, to thin- to medium-bedded, light-greenish-gray, fine-grained limestone, to lenses of calcareous shale and sandstone (Borowski 1982, Wilson 1986). The basal contact was exposed along the Clinch River in the K-25 Site area and consisted of calcareous shales and argillaceous limestone overlying thick-bedded dolomite of the Mascot Dolomite. The lower and upper parts of the formation consist of maroon, green, and gray argillaceous limestone. Bedding ranges from thin to medium, even, regular beds to mottled, uneven beds. Interbedded with the limestones are thick, irregularly-bedded, calcareous shales that are grayish-green and red. Within the middle part of the Pond Spring is a thick- to massive-bedded, dark-gray, micritic limestone with bed-parallel gray chert pods. Although the position of this unit in the Pond Spring may vary slightly across the map area, it is a fairly distinctive unit that may be a useful marker bed for correlating the upper and lower parts of the Pond Spring. Fossils are very rare, but a few silicified gastropods have been found.

3.3.2 Stones River Group—Murfreesboro Limestone

The Murfreesboro Limestone was named by Safford and Killebrew (1900) for exposures in and around Murfreesboro, Rutherford County, Tennessee. The Murfreesboro Limestone contact with the Pond Springs Formation is placed where argillaceous limestone and mudstone are overlain by thin- to thick-bedded, micrite and fine-grained crystalline limestone. The unit averages 100 m in thickness.

The lower part of the Murfreesboro consists primarily of micritic and fine-grained crystalline limestone. The limestones are usually thin bedded, although very thick to massive beds do occur in the section. Minor amounts of calcareous shale and argillaceous limestone also exist in the lower part. The middle part of the Murfreesboro consists of similar micritic and fine-grained limestones, but beds are commonly thin to medium, regular, and even. Bryozoans are the only fossils that have been observed in the middle part, and bed-parallel, ropy, black chert zones increase in abundance. Thick to massive beds interbedded with even, thin to medium beds become more common in the upper part of the Murfreesboro, but they are not as abundant as in the overlying Ridley Limestone. A characteristic feature of the limestones in the upper part of the Murfreesboro is that they commonly contain nodular, ropy, gray-black chert zones with silicified fossils.

3.3.3 Stones River Group—Ridley Limestone

The Ridley Limestone was named by Safford (1869) for exposures in Rutherford County, Tennessee, and is ~75 m thick in the map area. The contact with the underlying Murfreesboro Limestone is placed where regularly bedded, chert rich limestones of the Murfreesboro are overlain by thick- to massively-bedded, fucoidal limestones that contain little to no chert.

Thick- to massively-bedded, fucoidal-textured limestone is characteristic of the Ridley Limestone. "Fucoidal texture" is a term used to describe the presence of tan-brown, irregularly shaped, fine- to coarse-grained dolomitic patches within the limestone. The texture appears to be related to the preferred dolomitization of a preexisting mottling fabric. The limestones are generally dark-gray micrite that are commonly devoid of fossils. Within the middle part of the Ridley is a yellowish-red, mud-cracked, calcareous shale. The unit is fairly distinctive, but because of poor exposure, the thickness of this unit is not known, and it is not known whether the unit can be used as a marker for subsurface correlations. Within the upper part of the Ridley Limestone, minor amounts of gray-black chert are present, and fossils are very abundant in some coarse-grained limestone beds.

3.3.4 Stones River Group—Lebanon Limestone

The Lebanon Limestone was named by Safford and Killebrew (1900) for exposures near Lebanon, Wilson County, Tennessee. The Lebanon Limestone is ~40 m thick in the map area. The contact with the Ridley Limestone is placed where thick to massive beds of limestone are overlain by thin, cobbley-bedded, fucoidal, very fossiliferous limestone.

A distinctive characteristic of the Lebanon Limestone is the abundance of fossils. Whole-body and disarticulated brachiopods, bryozoans, gastropods, and cephalopods have been observed. Bedding in the Lebanon ranges from regular and even, thin to medium beds, to

irregular, cobbley beds. Cobbles are more pronounced after the beds have been extensively weathered and are elongate, micritic- to coarse-grained limestone lenses, parallel to bedding, that are surrounded by thin laminae of calcareous mud. Some thick to massive limestone beds also occur in the Lebanon. Fucoidal texture is common. Chert is rare.

3.3.5 Stones River Group—Carters Limestone

The Carters Limestone was named by Safford (1869) for exposures along Carters Creek in Maury County, Tennessee. The Carters Limestone is, ~ 150 m thick in the study area. The contact with the Lebanon Limestone was not exposed in the study area but is located between outcrops of thin-bedded, fossiliferous limestones of the Lebanon and thick-bedded limestones with few fossils of the Carters.

The lower part of the Carters Limestone consists of thick to massive beds of interbedded micritic- and coarse-grained limestone. Chert in the lower part consists of gray-black pods and lenses. Where outcrops are absent, chert blocks are relatively abundant in the residuum. The top of the lower part consists of olive-gray, argillaceous limestone that is mud-cracked and devoid of fossils and weathers into thin chips.

The middle part of the Carters Limestone consists of medium to thick, regular- and even-bedded, blue-gray limestone. Close examination of the beds indicates that some are storm deposits consisting of fining upward sequences of coarse-grained fossil hash to micrite. Fossil hash beds commonly have *Tetradium* coral. Fucoidal texture and gray chert pods are also common. Although no exposures were found, a quartz siltstone has commonly been observed in float around the middle part of the Carters. At the top of the middle part are two apple-green, sometimes partly maroon, metabentonite beds that range from 1 to 3 ft in thickness. Although exposures of the metabentonites were not found in the area during mapping, they have been observed along strike toward the southwest and northeast. An exposure of the metabentonites, however, was found along Poplar Creek before the K-25 Site was built (Fox and Grant 1944). The metabentonites are characteristic marker beds in the Carters Limestone and have been named T-3 and T-4 by Wilson (1949). The metabentonites range from mud-sized to fine-grained and are very micaceous. Relatively large biotite flakes are characteristic of T-4 and can be used to distinguish between the beds when only one unit is found (Milici and Smith 1969). Underlying each metabentonite bed are gray-black cherts that are commonly medium-bedded (table-top cherts) and fossiliferous. Formation of the cherts may be related to burial alteration of the metabentonites, causing silica to be dissolved and reprecipitated in the underlying limestone beds. Soils commonly contain small chert blocks that are fossiliferous and oolitic, as well as pieces of silicified fossils, which helps determine the location of the metabentonites where there are no bedrock exposures. In addition, the cherts are more resistant to weathering, which leads to the development of a small rise in topography that is easily observable on topographic maps. All of the foregoing characteristics have been used to approximate the position of the metabentonites in the map area. The metabentonites will be one of the most useful units for subsurface correlations in this part of the Chickamauga Supergroup.

The upper part of the Carters is poorly exposed but consists of micritic, greenish-gray and yellowish-gray, poorly-bedded, mud-cracked limestone.

3.3.6 Nashville Group—Hermitage Formation

The Hermitage Formation was named by Hayes and Ulrich (1903) for exposures near the Hermitage community in Davidson County, Tennessee. Limestones consists of thin to medium, irregular, uneven, cobbly beds that are abundantly fossiliferous. Fossils are commonly silicified and include crinoids, brachiopods, and bryozoans. Limestones range from light-gray to slightly reddish-gray, coarse-grained spar and micrite that can be partly argillaceous. A maroon, olive-tan, calcareous shale has been observed near the base of the unit and may be a useful marker bed. The Hermitage is ~35 m thick.

3.3.7 Nashville Group—Cannon Limestone

The Cannon Limestone was named by Ulrich (1911) for exposures in Cannon County, Tennessee. A type section was designated by Bassler (1932) in Cannon and Rutherford counties, Tennessee. The Cannon is poorly exposed and may exist only within the minor syncline in the middle of the plant area. The following description is based on exposures mapped along strike to the northeast between the K-25 Site and the city of Oak Ridge. The Cannon Limestone is ~27 m thick.

Limestones in the Cannon are commonly dark-gray, thick to massive beds, but thin and medium beds also occur. Fossils range from rare to a coquina consisting of crinoids, bryozoans, and brachiopods. A few large silicified coral forms were observed. Chert and fucoidal texture is rare, but stylolites are common and produce ridges on weathered outcrops.

3.3.8 Nashville Group—Catheys Formation

The Catheys Formation was named by Hayes and Ulrich (1903) for exposures along Catheys Creek in Lewis and Maury counties, Tennessee. The Catheys is poorly exposed and may exist only within the minor syncline in the middle of the plant area. The following description is based on exposures mapped along strike to the northeast between the K-25 Site and the city of Oak Ridge. The Catheys Formation is ~120 m thick.

The Catheys Formation is medium to dark-gray, thin- to thick-bedded, micrite and occasionally coarse-grained limestone with shale seams and partings. Some beds are very fossiliferous, and *Tetradium* have been found. Near the upper part are interbedded calcareous, green and red shales. Chert and siltstone fragments are common in soil.

4. STRUCTURE

4.1 MAP-SCALE STRUCTURES

The K-25 Site is located on the trailing edge of the Kingston thrust sheet, adjacent to the WM fault (Hardeman 1966). The Kingston fault outcrops to the northwest of the plant area along Dickey Ridge. Based on balanced structural cross sections through the region, the Kingston fault is estimated to be at a depth between 2.5 to 3.0 km below the plant site and has a minimum displacement of 2 km. The present northeast strike and southeast dip of the Knox Group on Blackoak Ridge and lower parts of the Stones River Group in East Fork Valley was derived from emplacement of the Kingston thrust sheet as it climbed a footwall ramp.

The emplacement of the WM thrust sheet, however, is interpreted to be responsible for the development of the East Fork Ridge syncline and the complex array of structures that underlie the K-25 Site area (Hatcher et al. 1992). The WM fault places a hanging-wall flat in the Rome Formation against a footwall ramp consisting of various stratigraphic units. The footwall ramp geometry in map view is indicated by the presence of footwall synclines, imbricates, and numerous stratigraphic cutoffs against the fault. Evidence for the hanging-wall flat geometry is the lack of stratigraphic cutoffs and the consistent position of the fault in the Rome Formation. A balanced cross section through the area indicates a minimum displacement of 10 km along the WM fault.

The East Fork Ridge syncline is typical of the structures that have formed on the trailing edge of the Kingston thrust sheet (Rodgers 1953, Hardeman 1966). The development of the syncline is related to the growth of the WM fault. Although only the southwestern portion of the syncline projects into the map area, a brief discussion of the geometry of the entire syncline is given below because various aspects of its geometry are related to structures in the K-25 Site area.

The East Fork Ridge syncline is a prominent topographic feature that involves the folding of Knox Group and younger rock units adjacent to the WM fault (Fig. 6). The syncline has an upright northwest limb and a southeast limb that is overturned to the northwest. Pieces of the southeast limb of the syncline still remain as imbricate slices adjacent to the WM fault, but most of the rock units have been removed by thrusting. The axial plane of the syncline strikes N66E and dips 84 SE, indicating an upright geometry with a slight northwest vergence to the fold. In general, the fold axis (long axis of the fold) is oriented northeast-southwest, parallel to the strike of the WM fault. The geometry of Ordovician and younger rock unit map contacts, however, indicates that the fold axis is doubly plunging. In other words, the fold axis is mildly warped along its trend so that the hinge of the fold projects out of the ground toward the northeast and southwest before rolling over and projecting back into the ground farther along trend. Stereographic projections of poles to bedding from the Rockwood Formation and younger rock units indicate that the northeastern hinge of the syncline has a fold axis with a trend and plunge of S56W / 02SW, and the southwestern hinge of the syncline has a fold axis with a trend and plunge of N66E / 02NE.

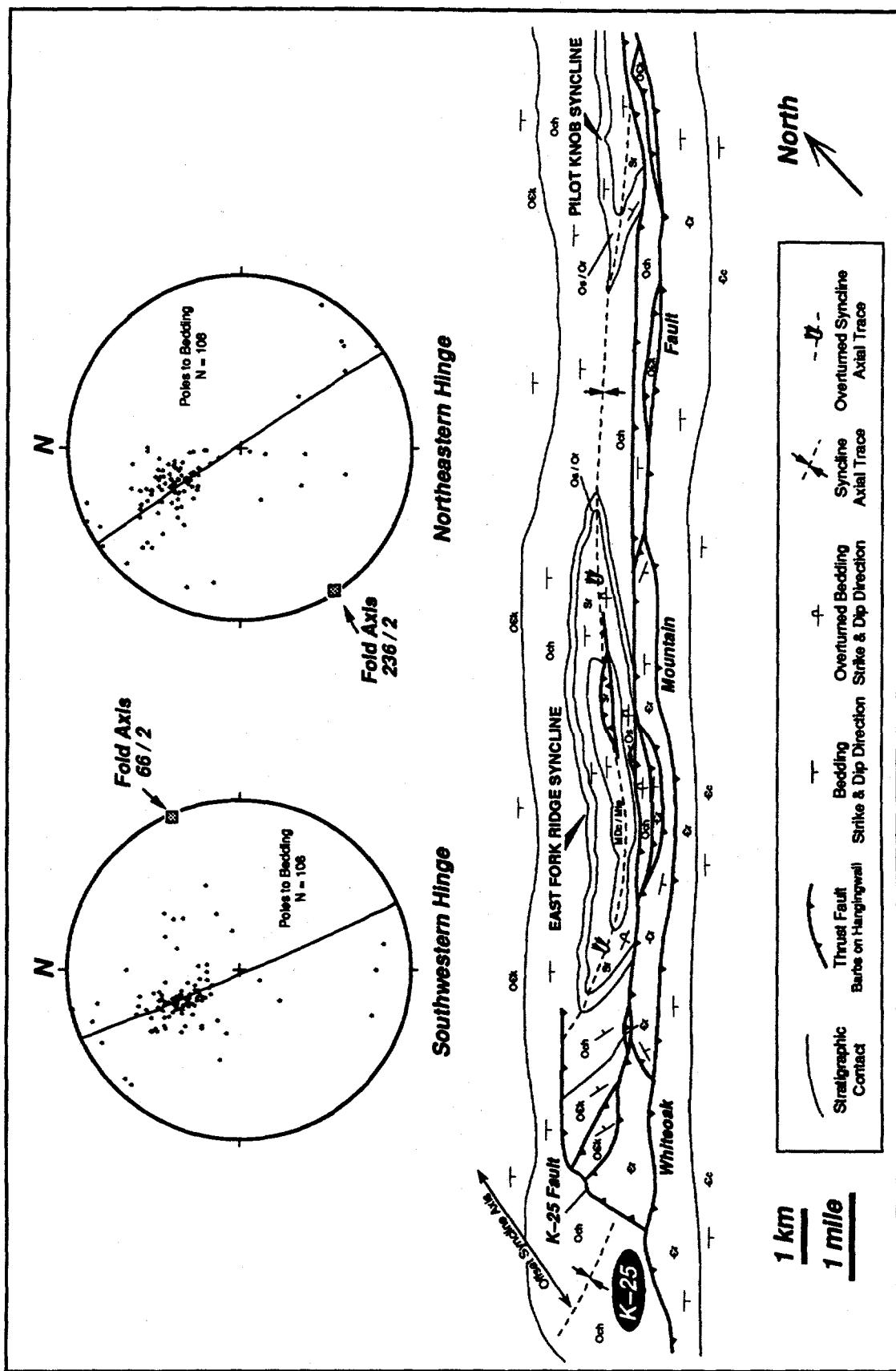


Fig. 6. Geology along the Whiteoak Mountain fault in the Oak Ridge area. Equal area, lower-hemisphere, stereographic projections of poles to bedding around the southwestern and northeastern hinges of the East Fork Ridge syncline. Each syncline hinge was plotted separately to determine the local fold axis orientations properly. See Fig. 5 for key to stratigraphic unit symbols.

The southwestern end of the East Fork Ridge syncline is offset by an array of faults that project farther into the footwall of the Kingston thrust sheet than anywhere else along the trace of the WM fault. The faults are located primarily within and to the south of McKinney Ridge. This zone of faulting is bounded to the southwest and north by a fault that, for the purpose of discussion, is named the K-25 fault (Fig. 7). In map view, the fault projects off the mapped trace of the WM fault striking to the northwest and then changes strike toward the northeast, where displacement decreases to zero at the tip line. The position of the fault to the north of McKinney Ridge is fairly well constrained by the truncation of Knox Group rock units. The location of the fault towards the northeast is fairly well-constrained based on bedrock attitudes in the Chickamauga carbonates, but it may continue down the valley parallel to the strike of bedding. The position of the fault to the southwest is the least certain, but its position continues to be better-constrained as more subsurface information about the K-25 Site area becomes available. Little can be inferred about the subsurface geometry of the K-25 fault, but down-plunge projections suggest that it dips beneath the East Fork Ridge syncline.

The geometry of the southwestern hinge of the East Fork Ridge syncline has been modified by displacement along the K-25 fault. Fault displacement appears to have caused a clockwise rotation of the fold hinge towards the northwest (Fig. 6). In addition, fault displacement has offset the syncline fold hinge in the Chickamauga carbonates and transported it towards the northwest. The Chickamauga carbonates in the plant area are folded not into a single large syncline but into an anticline and syncline pair. (See the B-B' cross section shown in Fig. 8.) Although the folds are open and not overturned, the orientation of the map-scale folds is similar to the larger East Fork Ridge syncline. The folds trend and plunge very gently to the northeast under the plant area. Numerous outcrop-scale folds and faults occur within the area and probably formed as a means to accommodate the shortening within the folded carbonates. Although offset on the faults observed in outcrop is commonly small, a few of the faults could have a significant amount of displacement.

A map of mesoscopic folds and faults found in outcrops across the area depicts a consistent zone of deformation that extends to the southwest, subparallel to the northeast striking portion of the K-25 fault (Fig. 9). The zone is located within the upper part of the Carters Limestone and may correlate with the northeast-striking portion of the K-25 fault. In order for the fault to extend in this direction, however, displacement must be decreasing along the fault to the southwest, because faulting has not disrupted formations in the Knox Group. Additional evidence for the presence of the fault at depth, however, may be the development of the syncline-anticline pair present in the Chickamauga carbonates in the K-25 Site area. In order for folding to occur in the carbonates, a fault must exist in the subsurface that detaches the overlying folded carbonates from the underlying rocks. The deformed zone in the upper Carters Limestone may be the location where the fault intersects the land surface. If this hypothesis is correct, then the northwest striking portion of the K-25 fault may not be continuous with the northeast-striking portion, but a different fault entirely that was truncated and offset by this northeast-striking thrust fault. Additional subsurface information is needed to constrain the above hypothesis, and therefore a continuous fault zone is not plotted on the preliminary geologic map.

In the hanging wall, the presently mapped K-25 fault cuts steeply through fault slices of the Rome Formation, Copper Ridge Dolomite, Chepultepec Dolomite and then through a

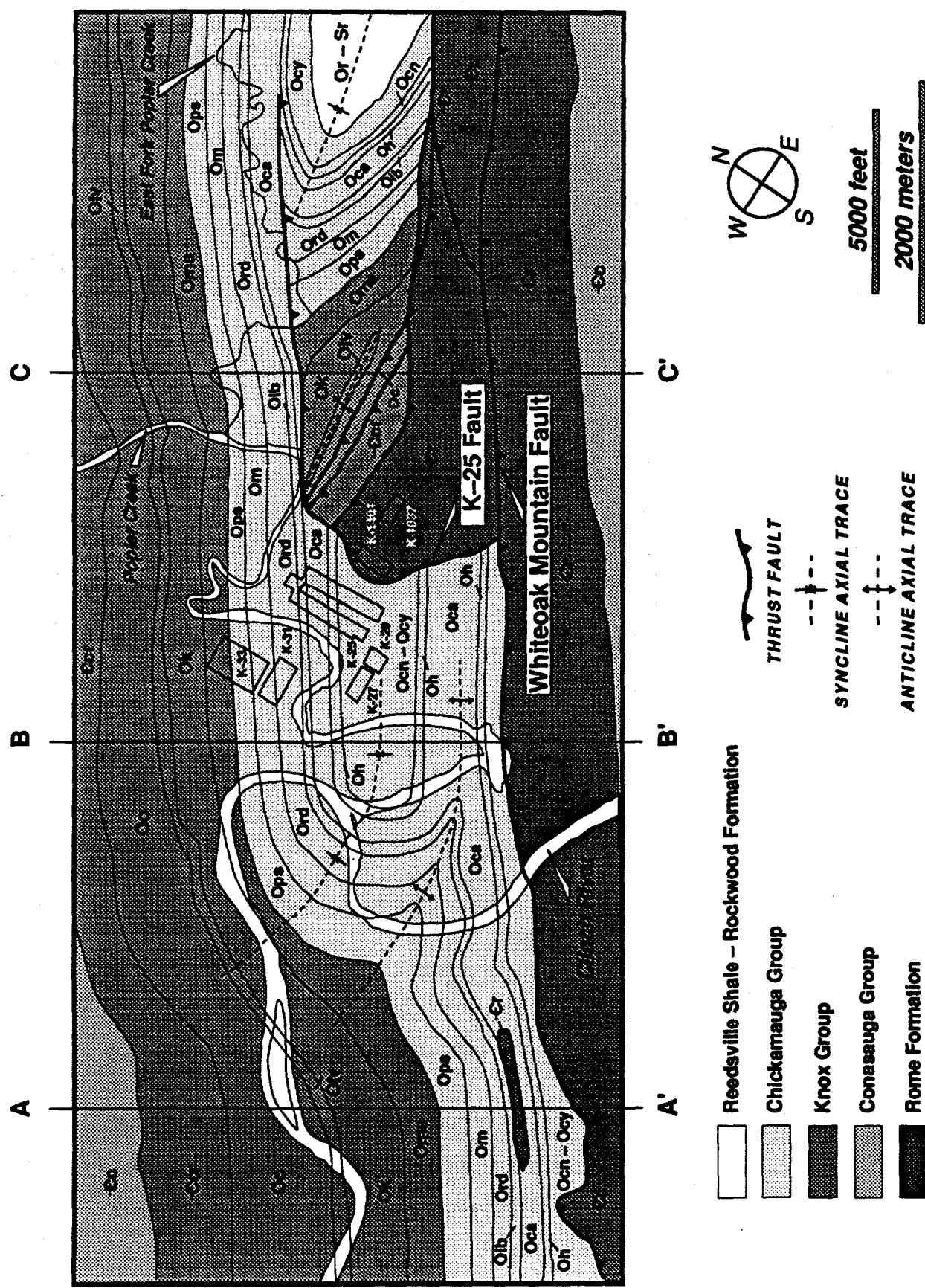


Fig. 7. Bedrock geologic map of the K-25 Site area with locations of cross sections. See Fig. 5 for key to stratigraphic unit symbols.

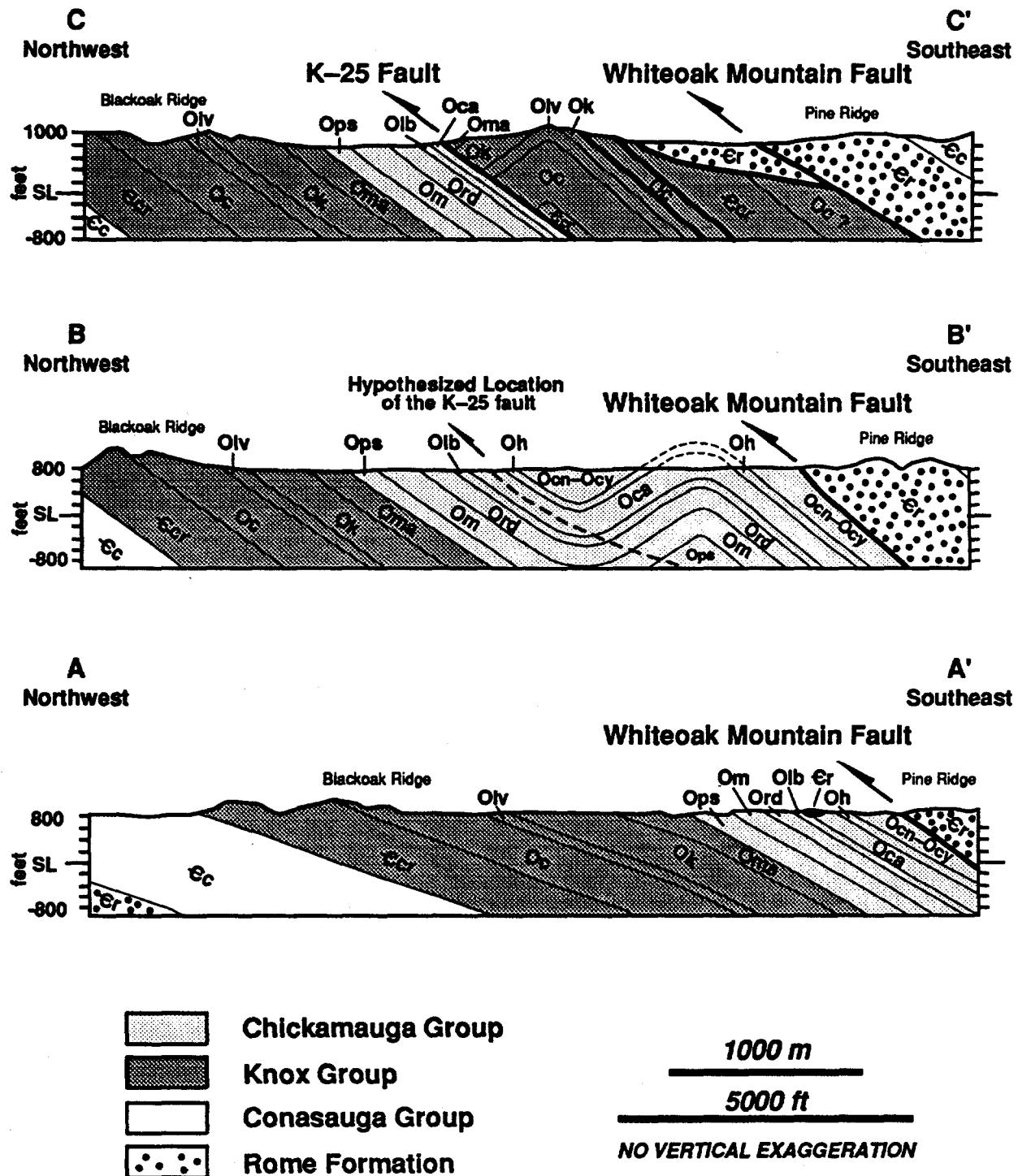


Fig. 8. Geological cross sections across the K-25 Site area. See Fig. 5 for key to stratigraphic unit symbols.

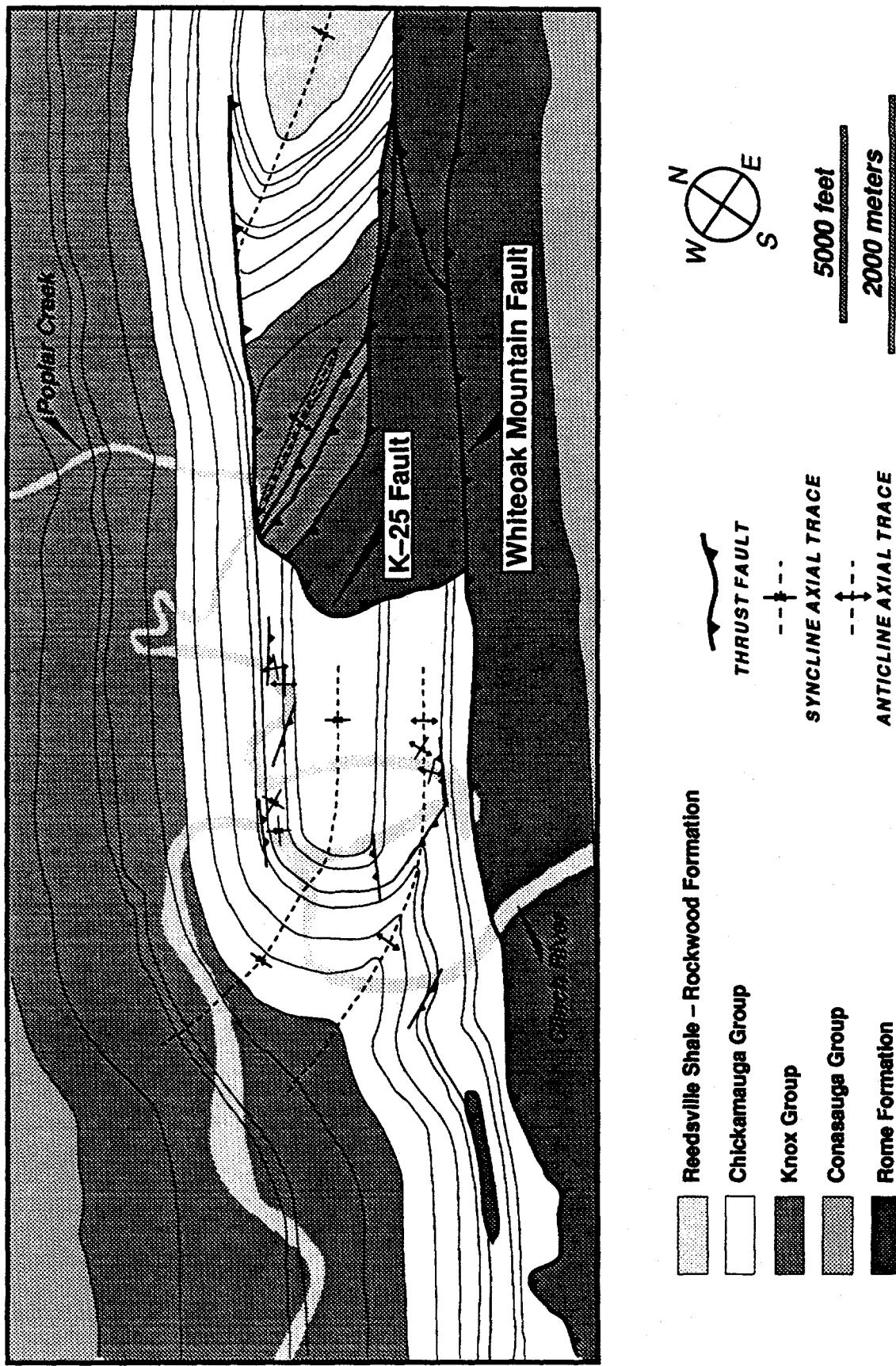


Fig. 9. Map of mesoscopic faults and folds.

folded sequence of the Kingsport Formation and Longview Dolomite that continues into the Chickamauga Supergroup. (See the C-C' cross section shown in Fig. 8.) In the footwall, the fault cuts obliquely through folded bedding of the Chickamauga Supergroup and then strikes subparallel to bedding in the Carters Limestone. The fault cuts through bedding at a high angle because stratigraphic cutoffs in both the hanging wall and footwall are closely spaced. The footwall cutoffs that match those in the hanging wall are not evident in map view and therefore must exist in the subsurface. The amount of displacement along the K-25 fault is unknown, but the direction of displacement along the fault is interpreted to be primarily towards the northwest because that was the regional shortening direction. Assuming northwest-directed displacement therefore requires that the northwest-striking portion of the fault be an oblique ramp and the northeast-striking portion of the fault be a frontal thrust.

Bedding orientations within the fault-bounded slice of the Rome Formation in the Grid D5 area (see Appendix B) suggest that it is complexly deformed by mesoscopic folds and faults. The slice appears to comprise primarily lower Rome shales, but the low hills are underlain by upper Rome sandstones. Except where the slice is truncated by the K-25 fault, the areal extent of the slice is not tightly constrained, because of the lack of surface exposures. A number of observations, however, indicate that the fault-bounded slice of the Rome sits on top of Chickamauga carbonates and may be relatively thin. First, approximately along strike to the southwest is a small fault-bounded slice (klippe) of the Rome Formation that sits on top of Chickamauga carbonates. Erosion through the lower Rome shales in the area exposed Chickamauga carbonates at relatively shallow depths. Similar fault-bounded slices of Rome sitting on carbonates are at various points along the trace of the WM fault (Hardeman 1966). Second, a few bedrock well logs in the area indicate that parts of the Rome are thin and may sit on top of carbonates. Third, regional structural relationships associated with the WM fault have been used to hypothesize that the fault had a late episode of movement that may have emplaced a continuous slice of the Rome Formation all along the footwall, which has now been dissected by erosion (Lemiszki and Hatcher 1992). The strong contrast in rock types across the fault zone suggests that the size and geometry of the fault slice could be accurately delineated with a combination of drilling and surface geophysical surveys.

One of the faults mapped in the Knox Group on McKinney Ridge is well exposed in the abandoned quarry off Blair Road. In the quarry, the fault is oriented approximately N70E / 66 SE, and juxtaposes the middle (?) part of the Chepultepec Dolomite against the upper part of the Kingsport Formation and therefore has accommodated some thrust displacement. Beds in both the hanging wall and footwall are variably folded, faulted, and fractured adjacent to the fault. Another reverse fault that places the Copper Ridge Dolomite against the Chepultepec Dolomite is interpreted to cut through a poorly exposed portion of the quarry. Previous studies of bedrock well logs in the area have been used to suggest that the fault slice of Copper Ridge Dolomite may contain a continuous sequence into the upper Conasauga Group on the south side of McKinney Ridge, but additional drilling is needed to test this hypothesis. One line of evidence that suggests that the McKinney Ridge structures are continuous on the south side of Blair Road is the similar bedrock attitudes measured in shales along the upper reaches of Mitchell Branch. Although shales in Mitchell Branch are mapped as Rome, there was not enough exposure to determine whether they are actually Conasauga Group shales that are either in a another thrust slice or part of a continuous sequence below the Copper Ridge Dolomite off of McKinney Ridge. Total displacement on the faults in the

Knox Group is unknown, but may be minor because the faults are cutting steeply through bedding with little stratigraphic separation.

4.2 BEDROCK FRACTURE SYSTEM

Bedrock groundwater flow on the ORR occurs primarily through a system of open and connected fractures (Solomon et al. 1992). Therefore, various attributes of the bedrock fracture system must be known in detail to best interpret groundwater flow tests and model contaminant plume migration. Previous studies of the bedrock fracture system on the ORR have concluded that the fractures are not randomly oriented, but belong to distinct sets (Hatcher et al. 1992). Each fracture set is defined by a consistent orientation, style, and cross-cutting relationship with other fracture sets within a particular area. Establishing the existence of distinct fracture sets is important because of the possibility of highly anisotropic fracture permeabilities and their control on karst conduit development. Since no previous work has been done, information pertaining to the fracture system in the K-25 Site area was collected during geologic mapping.

Time constraints prevented a complete fracture analysis of most outcrops during field mapping. Therefore, in order to acquire a data set representative of the fracture system in the area, fracture orientation data were collected by the selection method (Davis 1984). The method involves identifying individual fracture sets in each outcrop and taking one or two measurements to document the range in orientation of each set. A total of 114 fracture set measurements, primarily in the carbonates of the Chickamauga Supergroup were recorded by this method. Besides orientation, information pertaining to fracture type, timing, aperture, mineralization, and host rock type were recorded for each fracture set. The following discussion describes the characteristics and presents preliminary interpretations of the fracture system in the area. Future work on a number of outcrops, however, is needed to characterize the attributes of each fracture set more precisely.

The fracture system in the K-25 Site area consists of regional fracture sets that are similar to those mapped throughout the ORR and local fracture sets related to folding and faulting. In order to accommodate the background of the reader, the fracture orientation data are presented in four different ways: (1) a map of fracture strikes (Fig. 10), (2) a stereonet plot of poles to fracture planes, (3) a rose diagram of fracture strikes, and (4) a graph of fracture dip angle vs fracture azimuth (Fig. 11). All of the plots attest to the presence of a complex fracture system in the area, which is only beginning to be understood.

The map of fracture strikes is the most useful because it displays changes in fracture orientation across the area and how the fracture orientation relates to the bedrock geology (Fig. 10). Fracture strikes that are parallel and perpendicular to bedrock strike are representative of two major fracture sets in the area. These fracture sets have average strike and dips of N60 / 50NW and N30W / 90. Although more data are needed, orientation of each fracture set appears to rotate systematically across the plant area with changes in bedding strike. This is one reason for the wide distribution of fracture orientations seen on the other fracture plots. These fracture sets have been identified throughout the ORR and have been interpreted to have formed prior to the development of the thrust belt. Northeast of the plant area, previous work in the Kingston thrust sheet and East Fork Ridge syncline concluded that

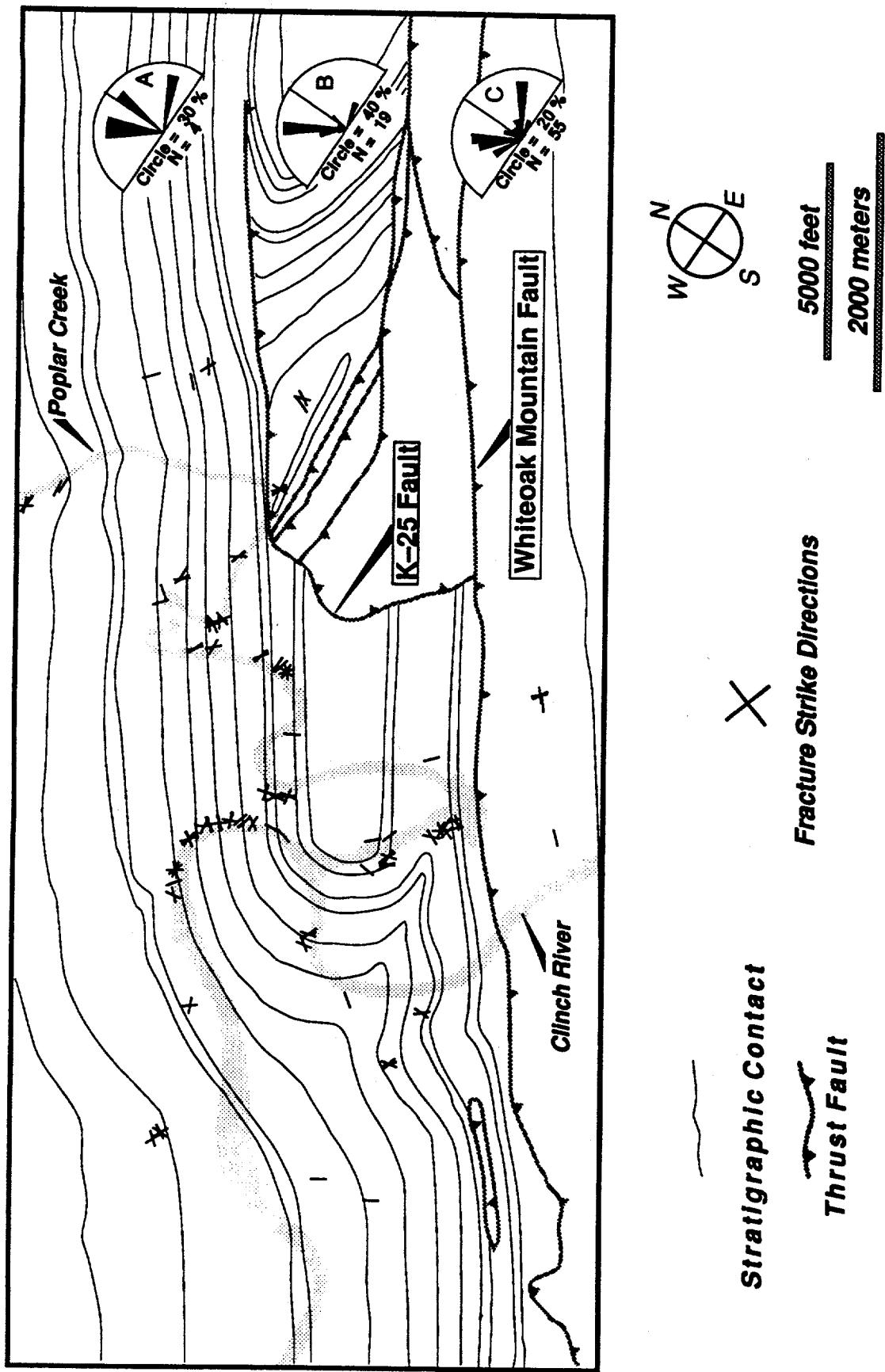


Fig. 10. Map of fracture set strikes measured in outcrops across the K-25 Site area. Inset A is a rose diagram of fracture strikes from Blackoak Ridge. Inset B is a rose diagram of fracture strikes from the southwest end of the East Fork Ridge syncline. Inset C is a rose diagram of fracture strikes from the Rome Formation in the Whiteoak Mountain thrust sheet.

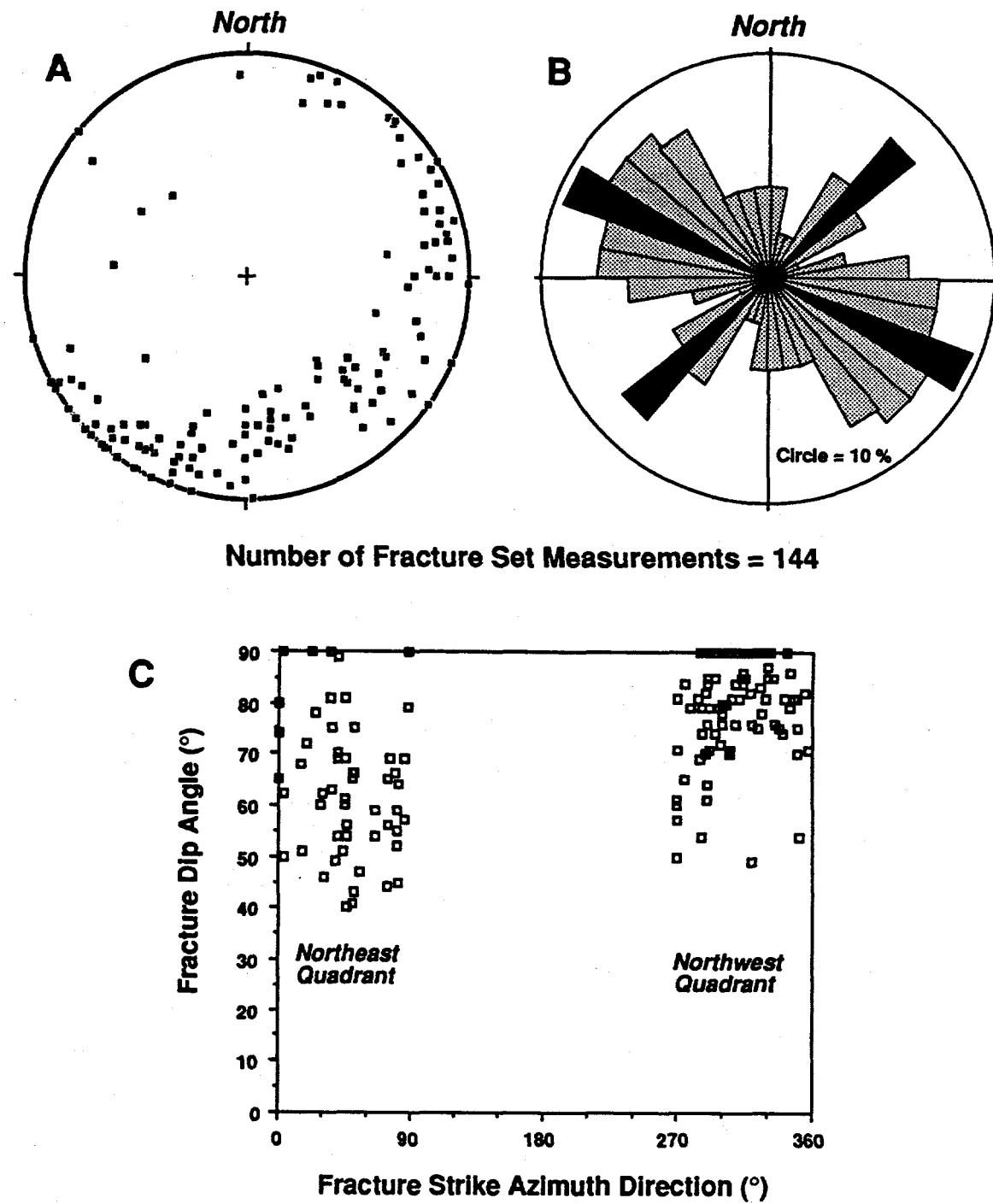


Fig. 11. Fracture data plots for the K-25 Site area. Plate A is an equal area, lower hemisphere, stereonet plot of poles to fracture set planes. Plate B is a rose diagram of fracture set strikes. Plate C is an x-y plot of fracture strike azimuth vs fracture dip angle.

the two dominant fracture sets have an average strike and dip of N65E / 53NW and N30W / 89NE (Hatcher et al. 1992).

The regional fracture sets consist primarily of extension fractures. The fractures are commonly oriented perpendicular to bedding, and although they may continue through a number of carbonate beds, they terminate at bed contacts where there is a distinct change in sedimentologic characteristics (i.e., lithology, bed thickness). The fractures are commonly widely spaced individual breaks, but zones of closely spaced fractures also occur. Many of the fractures are now open, but the presence of numerous calcite-filled fractures suggests that they were once all sealed and may be commonly sealed at depth. Calcite-filled fractures have apertures ranging from less than 1 mm to as much as 2 cm. Weathering of the calcite filling and surrounding rock has greatly enlarged the aperture measured in open fractures.

Overprinting the regional fracture sets are arrays of shear fractures that are more abundantly developed in the K-25 Site area than in any other part of the ORR. Shear fractures differ from the regional extension fracture sets because displacement is primarily parallel to the walls of the fracture. Shear zones range from single, discrete fractures to wide zones consisting of conjugate arrays of en echelon tension gashes (Fig. 12). The zones are commonly perpendicular to bedding. Shear zones indicative of both left-lateral and right-lateral strike slip displacement have been observed based on mineral filling geometries and offset chert markers. The development of shear fracture zones is closely related to folding and faulting in the area. Therefore, the relative distribution and geometry of shear fracture zones may be a useful way to detect the location of unknown faults. Much more information needs to be collected about these zones before their influence on groundwater flow can be ascertained. More studies are needed to determine (1) their distribution across the area; (2) the variables that control their overall dimensions, both parallel and perpendicular to bedding; and (3) the factors that control the development of long, continuous shear fractures vs shear zones of short, disconnected en echelon tension gashes.

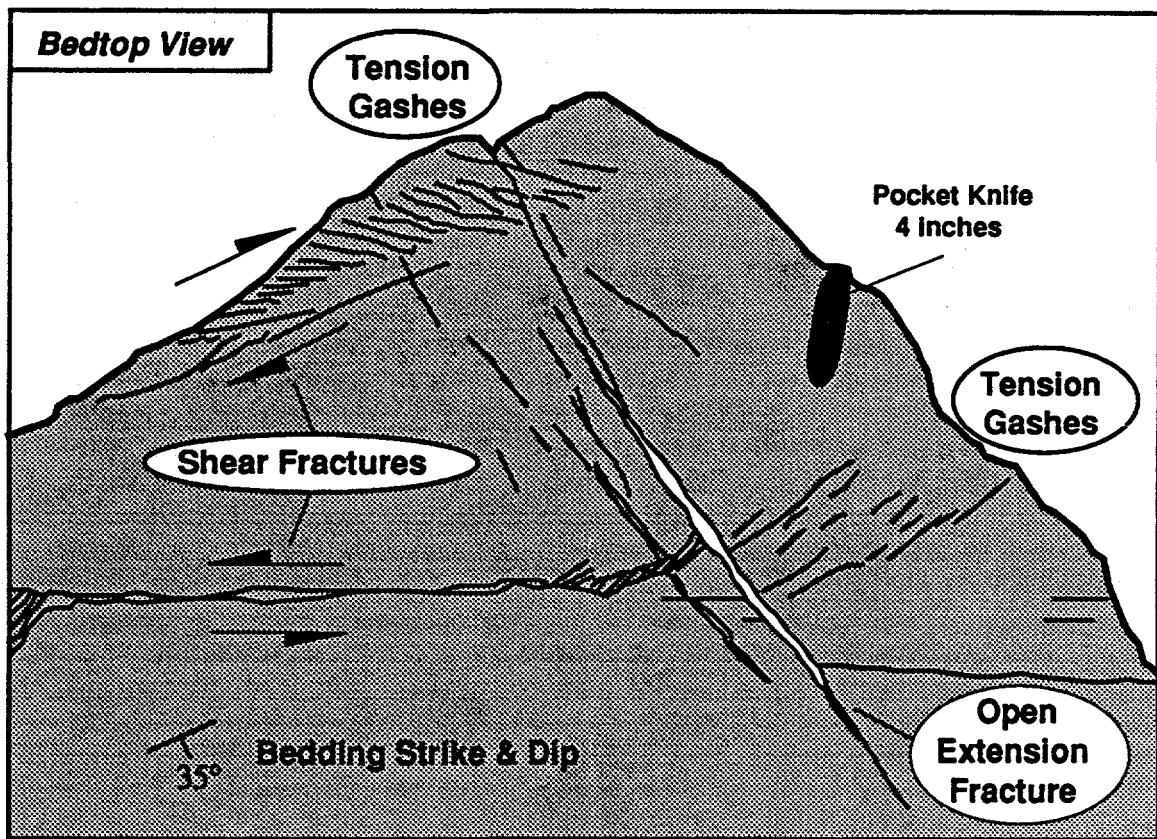


Fig. 12. Sketch from a photograph of an outcrop in the Murfreesboro Limestone. The style of extension and shear fracture sets observed in the K-25 Site Area is illustrated.

5. KARST LANDFORMS, SEEPS, AND SPRINGS

A number of karst landforms, seeps, and springs were encountered during field mapping (Fig. 13). Because of their importance in characterizing the groundwater system in the area, the location and general characteristics of these features were noted and can be used as a preliminary data base for future karst studies. Although a more complete karst study is needed, none of the karst features appeared to be preferentially developed within any particular stratigraphic unit. For simplicity, the term *spring* is used throughout the following text.

Open cavities ranged from bedrock exposures with human-sized enterable openings to small drains at the bases of sinkholes. The cave located on Blackoak Ridge in the Copper Ridge Dolomite is called Winkin Cave and has been explored and mapped (Bruce Zerr, personal communication 1993). This cave may be representative of those that develop in the Knox Group on Blackoak Ridge and should be more thoroughly studied. Some of the other open cavities were examined (Paul Rubin, personal communication 1993) to determine if they could be used as entry points into an underlying a cave system. Based on this analysis, the only cave that was enterable and extended any distance is located on McKinney Ridge near East Fork Creek (Fig. 13).

The majority of springs mapped are located along the banks of the Clinch River in the Chickamauga Supergroup. Most of the year the springs are underwater, but the springs were exposed because most of the mapping occurred during the winter low stage of the Clinch River. Springs ranged from water flowing out of bedrock openings to large water-filled potholes in the river bank flats. The potholes were actively filling at their base and overflowing at the tops to drain into the nearby river. Spring flows ranged from small trickles of water to estimated flows of as much as 25 gal/min. The locations of the springs encountered were mapped as accurately as possible so that they could be revisited for future water sampling. In addition, detailed knowledge of the location of underwater springs in the Clinch River can be used to test for suitable methods that can detect underwater springs in the area. A few springs were also mapped in drainages off of hills underlain by the Rome Formation.

One sinking stream was found during mapping (Fig. 13). The location of the sinking stream is on the southeast side of Blackoak Ridge at the corner of East Fork and Herrell roads. The stream is fed from a catchment on the ridge and sinks into a cavity in the Mascot Dolomite at the base of the ridge near the contact with the Pond Spring Formation. The exact location of the spring related to the sinking stream is unknown, but some springs were located towards the southwest near East Fork creek.

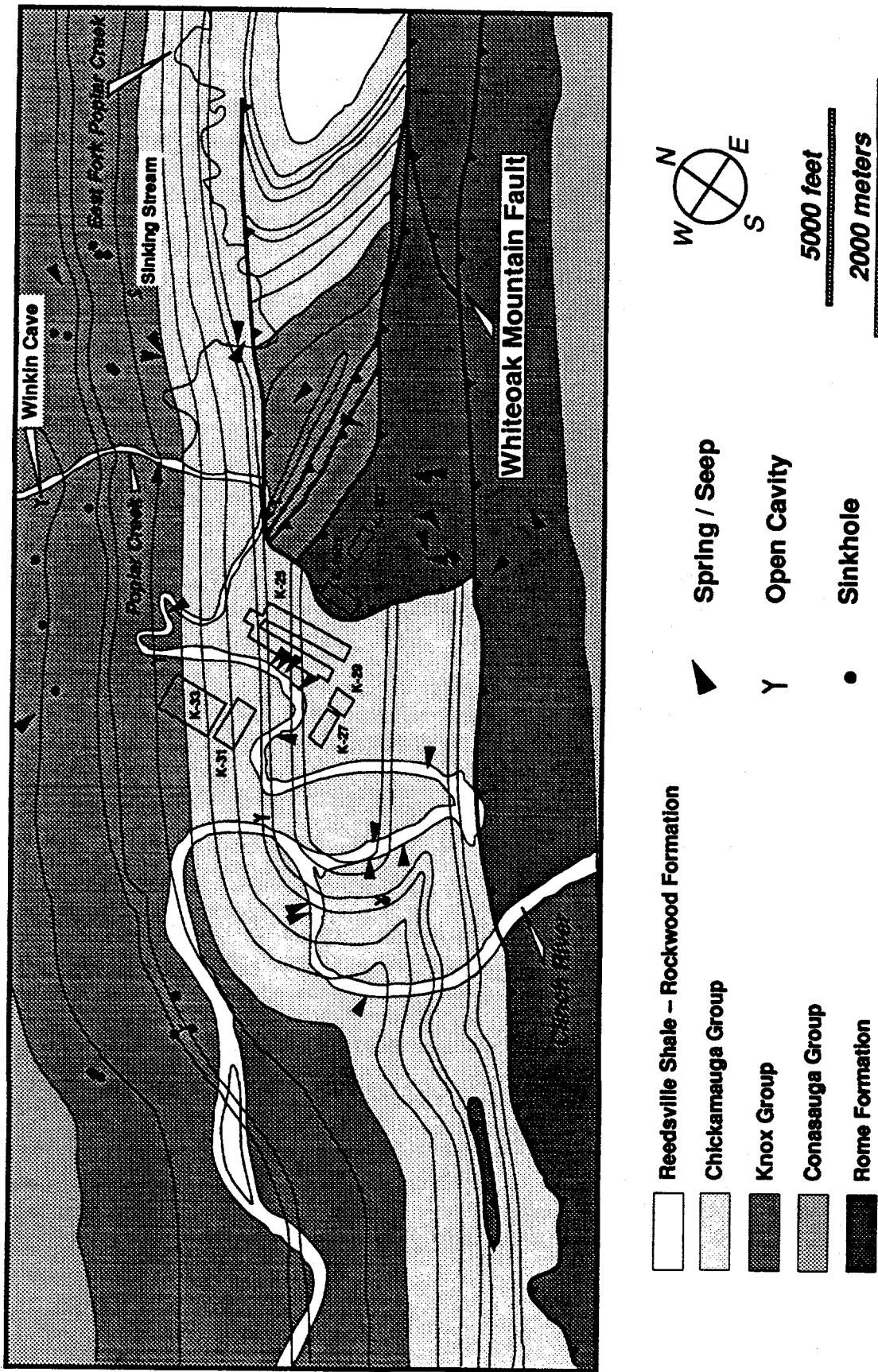


Fig. 13. Map of karst landforms, seeps, and springs area encountered during geological mapping in the K-25 Site.

6. SUMMARY AND SUGGESTIONS FOR FUTURE WORK

The primary goal of site geologic studies should be to develop a thorough and defensible understanding of the K-25 Site geology and how it relates to the groundwater flow system. Geologic mapping is the first step toward attaining this goal and will provide the framework in which to develop and interpret future detailed geologic and groundwater studies.

Geologic mapping in the K-25 Site area has resulted in better definition of the location of contacts between the major rock units (Rome Formation, Knox Group, and Chickamauga Supergroup) and allowed for division of the Knox Group and Chickamauga Supergroup into mappable units based on field criteria. In addition, excellent exposures of the Chickamauga Supergroup along the Clinch River and East Fork Poplar Creek has lead to a better understanding of the rock types composing the individual formations.

As expected, the structures within the plant site are complex and appear to consist of an anticline and syncline pair affecting only rocks of the Chickamauga Supergroup. The amount of internal deformation (faulting) within the anticline and syncline, however, is poorly constrained. Similarly, because of poor exposure, the location of the WM fault has not been constrained any more precisely than in previous maps. Finally, a preliminary analysis of the fracture system in the area indicates the presence of the reservation-wide regional fracture sets, as well as the development of an extensive array of shear fractures related to the local folds and faults.

As indicated above, more information needs to be gathered concerning a number of factors related to the site geology. The sections that follow comprise a partial list of recommendations for future geologic studies that should lead to a better understanding of the plant geology.

6.1 BEDROCK CORE DRILLING AND GEOPHYSICAL WELL LOGGING

Drilling should intersect a number of key targets, both stratigraphic and structural, to begin constraining subsurface structural interpretations related to: (1) the hypothesized fault underlying the folded carbonates in the plant area, (2) the geometry of the K-25 and Whiteoak Mountain faults, (3) the lateral and vertical extent of the fault slice of the Rome Formation, and (4) the extent of internal faulting within folded carbonates in the plant area.

Subsurface stratigraphic and structural relationships determined from drilling can be combined with surface maps to create detailed cross sections and block diagrams.

Coring is needed to characterize the style, distribution, and geometry of mesoscopic structures in the subsurface, such as fractures, folds, faults, and stylolites, and their relationship to bed thickness, lithology, structural position, and depth.

The development of coring-induced fractures in rock cores can be used to estimate the orientation of the in-situ stress field, which, depending upon its orientation, can affect the effective aperture of certain fracture sets.

6.2 OUTCROP STRUCTURAL ANALYSIS

Fracture development has a strong influence on both solution development in the carbonates and preferential groundwater flow paths in the noncarbonates. The purpose of outcrop structural analysis is to relate the characteristics of the local fracture system to the mechanical characteristics of the stratigraphy and regional and local structural history. The study should incorporate a combination of detailed outcrop fracture mapping (orientation, spacing, lengths, etc.); petrographic analysis of veins to determine fracture opening modes; timing relationships; initial apertures; local secondary porosity characteristics; and mineral filling compositions. The information can then be used to: (1) evaluate which rock units will have the potential for enhanced fracture porosity and permeability, (2) predict units with potential confining capabilities, (3) predict potential conduit orientations, and (4) develop an understanding of the changes in open fracture development with depth.

6.3 OUTCROP STRATIGRAPHIC ANALYSIS

Outcrop stratigraphic analysis is needed to provide a more detailed description of each rock unit in the K-25 Site area. Sedimentologic studies should include (1) measurement of true stratigraphic thicknesses, (2) documentation of lithologic characteristics, (3) evaluation of the potential for lateral and vertical facies changes within each rock unit, and (4) thin-section analysis to determine rock mineral constituents and their chemical composition. Such studies are needed prior to or in conjunction with drilling to help interpret and correlate core descriptions within a larger depositional framework.

6.4 MATRIX POROSITY ANALYSIS

Although primary matrix porosity is very low in the rock units on the ORR, secondary matrix porosity is closely related to depth, composition, and local geologic relationships associated with a particular rock unit. Secondary and primary matrix porosity values are needed for modelling diffusional transport of contaminants and are closely related to the development of conduits in certain rock units. Matrix porosity values can be obtained by two easy and inexpensive methods. First, point-counting pore spaces during petrographic analysis of outcrop and core samples is a direct means of determining the matrix porosity of a particular sample and relating it to diagenetic relationships observed in the sample. Second, porosity analysis by the weight-reduction method can provide estimates of total porosity that can be compared with thin-section estimates.

6.5 GEOLOGY AND KARST DEVELOPMENT

An effort should be made to correlate karst landforms and features in bedrock well logs with particular stratigraphic units. Mature karst aquifers tend to be nonhomogeneous and

anisotropic when subjected to intensive weathering and where stratigraphy, structure, and topography contribute to complex permeability and porosity distributions. In the K-25 Site area, the distribution of conduits within the stratigraphic column should provide a measure of the solutioning in each type of carbonate and therefore measure the amount of lithologic control exerted on solution development. Factors influencing the development of intergranular, vugular, and fracture-controlled porosity and permeability should be of interest because they may account for the size and distribution of solution openings and contribute to the gross transmissive and storage characteristics of the aquifer. Furthermore, detailed geologic and hydrologic cave mapping may provide insight on some of the local geologic controls on karst development.

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Appendix A

STRATIGRAPHIC AND STRUCTURAL DATA

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Appendix A. STRATIGRAPHIC AND STRUCTURAL DATA

Table A-1 lists the grid location, rock unit, bedding orientation, and fracture set orientations recorded at each outcrop during field mapping. The following is an explanation of the table headings and abbreviations:

Station Station number recorded in field notes.

Grid Grid location based on S-16A topographic map.

Rock unit Stratigraphic group or formation; see Fig. 5 for symbol abbreviations.

Lithology CH = chert

DOL = dolomite

LS = limestone

SH = shale

SS = sandstone

Strike Positive numbers are northeast quadrant; negative numbers are northwest quadrant.

Dip Angle of dip from horizontal.

DD Dip direction.

Table A.1. K-25 Site area stratigraphic and structural data

STATION	GRID	ROCK UNIT	LITHOLOGY	FRACTURE			BEDROCK		
				STRIKE	DIP	DD	STRIKE	DIP	DD
1	A5	Ock	DOL	4	62	N	35	36	S
1	A5	Ock	DOL	80	55	N			
2	A5	Ock	DOL	52	75	N	62	39	S
3	A5	Ock	DOL				60	45	S
4	C5	Ock	DOL				-35	29	N
5	B6	Ock	DOL				50	30	S
6	B6	Ock	DOL				45	35	S
7	B6	Ock	DOL				50	25	S
8	B6	Ock	DOL	-48	85	S	55	32	S
9	B6	Ock	CH				65	45	S
10	A5	Ock	DOL				44	34	S
11	A5	Ock	DOL				42	37	S
12	A5	Ock	DOL				50	31	S
13	D4	Och	LS				61	32	S
14	D4	Och	LS				80	52	N
15	D4	Och	LS				70	18	N
16	D4	Och	LS						
17	D4	Och	LS				5	11	S
18	D4	Och	LS				66	59	S
19	D4	Och	LS				70	62	S
20	D4	Och	LS				50	65	S
21	D4	Och	LS				64	39	N
22	D4	Och	LS				78	22	S
23	D4	Och	LS				60	55	S
24	D4	Och	LS				50	52	N
25	D4	Och	LS				32	44	S
26	D4	Cr	SS/SH	-40	49	N	-61	41	S
26	D4	Cr	SS/SH	-61	76	S			
26	D4	Cr	SS/SH	-55	71	N			
26	D4	Cr	SS/SH	50	41	N			
27	D4	Cr	SS/SH				49	36	S
28	D4	Cr	SS/SH				45	61	S
29	D4	Cr	SS/SH	51	66	N	61	45	S
30	B4	Ock	CH				60	74	S
33	B4	Ock	DOL				15	33	S
34	D3	Cr	SS						
36	D3	Cr	SS/SH	40	89	S	61	41	S
37	D3	Och	LS				75	65	S
38	D3	Cr?	SH				75	55	S
39	C3	Och	LS	4	50	S	-30	51	S
40	C3	Och	LS	-23	75	N	74	32	N
40	C3	Och	LS	-26	85	S			
40	C3	Och	LS	-46	84	S			
41	C3	Och	LS				82	27	N
41	C3	Och	LS	-72	70	S	70	25	N
41	C3	Och	LS	-65	74	S			
41	C3	Och	LS	88	79	S			
41	C3	Och	LS	-15	86	S			
41	C3	Och	LS	-86	?	?			
42	C3	Och	LS	-58	80	N	70	25	N
43	C3	Och	LS				60	40	N
44A	C3	Och	LS				60	20	S
44B	C3	Och	LS				61	15	S
45	B2	Ock	DOL				-60	86	N
46	B2	Ock	DOL				46	28	S
47	B2	Ock	DOL	-65	90	N	14	35	S

Table A.1 (continued)

STATION	GRID	ROCK UNIT	LITHOLOGY	FRACTURE			BEDROCK		
				STRIKE	DIP	DD	STRIKE	DIP	DD
47	B2	Ock	DOL	40	70	N			
48	B2	Ock	CH	-65	85	S	24	39	S
48	B2	Ock	CH	0	65	W			
48	B2	Ock	CH	30	62	N			
49	B2	Ock	DOL/CH				15	45	S
50	B2	Ock	CH				30	35	S
51	B2	Ock	LS				26	41	S
52	B2	Ock	LS				30	21	S
53	B2	Ock	DOL				31	21	S
54	B2	Ock	CH	65	59	N	36	41	S
54	B2	Ock	LS	-40	90	N			
55	B2	Ock	CH				42	41	S
56	B2	Ock	DOL				25	35	S
57	B2	Ock	DOL				40	60	S
58	C1	Ock	CH				-81	22	S
59	B1	Ock	CH				81	45	S
60	D2	Och	LS				-80	15	S
61	D2	Och	LS	-45	85	N	-87	15	S
61	D2	Och	LS	2	90	N			
62	D2	Och	LS				86	24	S
63	D2	Och	LS				81	21	S
64	D2	Och	LS				-86	21	S
65	C2	Och	LS	36	75	S	39	20	N
66	C2	Och	LS				51	47	S
67	C3	Och	LS				-39	4	N
68	C3	Och	LS				-75	25	N
69	C3	Och	LS				-50	28	N
70	C3	Och	LS				-31	31	N
71	C3	Och	LS				-67	30	S
72	C3	Och	LS				5	25	S
73	C3	Och	LS				25	15	S
74	C3	Och	LS				0	17	W
75	C3	Och	LS				-40	14	N
76	C3	Och	LS	-70	85	S	-35	19	N
76	C3	Och	LS	-50	90	N			
76	C3	Och	LS	-15	79	S			
77	C3	Och	LS				-55	24	N
78	C3	Och	LS	-10	75	S	-60	25	N
78	C3	Och	LS	35	90	N			
79	D2	Och	LS				25	80	N
80	D2	Och	LS				20	24	S
81	C3	Och	LS	-17	90	N	76	44	S
81	C3	Och	LS	76	69	N			
82	C3	Och	LS	-60	80	N	70	36	S
82	C3	Och	LS	-60	90	N			
83	C3	Och	LS	-10	70	S	70	74	S
84	C3	Och	LS				60	60	S
85	C3	Och	LS	-10	81	S	50	46	S
85	C3	Och	LS	80	52	N			
85	C3	Och	LS	-30	85	S			
86	C3	Och	LS				70	50	S
87	C3	Och	LS				62	44	N
88	C3	Och	LS	-72	82	S	66	21	N
89	C3	Och	LS	-44	90	N	85	30	N
90	C3	Och	LS				60	47	S
91	C3	Och	LS				74	51	S

Table A.1 (continued)

STATION	GRID	ROCK UNIT	LITHOLOGY	FRACTURE			BEDROCK		
				STRIKE	DIP	DD	STRIKE	DIP	DD
93	C3	Och	LS	15	68	N	62	46	S
94	C3	Och	LS				61	59	S
95	C3	Och	LS				62	60	S
96	C4	Och	LS	16	51	N	51	20	S
96	C4	Och	LS	-56	70	N			
97	B4	Och	LS	50	66	N	64	35	S
97	B4	Och	LS	-40	76	N			
98	B4	Och	LS	29	60	N	50	37	S
98	B4	Och	LS	-55	90	N			
99	B4	Och	LS	50	65	N	55	31	S
100	B4	Och	LS				60	42	S
101	B4	Och	LS				61	28	S
102	B4	OCK	DOL				60	25	S
103	B4	OCK	DOL				60	31	S
104	B4	OCK	DOL				59	32	S
105	B4	Och	LS				46	25	S
106	B4	Och	LS	-71	64	N	60	41	S
106	B4	Och	LS	-50	90	N			
107	B4	Och	LS				71	31	S
108	B4	Och	LS	86	69	N	61	30	S
108	B4	Och	LS	-44	90	N			
109	B5	Och	LS				74	30	S
110	B5	Och	LS				70	25	S
111	B5	Och	LS				61	30	S
112	C4	Och	LS	-31	90	N	65	38	N
113	C4	Och	LS				75	34	S
114	C4	Och	LS				65	39	S
115	C4	Och	LS				71	44	S
116	C4	Och	LS				67	39	S
117	C4	Och	LS				66	36	S
118	C4	Och	LS				64	41	S
119	C4	Och	LS				69	54	S
120	C4	Och	LS				66	49	S
121	C4	Och	LS	45	81	N	44	37	S
121	C4	Och	LS	-52	90	N			
121	C4	Och	LS	-2	71	S			
121	C4	Och	LS	90	57	N			
122	C4	Och	LS	-76	69	N	55	21	S
123	C4	Och	LS	90	71	N	36	39	S
123	C4	Och	LS	-86	84	N			
124	C4	Och	LS				24	22	S
125	C4	Och	LS				43	21	S
126	C4	Och	LS	-70	90	N	69	29	S
126	C4	Och	LS	-76	90	N			
126	C4	Och	LS	-51	90	N			
128	C4	Och	LS				67	22	S
129	C4	Och	LS				61	20	S
130	C3	Och	LS				59	32	S
131	C3	Och	LS	-25	76	S	51	39	S
131	C3	Och	LS	65	54	N			
131	C3	Och	LS	74	65	N			
131	C3	Och	LS	74	56	N			
132	C3	Och	LS				46	36	S
133	C3	Och	LS				51	41	S
134	C3	Och	LS	40	54	N	42	34	S
134	C3	Och	LS	45	69	N			

Table A.1 (continued)

STATION	GRID	ROCK UNIT	LITHOLOGY	FRACTURE			BEDROCK		
				STRIKE	DIP	DD	STRIKE	DIP	DD
134	C3	Och	LS	-37	90	N			
135	B3	Och	LS	44	51	N	41	36	S
135	B3	Och	LS	-41	90	N			
136	B3	Och	LS	82	64	N	46	46	S
136	B3	Och	LS	-30	87	N			
137	B3	Och	LS				46	40	S
138	B3	Och	LS				46	34	S
139	B3	OCh	DOL	47	40	S	46	42	S
140	C3	Och	LS				50	36	S
141	C3	Och	LS				62	41	S
142	C3	Och	LS				59	45	S
143	C3	Och	LS				61	42	S
144	C3	Och	LS				49	44	S
145	C3	Och	LS	90	81	N	50	41	S
145	C3	Och	LS	35	81	N			
146	C3	Och	LS	-70	84	N	56	26	S
146	C3	Och	LS	-74	54	N			
147	C3	Och	LS	74	44	N	51	30	S
148	B5	OCh	DOL	-31	81	N	54	31	S
148	B5	OCh	DOL	90	60	N			
148	B5	OCh	DOL	-70	76	N			
149	B5	OCh	DOL	-86	65	N	49	48	S
149	B5	OCh	DOL	90	60	N			
150	B5	OCh	DOL				57	31	S
151	B5	OCh	DOL				49	38	S
152	B5	OCh	DOL				54	41	S
153	B5	OCh	DOL				51	37	S
154	B5	OCh	DOL	85	57	N	61	31	S
155	B5	OCh	DOL				52	32	S
156	B5	OCh	DOL				56	47	S
157	B5	OCh	DOL	90	50	N	46	34	S
158	B5	OCh	DOL				62	33	S
159	B5	OCh	DOL				59	32	S
160	B5	OCh	DOL				54	34	S
161	B5	Och	LS				42	26	S
162	B5	OCh	DOL				62	46	S
163	B5	OCh	DOL	-36	75	S	57	39	S
163	B5	OCh	DOL	-62	72	N			
164	B5	OCh	DOL	90	61	N	61	51	S
165	B5	Och	LS				49	60	S
166	C5	Och	LS				34	46	S
167	C5	Och	LS				32	42	S
168	C5	Och	LS	-69	71	N	59	29	S
168	C5	Och	LS	-31	90	N			
168	C5	Och	LS	-74	74	N			
169	C5	Och	LS				56	30	S
170	C5	Och	LS				60	36	S
171	C5	Och	LS				56	47	S
172	B4	OCh	DOL	40	69	N	58	41	S
173	B4	OCh	DOL	-49	81	N	45	39	S
174	B4	OCh	DOL				47	34	S
175	B4	OCh	DOL				59	36	S
176	B4	OCh	DOL				61	31	S
177	D3	Och	LS				54	24	S
178	D3	Och	LS	23	90	N	61	24	S
178	D3	Och	LS	-77	81	N			

Table A.1 (continued)

STATION	GRID	ROCK UNIT	LITHOLOGY	FRACTURE			BEDROCK		
				STRIKE	DIP	DD	STRIKE	DIP	DD
179	D3	Och	LS	-51	84	N	36	20	S
180	D3	Och	LS	51	43	N	70	46	S
181	D3	Och	LS				81	45	S
182	D3	Och	LS				54	33	S
183	D3	Och	LS	0	74	W	59	41	S
183	D3	Och	LS	45	60	N			
184	D3	Och	LS	88	90	N	71	44	S
185	D3	Och	LS	82	45	N			
185	D3	Och	LS	-35	83	S	68	36	S
185	D3	Och	LS	36	63	N			
186	D3	Och	LS	-20	74	S	61	10	S
186	D3	Och	LS	25	78	N			
187	D3	Och	LS				56	62	N
188	D3	Och	LS				76	31	S
189	D1	Och	LS				50	10	S
190	C2	OCh	DOL				25	14	S
191	C2	OCh	DOL				35	15	S
192	C2	OCh	DOL				32	32	S
193	C2	OCh	DOL	-31	90	S	46	28	S
194	C2	OCh	DOL				31	26	S
195	C2	Och	LS	-12	81	S	11	31	S
195	C2	Och	LS	-51	90	N			
195	C2	Och	LS	-74	79	N			
196	C2	Och	LS				21	19	S
197	D5	Cr	SS				60	51	S
198	D5	Cr	SS				61	67	S
199	D5	Cr	SS				61	81	S
200	D5	Cr	DOL				82	79	S
201	C5	OCh	DOL	0	80	W	75	69	N
201	C5	OCh	DOL	-71	61	N			
201	C5	OCh	DOL	-61	90	N			
201	C5	OCh	DOL	-42	82	S			
202	C5	OCh	DOL				31	41	S
202	C5	OCh	DOL				60	66	S
203	C5	OCh	DOL				80	31	S
204	C5	OCh	DOL				60	46	S
205	C5	OCh	DOL				-80	70	N
206	C5	OCh	DOL	19	72	N	-74	56	N
207	C5	OCh	DOL	31	46	S	-71	51	N
207	C5	OCh	DOL	-19	81	S			
208	C7	Och	LS				-10	28	N
209	B3	OCh	DOL	-63	79	N	66	34	S
209	B3	OCh	DOL	-82	79	N			
209	B3	OCh	DOL	-71	61	N			
209	B3	OCh	DOL	30	62	N			
209	B3	OCh	DOL	-46	86	S			
209	B3	OCh	DOL	39	49	N			
210	B3	OCh	DOL	-51	76	N	34	34	S
211	B3	OCh	DOL				51	36	S
212	B3	OCh	DOL				32	46	S
213	B3	OCh	DOL				31	34	S
214	B3	OCh	DOL				48	44	S
215	B3	OCh	DOL				61	32	S
216	B3	OCh	DOL	-34	78	N	51	36	S
216	B3	OCh	DOL	79	66	N			
216	B3	OCh	DOL	-69	79	N			

Table A.1 (continued)

STATION	GRID	ROCK UNIT	LITHOLOGY	FRACTURE			BEDROCK		
				STRIKE	DIP	DD	STRIKE	DIP	DD
216	B3	Ock	DOL	46	56	N			
217	B3	Ock	DOL				60	43	S
218	B3	Ock	DOL	-54	81	N	40	36	S
219	B3	Ock	DOL	46	54	N	30	34	S
219	B3	Ock	DOL	-9	54	S			
220	B3	Ock	DOL				46	44	S
221	C6	Och	LS				66	39	S
222	B6	Och	LS				64	30	S
223	B6	Och	LS				60	35	S
224	B6	Och	LS				51	32	S
225	B6	Och	LS	-61	78	N	45	34	S
225	B6	Och	LS	55	47	N			
226	B6	Och	LS				45	32	S
227	B6	Och	LS				47	49	S
228	B6	Och	LS				46	37	S
229	B6	Och	LS	45	61	N	44	36	S
230	B5	Ock	DOL				55	32	S
231	B5	Och	LS				55	32	S
232	B5	Och	LS				54	37	S
233	B5	Och	LS				56	42	S
234	B5	Och	LS				54	24	S
235	B5	Och	LS				61	34	S
236	B5	Ock	DOL				71	34	S
237	B5	Ock	DOL				51	44	S
238	B5	Ock	DOL				44	39	S
239	D5	Cr	SS				-10	15	S
240	C5	Cr	SS				72	69	N
241	C5	Cr	SS				90	51	N
242	C5	Cr	SS				82	85	N
243	C5	Cr	SS				86	72	N
244	C1	Ock	DOL				40	22	S
245	C1	Ock	DOL	-29	90	N	51	24	S
246	D1	Och	LS				55	27	S
247	D1	Och	LS				50	28	S
248	D1	Och	LS				52	30	S
249	D2	Cr	SS				65	45	S
250	E2	Cpv	SH				28	34	S
251	D4	Och	LS				75	54	N
252	D4	Och	LS	-46	90	N	42	50	S
253	D4	Och	LS				75	51	S
254	B5	Ock	DOL				41	22	S
255	B5	Ock	DOL				56	45	S
256	B5	Ock	DOL				48	41	S
257	B5	Ock	DOL				80	32	S
258	B5	Och	LS				57	39	S
259	B5	Och	LS				44	37	S
260	B5	Och	LS				58	36	S
261	A5	Ock	DOL	81	59	N	39	42	S
262	A5	Ock	DOL				48	46	S
263	A5	Ock	DOL				51	38	S
264	C3	Och	LS	-5	82	S	70	39	S
265	C3	Och	LS				66	26	N
266	C3	Och	LS				-11	10	N
267	C3	Och	LS				-39	31	N
268	C3	Och	LS				61	12	N
269	C3	Och	LS				-80	59	S

Table A.1 (continued)

STATION	GRID	ROCK UNIT	LITHOLOGY	FRACTURE			BEDROCK		
				STRIKE	DIP	DD	STRIKE	DIP	DD
270	C3	Och	LS				75	35	N
271	C3	Och	LS				45	41	N
272	D2	Och	LS				50	29	S
273	D2	Och	LS				60	67	N
274	D2	Och	LS				64	21	S
275	D2	Och	LS				61	24	S

Appendix B

GEOLOGIC MAP OF THE OAK RIDGE K-25 SITE AREA

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