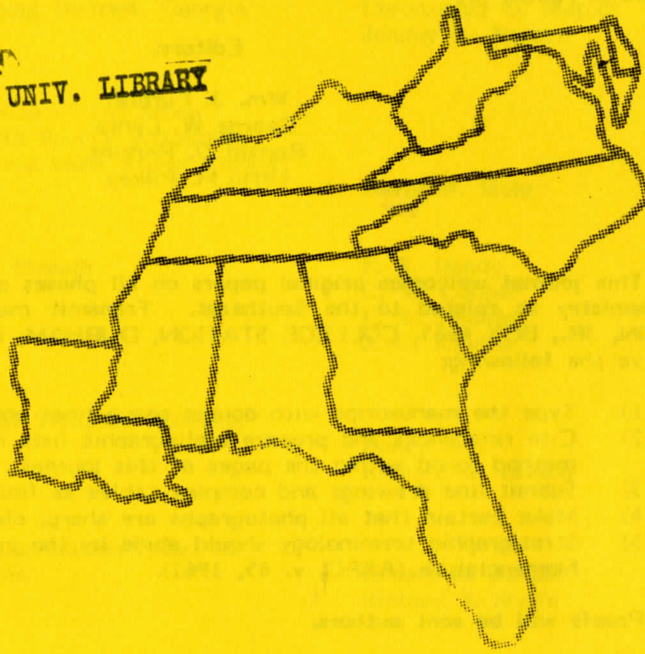
Southeastern Geology: Volume 24, No. 4
March 1984

Edited by: S. Duncan Heron, Jr.

Abstract

Academic journal published quarterly by the Department of Geology, Duke University.

SOUTHEASTERN GEOLOGY



PUBLISHED AT DUKE UNIVERSITY DURHAM, NORTH CAROLINA

VOL. 24, NO. 4 MARCH, 1984

SOUTHEASTERN GEOLOGY

PUBLISHED QUARTERLY

AT

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SOUTHEASTERN GEOLOGY

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ALGAL-ARCHAEOCYATHAN PATCH REEFS FROM THE CARTERSVILLE MINING DISTRICT, GEORGIA

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ABSTRACT

A paucispecific archaeocyathan assemblage consisting of *Metaldetes* aff. *M. profundus* and *Archaeocyathus atlanticus* bound by algae (presumably *Renalcis /Epiphyton*) formed patch reefs in the Shady Dolomite at Cartersville, Georgia, similar to those described by James and Kobluk (1978) from Labrador. These algal-archaeocyathan patch reefs are biostratigraphically correlated with the Elankian Stage of the U.S.S.R. Reef-associated fauna include Coscinocyathidae, Hyolithids, and trilobites. Evidence that algae and archaeocyathan formed ecologic reefs (Dunham, 1970) include:
(1) algal binding of erect, archaeocyathan skeletal material, (2) presence of archaeocyathan budding and exothecal development, and (3) early reef-core cementation. Early reef-core cementation is judged to be responsible for occlusion of barite mineralization, abundant in non-reefal rocks, from reef complexes. Reef formation marks a period of maximum marine transgression and stillstand during Early Cambrian time in Georgia.

INTRODUCTION

In this report, we present evidence of algal-archaeocyathan patch reefs from the area of Cartersville, Georgia, and an analysis of these patch reefs in light of recent paleoecological and sedimentological interpretations (James and Kobluk, 1978; James and Debrenne, 1980; Debrenne and James, 1981). We have applied the results of these analyses to a paleoenvironmental reconstruction for the Lower Cambrian strata of Bartow County, Georgia.

Surface exposures of Paleozoic sedimentary rocks in Georgia are confined to the Valley and Ridge Province situated in the northwestern corner of the state. The Valley and Ridge Province of Georgia is bounded on the south by the east-west trending Emerson Fault and on the east by the north-south trending Great Smoky Fault (Cressler and Crawford, 1976). The intersection of these two fault systems is approximately 5 kilometers southeast of Cartersville near Emerson, Georgia (Figure 1), and is largely responsible for the barite mineralization and subsequent mining activity in the area.

All archaeocyathans reported in this and in previous works concerning the southern Appalachians occur in the Lower Cambrian Shady Dolomite. Natural exposures of Shady Dolomite are virtually non-existent in the area of Cartersville, Georgia; however, strip mining of weathered residuum for barite occasionally produces short-lived exposures of the Shady Dolomite. The weathering profile near Cartersville is up to 75 meters deep and often produces pinnacles of bedrock with 30 meters or more of vertical relief (Reade, and others, 1980). The algal-archaeocyathan reefs and associated facies occur as pinnacles of Shady Dolomite exposed by mining operations of the New Riverside Ochre Mining Company. These exposures, subsequently covered by mine reclamation, are situated within the Cartersville city limits, approximately 300 meters east of U. S. Highway 41 (Figure 1).

PREVIOUS WORKS

Archaeocyathans were first reported from the Cartersville Mining District of Georgia by Hull (1920) when a single specimen of *Ethmophyllum profundum* (Billings) (now referred to the genus *Metaldetes*) was discovered at the Bertha Mine. Shortly

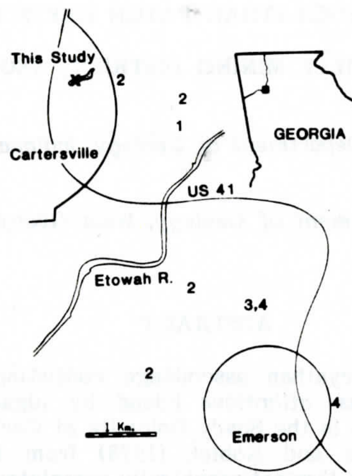

Figure 1. Location map showing previously reported archaeocyathan localities in the Cartersville, Georgia area. (1) Hull (1920); (2) Resser (1938); (3) Kesler (1950); (4) Willoughby (1969).

after Hull's report, archaeocyathans from the Roan Iron Mine and various other localities within the Cartersville Mining District were collected by T. L. Kesler and C. E. Resser and identified in Resser (1938). Subsequent workers have reported archaeocyathans from the Cartersville area (Okulitch, 1943; Butts and Gildersleeve, 1948; Kesler, 1950; Rodgers, 1956; Hill, 1965, 1972; Willoughby, 1969; Palmer, 1971; Chowns, 1977; Bearce and McKinney, 1977; Maples, 1980; Reade, and others, 1980) but, owing to extensive dolomitization and poor preservation of the fauna, the paleoecology of these archaeocyathans is poorly documented (Figure 1; Table 1). Maples (1980) first suggested that archaeocyathans form bioherms in this area. Previous workers had reported individual specimens as scattered throughout a thin interval. Willoughby (1969) suggested the presence of an actual reef mass situated approximately 1.2 kilometers east of Emerson, Georgia, even though he was unable to find archaeocyathans occurring in colonial masses. Because of intense folding and faulting in the area, the exact stratigraphic position within the Shady Dolomite of most archaeocyathan-bearing intervals is uncertain; however, some authors report archaeocyathans from the basal portions of the Shady (Resser, 1938; Kesler, 1950) and geologists working in the area generally agree that the archaeocyathan horizon occurs in the lower portions of the Shady (S. Bearden, pers. comm., 1982).

Despite the many published reports of archaeocyathans from the Cartersville area, to our knowledge only a single specimen from this area has been figured in any published work (Okulitch, 1943, Pl. 4, Fig. 5). Resser (1938, p. 2, Fig. 28) figured one specimen of *Archaeocyathus* from southwestern Virginia and reported the genus as present in the Cartersville area. Bearce and McKinney (1977) reported and figured archaeocyathan specimens of the suborder Coscinocyathina and the family Robustocyathidae (suborder Ajacicyathina) from the Shady Dolomite of the Sleeping Giants area in Alabama. Bearce and McKinney's specimens also occur as single and or fragmented individuals that may have locally trapped sediment to form a mound, but apparently were not wave resistant (Bearce and McKinney, 1977). Thompson (1973) reported very poorly preserved algal masses from the Shady Dolomite near Oldfield, Alabama, which apparently is the only published paper describing Lower Cambrian bioherms of any sort south of Austinville, Virginia.

STRATIGRAPHIC SETTING

Lithostratigraphy

The Lower Cambrian strata of Georgia can be viewed as consisting of three general lithological divisions (Figure 2): a lower, coarse clastic unit (Chilhowee Group),

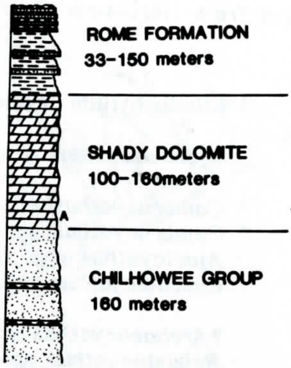

Figure 2. Lower Cambrian stratigraphy of northwest Georgia (redrawn from Chowns, 1977). "A" marks approximate position of algal-archaeocyathan reefs.

a middle carbonate unit (Shady Dolomite), and an upper fine clastic unit (Rome Formation). In Georgia, the upper portion of the Chilhowee Group consists of the Weisner Formation and underlying Wilson Ridge Formation. Mack (1980) has interpreted this succession as a marine transgressive phase that brought crossbedded and horizontally laminated beach-barrier island sands and conglomerates (Weisner Formation) over tidal flat sediments (Wilson Ridge Formation). The Weisner Formation grades conformably, although abruptly, into overlying carbonates of the Shady Dolomite (S. Bearden, pers. comm., 1982), reflecting either continued marine transgression into the area or a sudden decrease in sediment influx. The algal-archaeocyathan reefs reported here occur in a silty, ferroan dolostone near the base of the Shady Dolomite. The Shady Dolomite is conformably overlain by alternating shales, dolostones, and bedded cherts of the lower Rome Formation. Within the Rome Formation, these lithologies grade upward into red and green mud-cracked, ripple-marked, and fossiliferous shales and siltstones characteristic of tidal flat sedimentation.

Biostratigraphy

Olenellus fragments have been known to occur in the Shady Dolomite of the Cartersville Mining District since at least 1910 (Walcott, 1910, p. 340). Resser (1938, p. 7) reported, "A very large species of *Hyolithes*, fragments of *Wanneria*, and poorly preserved brachiopods associated with archaeocyathid reefs in northern Georgia." Kesler (1950) made extensive faunal collections from at least 25 Shady Dolomite exposures in and around Cartersville. In addition to the archaeocyathans, Kesler reported several braciopods, gastropods, and three trilobites: *Olenellus* sp., *Rimouskia* sp., and *Wanneria walcottana*.

Archaeocyathans reported herein and by previous authors (Table 1) indicate the Elankian Stage (Russian terminology) of late early Cambrian age (see Rozanov and Debrenne, 1974). This age assignment correlates with that of the exposures in Newfoundland and Labrador (Debrenne and James, 1981). Debrenne and James' correlation with the Elankian Stage of the Siberian Platform is based principally on the occurrence of the genus *Archaeocyathus* because there is no record of the genus *Metaldetes* from the U.S.S.R. We base our correlation with archaeocyathan assemblages of Labrador and Newfoundland partly on the presence of *?Archaeocyathus atlanticus* (Billings, 1861) and partly on the presence of *Metaldetes* aff. *M. profundus* (Billings, 1865), a species reported by Debrenne and James (1981) to have occurred only in eastern Canada.

PALEOECOLOGY

Regardless of their higher taxonomic affinities, archaeocyathans are generally acknowledged to have been sessile marine filter-feeding organisms with world-wide geographical distribution and temporal restriction to Lower Cambrian and lower Middle Cambrian strata. They are thought to have possessed calcareous skeletons, in the basic

TABLE I. Archaeocyatha reported from Northwest Georgia

Report	*Taxa*
Hull, 1920	* *Ethmophyllum profundum* (Billings)
Resser, 1938	*Archaeocyathus atlanticus* (Billings)
Okulitch, 1943	* *Cambrocyathus* cf. *C. profundus* (Billings) * *Cambrocyathus* sp. *Ajacicyathus* spp. (2 or 3) *Coscinocyathus* spp. (3)
Willoughby, 1969	?*Archaeocyathus* sp. *Robustocyathus* sp. *Ajacicyathid gen.* et sp. indet. *Coscinocyathid gen.* et sp. indet.
This report	?*Archaeocyathus atlanticus* (Billings) *Metaldetes aff. M. profundus* (Billings) *Coscinocyathid gen.* et sp. indet.

*Now assigned to the genus Metaldetes (see Debrenne and James, 1981).

form of an inverted cone, often consisting of two walls separated by septa. The wide distribution of species and genera, and analogy with coelenterates and sponges, suggest that the Archaeocyatha had a planktonic larval stage that was without skeleton (Hill, 1972). Asexual budding was also an important reproductive feature in colonial forms. When archaeocyathans occur in reefs, they always exhibit budding and exothecal development (James and Debrenne, 1980). Because of their common association with various algal genera and species and their tendency to occur in shallow marine carbonate facies, the Archaeocyatha are thought to have lived in the photic zone to a depth of about 100 meters with a 20 to 50 meter depth preference (Zhuravleva, 1960). Zhuravleva (1960) also noted that archaeocyathan-algal buildups did not begin growth until the insoluble residue content of the enclosing sediments reached at least 6 percent, and that they actually flourished best in sediments containing insoluble residues of 19 percent to 34 percent. This observation led Balsam (1973) to speculate that the primary food source for the Archaeocyatha may have been bacteria adsorbed to clays and other fine-grained particles in the water column. This food source may have been supplemented by suspended and/or water soluble organic material derived from the associated high algal productivity and subsequent decay within and proximal to algal-archaeocyathan reefs.

Lower Cambrian strata in Georgia are apparently vertically conformable and reflect a marine transgressive-regressive sequence from tidal-flat to beach-barrier island complex in the upper Chilhowee Group (Mack, 1980) to offshore carbonate bank, represented by Shady Dolomite, with a subsequent return to tidal-flat sedimentation in the Rome Formation. Algal-archaeocyathan reef formation marks a period of maximum marine transgression and apparent stillstand during Early Cambrian deposition in northwest Georgia (Figure 3). This tripartite paleodepositional sequence of transgression, stillstand, and regression appears to be laterally continuous along most of the eastern margin of North America from Alabama to Newfoundland (see Palmer, 1971).
This report is in agreement with the general occurrence of algal-archaeocyathan patch reefs in relatively thinner tripartite packages along this margin, with exception of archaeocyathan occurrences in the area of Austinville, Virginia (see Willoughby, 1977). Thomas (1977) has interpreted thin Cambrian depositional units as having been deposited in association with Cambrian promontories formed during the early stages of continental rifting and, if this is the case, algal-archaeocyathan reefs apparently formed preferentially in these areas.

Algal-archaeocyathan patch reefs described in this report are paucispecific assemblages. Paucispecificity in late Early Cambrian algal-archaeocyathan reefs did not result from stressed environmental conditions, but reflects declining archaeo-

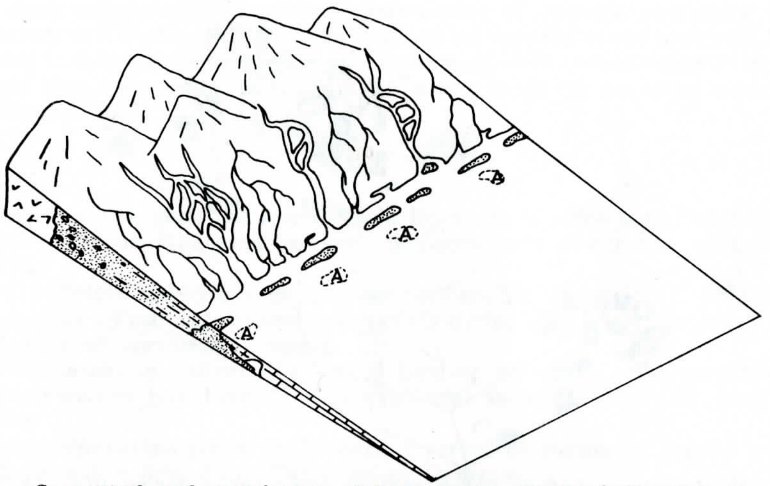

Figure 3. Suggested paleoenvironmental reconstruction of late Early Cambrian deposition in northwest Georgia. A = algal-archaeocyathan patch reef. Modified from Mack (1980).

cyathan diversity on a worldwide basis (Rozanov and Debrenne, 1974). Poor preservation of the fauna also contributes to the low archaeocyathan diversity encountered in this study. Of the recognizable archaeocyathans present within the reef mass, there are 2 species, both of which belong to the Class Irregulares. Approximately 95 percent of archaeocyathans present in reefs belong to the species *Metaldetes* aff. *M. profundus* with the remaining 5 percent belonging to the species ?*Archaeocyathus atlanticus*. One definitive member of the Class Regulares, a Coscinocyathidae, was not found in the reef mass, but was situated in a shelly zone of toppled and broken archaeocyathans. These archaeocyathan debris zones attest to the presence of occasional, strong wave activity during reef growth. The associated algae are unidentifiable, however we judge that they are intergrowths of *Renalcis* and *Epiphyton*, typically associated with Archaeocyatha.

REEFS OR BIOHERMS?

Since shortly after the initial report of Capt. H. W. Bayfield (1845), archaeocyathans have been known to occur in mounds or reefs. The debate as to whether or not archaeocyathans formed true ecological reefs (*sensu* Dunham, 1970) has continued for a number of years. James (1983, p. 380) in reference to ecologic reefs states "If this concept were rigidly applied, many modern reefs would not qualify because most are not organically bound, especially those in the platform interior and deep water. . .". James (1983) refers to Early Cambrian archaeocyathan buildups as reef mounds and regards them as half-reefs or incomplete reefs. James and Debrenne (1980, p. 665) found through detailed study of the Elankian Stage archaeocyathan-rich bioherms in Labrador that, "all of the sedimentologic and paleoecologic attributes we generally ascribe to reefs are present in these older structures." They feel that actual reef formation was confined to middle and late Early Cambrian time when archaeocyathans became larger, possibly semi-colonial and developed polymorphism.

Our work on algal-archaeocyathan buildups in the Cartersville Mining District implies that the archaeocyathans and algae in the Shady Dolomite formed true ecological reefs (*sensu* Dunham, 1970) and were not simply biostrome-like debris zones or biohermal masses of loosely bound skeletal debris acting as sediment baffles (Figure 4). We base our conclusion on three lines of evidence:

1. Algal binding of skeletal material furnished by the archaeocyathans with subsequent binding of lime mud into the reef masses. Algal binding of skeletal material is implied from ancient reef facies (Riding and Toomey, 1972; Wray and Playford, 1970) and algae contribute significantly to modern reef formation and stabilization (see James and Ginsburg, 1979). Algae, used loosely in this paper as a result of poor preservation of

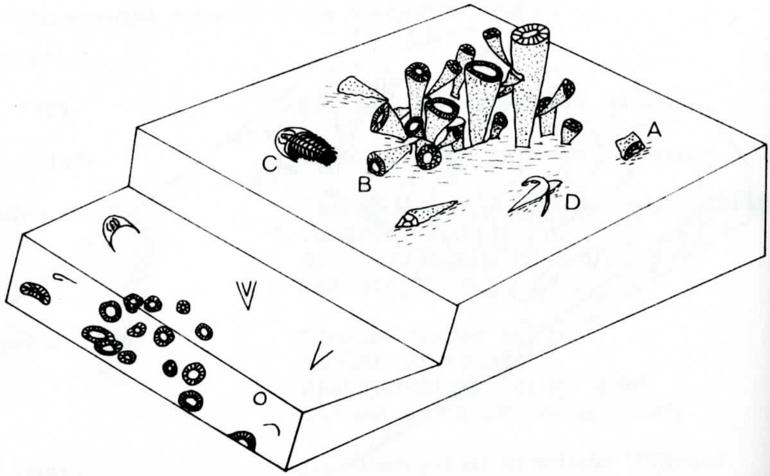

Figure 4. Algal-archaeocyathan patch reef as interpreted during life. A, ?Archaeocyathus atlanticus; *B,* Metaldetes *aff.* M. profundus; *C,* Olenellus; *D, hyolithid. Algae* (Renalcis-Epiphyton) *not shown but is suggested to have grown around and between archaeocyathans.*

the material, probably are represented by the genera *Epiphyton* and *Renalcis*, which are commonly intergrown. Algae comprise approximately 30 percent of the reef mass and potentially bound both archaeocyathans, which also comprise around 30 percent of the reef mass, and some lime mud (now dolomitic mudstone), which constitutes the remaining percentage. We feel that potential wave resistance is implied by the presence of algae in association with archaeocyathans.

2. Presence of budding and exothecal development among many archaeocyathans along with associated growth deformation and polymorphism. James and Debrenne (1980, p. 666) state that when archaeocyathans occur in reefs, they always exhibit budding and exothecal development. Note that the inverse of this statement is not necessarily true; however, there is some implication toward this interpretation. Additionally, polymorphism resulting in part from apparent interference by the algae and in part from intraspecific competition for available growth space further implies these algal-archaeocyathan reefs may have been tightly bound masses with potential wave resistance.

3. Early reef-core cementation. A major, unanswered question among geologists interested in the Cartersville Mining District concerns the origin of barite mineralization in the area. Different techniques to answer this question (Hull, 1920; Kessler, 1950; Rife, 1971; Reade, and others, 1980) either imply or directly state that barite mineralization was a late epigenetic event. However, algal-archaeocyathan reefs contain almost no barite, the minor amount present resulting from joint mineralization, whereas the associated facies are heavily mineralized. In addition, none of the reef-associated archaeocyathans have barite-filled internal cavities, whereas barite filling of internal cavities is a common phenomenon among those non-reef archaeocyathans. Wolf (1965, p. 183) noted that algal reefs are poor reservoir rocks yet the associated detrital limestones are often very receptive to hydrocarbon accumulation. The reason for this discrepancy appears to be early cementation of void spaces within algal bioherms and biostromes by a process of alternating generations of fibrous calcite and internal sediments. Because the internal sediments are deposited from surface fluids penetrating into the reef-framework, an early genesis of the fibrous calcite seems certain, especially where several generations of fibrous calcite and internal sediments alternate (Wolf, 1965, p. 198). James and Kobluk (1978) reported early reef-core cementation in the classic Labrador Cambrian reefs as evidence of potential reef formation. This same type of process has been reported from Devonian buildups in Alberta, Canada (Mountjoy and Walls, 1977) and analogous features have been described by Brasier (1976) as coniatolites in Archaeocyatha-*Renalcis* intergrowths from South Australia. Although our material is badly dolomitized, the reef-associated archaeo-

cyathans show suggestions of several generations of cement possessing a remnant fibrous texture oriented normally to the surface of deposition and sediment both within and between individual archaeocyathans. Early reef-core cementation of primary void space would also seem to be a fundamental prerequisite for potential wave resistance of an ecological reef.

CONCLUSIONS

1. Using archaeocyathans, the lower Shady Dolomite is correlated biostratigraphically with similar archaeocyathan-bearing units in Labrador and with the Elankian Stage of the U.S.S.R.
2. Algae (*?Renalcis/Epiphyton*) and archaeocyathans (*Metaldetes* aff. *M. profundus* and *?Archaeocyathus atlanticus*) formed patch reefs during late Early Cambrian time in the Shady Dolomite of northwest Georgia.
3. Reef formation is indicated by algal binding of erect, archaeocyathan skeletal material, archaeocyathan budding and exothecal development, and early reef-core cementation.
4. Algal-archaeocyathan patch reefs mark a period of maximum marine transgression and stillstand in the late Early Cambrian of Georgia.
5. Barite mineralization occurs abundantly in non-reefal rocks, but is occluded from reefs by early reef-core cementation.

ACKNOWLEDGEMENTS

We express or sincere thanks to Stanley Bearden of New Riverside Ochre Mining Company, and to Ernest Reade of Paga Mining Company, both of Cartersville, for allowing free access to exposures of Shady Dolomite situated within these two mines. Ideas concerning overall paleoenvironmental interpretations benefitted greatly from discussions with T. M. Chowns and R. H. Willoughby. T. J. Crawford was responsible for information concerning exposures and general geology of the area. Jon Maples assisted with some of the field work. A. S. Horowitz read early drafts of this manuscript. Thanks also go to N. P. James, who critically reviewed this paper. Bonita Stewart typed and edited the final versions of this paper.

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THE NATURE OF INTRUSION OF THE STONE MOUNTAIN PLUTON, WITH SPECIAL ATTENTION TO ATTITUDES OF QUARTZ VEINS WITHIN COUNTRY ROCK

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ABSTRACT

Structural data on attitudes of quartz veins within metamorphic country rock surrounding the Stone Mountain pluton were studied and integrated with geological observations in order to shed new light on the intrusion mechanics of the Stone Mountain pluton.

Most quartz veins are of metamorphic origin and were emplaced before intrusion of the Stone Mountain granite. Evidence for this includes the following: At common intersections granite and pegmatite dikes almost invariably cut quartz veins. Also patterns of both distribution and structural attitudes of quartz veins show no relation to the Stone Mountain pluton, but do show some relation to deformational structures of earlier date within the country rock. Attitudes of quartz veins form a great-circle pattern whose pole trends and gently plunges NNE. Save for certain areas adjacent to the Stone Mountain intrusion, this pattern has been little modified by later deformation.

Emplacement of the postmetamorphic Stone Mountain granite had variable structural effects on the adjacent country rock. Along the southern border, south and southeast of the monadnock of Stone Mountain, both country rock and quartz veins were tilted together, about a subhorizontal E-W axis parallel to the contact. Resulting attitudes of country rock are sub-parallel to the contact and nearly vertical. West and north of the intrusion more brittle deformation, with formation of numerous small faults, occurred. Some scattering, but no systematic rotation of previously-formed structures is found. To the northeast and east, the granite appears to have been intruded in a number of semi-discordant sheets, and the contact area is apparently little deformed.

Combination of data presented here with that of Grant and others (1980) supports the hypothesis of these authors that the intrusion has the shape of a phaco-laccolith. The main blister seems to have been along the southern contact, adjacent to the area of subvertical country rock. The intrusion is likely to be somewhat thinner in other regions, becoming little more than a series of thin sheets to the east.

INTRODUCTION

In recent years, the geology of the Inner Piedmont of the Atlanta region has been intensely studied, and a great deal of attention has been paid to the Stone Mountain pluton and to surrounding country rock. Herrmann (1954) mapped the Stone Mountain pluton, and the country rock on its southern and eastern sides. Mohr (1965) extended Herrmann's (1954) map to the north and west, and made a study of quartz veins, pegmatites, and granite dikes in country rock about the pluton. More recent studies include those of Grant and others (1980) and Whitney and others (1976) on the Stone Mountain pluton itself, and Dallmeyer (1978), Atkins and others (1980), Atkins and Higgins (1980), Higgins and Atkins (1981), and Van Breeman and Dallmeyer (1983), chiefly on surrounding country rock. This paper is a publication of part of the thesis of Mohr (1965), interpreted in the light of more recent work by others.

The location of this report is the area surrounding the Stone Mountain pluton, about 30 km east of Atlanta. The study area covers about 80 km^2 in eastern DeKalb and southwestern Gwinnett Counties. About 50 km^2 of this region was previously mapped by Herrmann (1954), with only minor revisions by Mohr (1965). About 30 km^2 north and west of the boundaries of Herrmann's (1954) map were mapped by Mohr (1965).

A study of geological structures within country rock surrounding the Stone

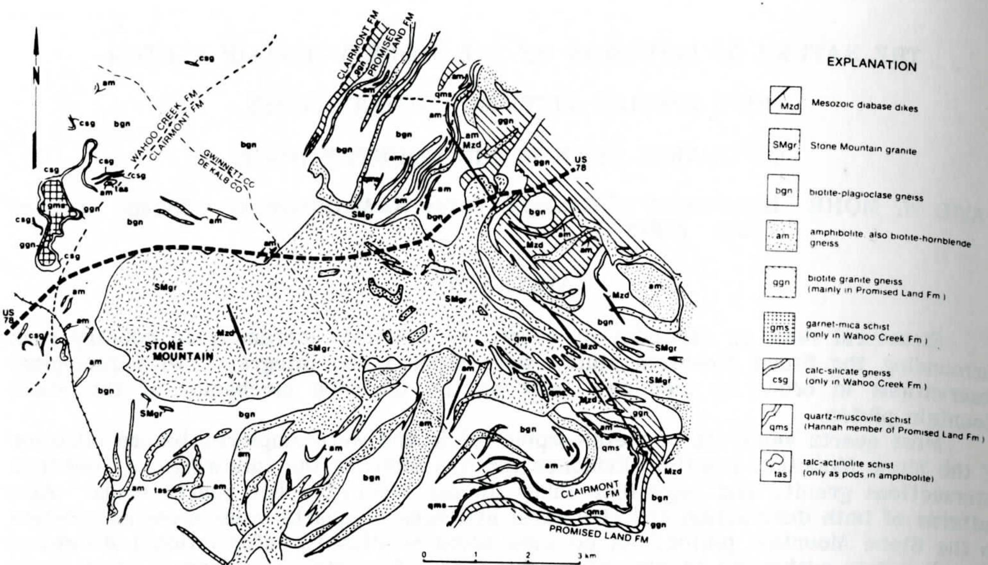


Figure 1. Geologic map of the Stone Mountain district, Georgia, as mapped by Herrmann (1954) and Mohr (1965). Formational boundaries of Higgins and Atkins (1981) are superposed.

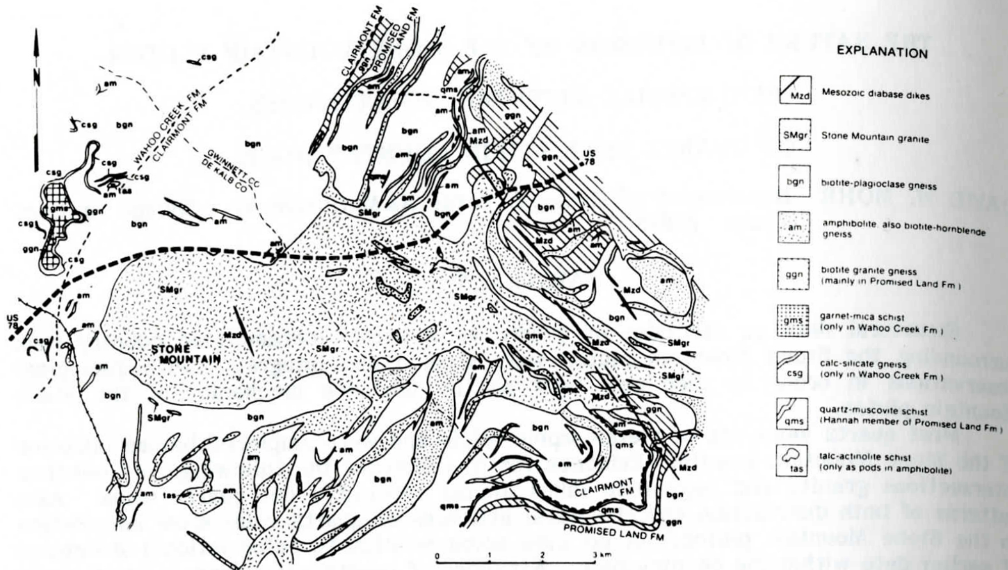
Mountain pluton included measurements of attitudes of 580 quartz veins, as well as observations on structural relations of quartz veins, granite and pegmatite bodies, and faults within country rock surrounding the Stone Mountain pluton. Only reconnaissance observations were made within the granite itself.

SUMMARY OF ROCK TYPES

Figure 1 is a geologic map of the study area, as mapped by Herrmann (1954) and Mohr (1965). Superposed on this map are the formational units of the Atlanta Group, as determined by Higgins and Atkins (1981); neither Mohr (1965) nor Herrmann (1954) mapped stratigraphic formations within the country rock. Lithologies of the various formations are described in Higgins and Atkins (1981), and that of the Stone Mountain granite is available in Whitney and others (1976) and Grant and others (1980).

Country rock of this region is typical of the intensely deformed and metamorphosed units of the Inner Piedmont. Dominant lithologies include biotite-plagioclase gneiss, granitic gneiss, and amphibolite. Foliation and compositional layering are generally subhorizontal and show undulations on both outcrop and map scale. Atkins and Higgins (1980) conclude that at least five folding episodes are present. The first two (Buck Branch and Klondike) are marked by tight to isoclinal folds of outcrop size, whose fold axes trend NNE. Axial planes of Buck Branch folds are recumbant, but those of Klondike folds vary from recumbant to reclined. The third (Elijah Mountain) formed gentle folds of map size, whose fold axes trend NW, and is responsible for much of the warping of the present map pattern. The last two (Scott Creek and Tara) are marked by gentle upright folds of outcrop size, whose fold axes trend N-S and E-W respectively. Dallmeyer (1978) and Van Breeman and Dallmeyer (1983) report widespread homogenization of Sr isotopes among country-rock minerals at 365 ± 10 my. This event may mark the culmination of metamorphism in the region.

The Stone Mountain granite intrusion is located within the Inner Piedmont belt of Georgia, about 30 km east of Atlanta. Numerous studies have been made of this intrusion (Herrmann, 1954; Grant, 1962; Grant and others, 1980; Wright, 1966; Whitney and others, 1976; Whitney and Wenner, 1980; Dallmeyer, 1978). The pluton extends east-west across the map area (figure 1), covering about 28 km^2 of terrain. Although numerous satellite sheets occur south and east of the massif, virtually none occur to the north or west. The monadnock of Stone Mountain is located in the southwestern corner of the main pluton.



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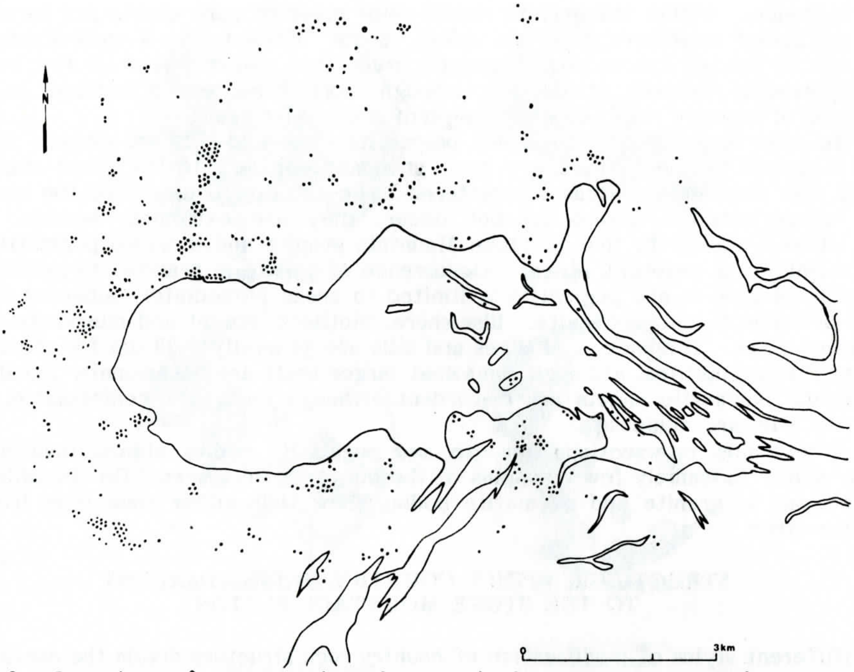


Figure 2. Locations of quartz veins whose attitudes were measured for this study.

The rock is a two-mica adamellite with muscovite of golden-brown color generally in excess of biotite. Some of the smaller satellite sheets show a change to biotite-free varieties containing pale-green muscovite. Both the main massif and its satellite sheets show discordant contacts with the country rock. Contacts are rather sharp, but neither chill zones nor thermal aureoles occur. Alkali metasomatic alteration of country rock occurs adjacent to the contacts.

Several authors have published radiometric dates for the Stone Mountain granite. Higgins and Atkins (1981) report a pair of concordant zircon dates averaging 325 my. Whitney and others (1976) furnish a mineral-controlled Rb/Sr isochron date of 291 ± 7 my for the intrusion. Dallmeyer (1978) reports $^{40}Ar/^{39}Ar$ dates of 283 ± 5 my for muscovite and 281 ± 5 my for biotite separated from the granite. These latter dates clearly show time of cooling of the intrusion to a temperature of 300-350°C. Either the 325 my date of Higgins and Atkins (1981) or the 291 ± 7 my date of Whitney and others (1976) may give the time of granite intrusion. Both dates are definitely younger than the 365 ± 10 my determination of Van Breeman and Dallmeyer (1983) for time of country-rock metamorphism. Based on $^{40}Ar/^{39}Ar$ dates of hornblende and biotite from country rock near the Stone Mountain intrusion, Dallmeyer (1978) ascertains regional temperatures near 480°C at 325 my and near 300°C at 291 my.

The western half of the massif lacks xenoliths larger than outcrop size, and has been discussed by Grant and others (1980). Flow foliation of micas and granitic banding are well developed in the central and southern parts of this region, disappearing toward the north. At the southern contact, these strike sub-parallel to the contact and dip steeply beneath it; elsewhere they show gentle dips. Based on a study of structural elements, Grant and others (1980) conclude that the massif is a phaco-laccolith, with the main blister possibly located near the southern edge of the pluton.

Toward the east, map-size xenoliths of country rock appear and become increasingly abundant; the eastern end of the intrusion is basically a series of semi-discordant granite sheets ranging from outcrop to map size. Where visible, flow foliation parallels dike walls.

Dikes and sills composed entirely of crystalline quartz occur frequently within country rock. They are more commonly found on outcrops showing deformed foliation than on those showing gently-dipping, undeformed structure. Frequency of occurrence, shown in figure 2, shows no relation to proximity of Stone Mountain granite or any other intrusion. Within the granite itself, veins made of pure quartz are rare. Most veins are planar structures, 2-20 cm thick. Some "blowouts" to 3 meters occur, but these are of limited extent and frequently grade into planar veins. A few veins are curved, showing variable attitude. Although most veins are discordant to planar structures of country rock, about 20 percent are conformable.

The vast majority of granite and pegmatite dikes and sills are derived from the Stone Mountain pluton. These are most abundant adjacent to the main massif and become less abundant in areas of scattered large satellite bodies. To the north and west, where satellite bodies do not occur, they are extremely scarce. Their composition is similar to that of Stone Mountain granite and included pegmatite, save that tourmaline is generally absent. Occurrence of biotite in granite and golden-brown muscovite in granite and pegmatite is limited to areas immediately adjacent to large bodies of Stone Mountain granite. Elsewhere, biotite is absent and muscovite shows a pale-green color. Thicknesses of dikes and sills are generally 5-30 cm for granites and 1-30 cm for pegmatites, although somewhat larger units are occasionally found. Most granite and pegmatite sheets are discordant although many are conformable. Many dikes and sills are composite.

At common intersections, granite and pegmatite bodies almost invariably cut quartz veins. Extremely few examples of the converse were seen. On the other hand, intersections of granite and pegmatite bodies show that either rock type frequently cuts the other.

STRUCTURES WITHIN COUNTRY ROCK ADJACENT TO THE STONE MOUNTAIN PLUTON

Different styles of modification of country rock structure divide the contact zone into three separate areas. In all areas, granite and pegmatite bodies are abundant near the contact and become progressively more scarce farther away.

South of the Stone Mountain pluton is a region where planar structures of country rock are subvertical. This area extends for 5.5 km along the contact, from south of the monadnock to about 1 km east of the Gwinnett County line. The width of this zone is greatest (900 meters) in the central portion and tapers to both east and west. One large apophysis of Stone Mountain granite cuts across this area. Foliation and banding of country rock strike parallel to both the main axis of the pluton and to the main contact. Faults are present, although not abundant. Most of these dip gently away from the granite contact, with movement directed so that the upper plate moves toward the pluton. To the south this region grades into country rock structures apparently undeformed by the intrusion of granite but obviously affected by Elijah Mountain folding.

The second area extends around the western and northern margin of the Stone Mountain pluton, from just southeast of the town of Stone Mountain to about 1 km east of the Gwinnett County line. This belt is no more than 0.75 km wide. In this region the country rocks near the granite show widely varying strikes within small regions, although dips remain gentle. Large numbers of faults occur within this belt, but lack of exposure prohibits structural analysis. Most faults are subhorizontal and generally conformable to planar structures of country rock. Movement along these is such that the upper plate slides toward the pluton. Some faults dip more steeply away from the granite contact; displacement along these is such that the block closer to the granite moves up. This region grades into country rock farther from the contact by decrease and virtual disappearance of faults and granite and pegmatite bodies. Planar structures of country rock become more regular, save where modified by metamorphic folding. No systematic tilting of country rock occurs in this region.

Along the eastern portions, more than 1 km east of the Gwinnett County line along both north and south contacts, country rock adjacent to the pluton shows little deformation. Foliations of country rock are conformable to regional trends away from the granite, and few faults occur.

STRUCTURAL ANALYSIS OF ATTITUDES OF QUARTZ VEINS

Equal-area stereonet diagrams of attitudes of quartz veins within country rock

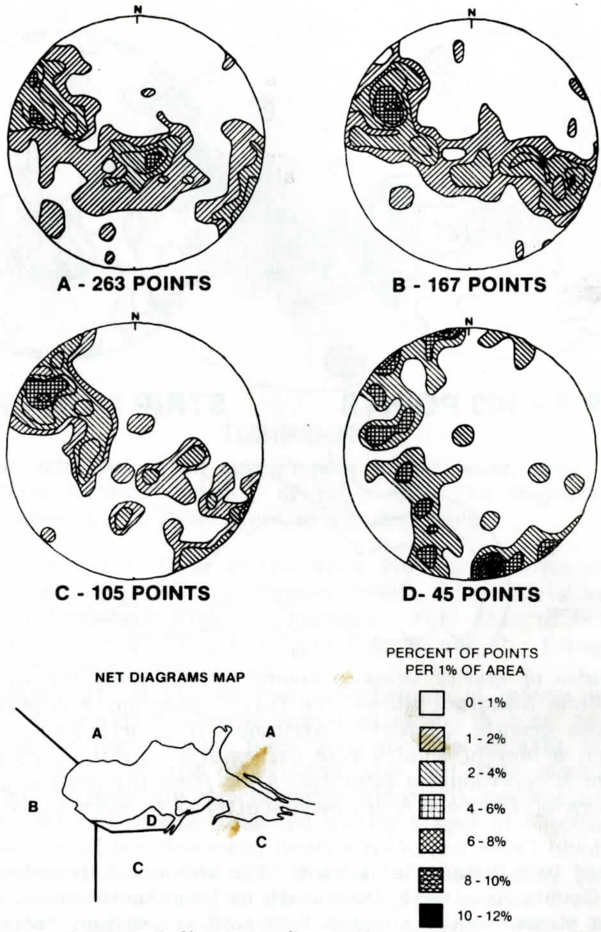


Figure 3. Equal-area stereonet diagrams (lower hemisphere projections) of poles to the planes of quartz veins occurring in the metamorphic rocks. Zones A, B, and C show essentially unmodified attitude patterns which formed before intrusion of the granite. In zone D this pattern has been rotated by tilting.

are shown in figures 3-5. In all diagrams, poles of quartz-vein attitudes are plotted and contoured in terms of percent of points per each one percent of diagram area. In figure 3 four domains, A-D, are shown; save for area D (45 measurements), all areas contain over 100 separate measurements of quartz-vein attitudes. Structural domain D corresponds to the area of subvertical foliation along the southern contact of the main Stone Mountain pluton. Boundaries of the other three domains are somewhat arbitrary, and are placed at the northwestern and southwestern corners of the Stone Mountain intrusion.

Resulting patterns are very similar in areas A, B, and C, and these areas do not constitute separate structural domains. All show a girdle whose orientation defines a pole trending N20-30°E and dipping approximately 20°NE. Also, all three girdles show maxima corresponding to attitudes of N20-30°E, 70-90°SE. Other features are not consistent, but it appears that none of the girdles is completely cleft. The girdle of area C, an area of pronounced Elijah Mountain folding, seems to be slightly broadened. Within area D, a girdle of somewhat different orientation is present; here a pole trending N60°E and plunging 60°NE is defined. The small number of data points within area D prevents further analysis.

A separate analysis of quartz-vein attitudes west and northwest of the Stone Mountain pluton is shown in figure 4. This region forms a belt extending from the

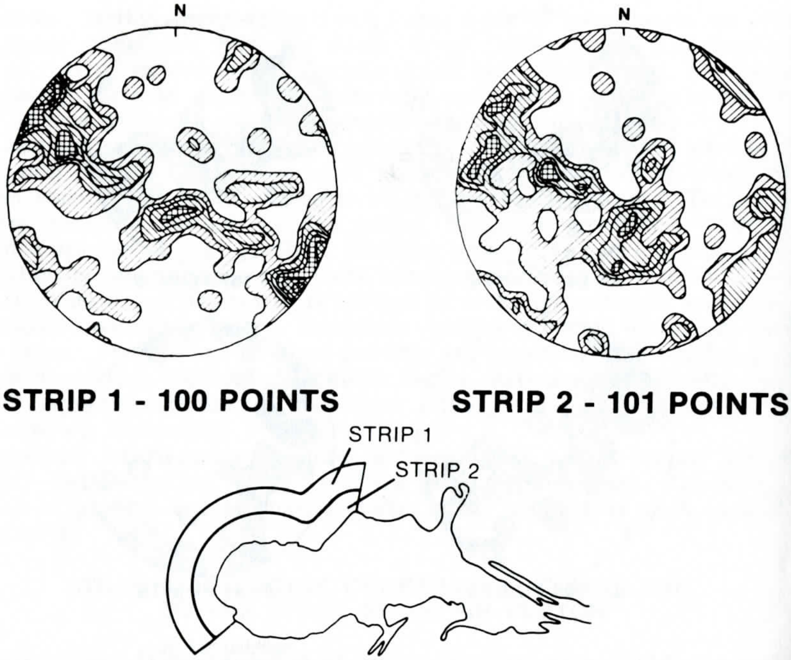


Figure 4. Attitudes of quartz veins in country rocks along the western and northern margins of the Stone Mountain pluton (see text). Diagram A represents a strip 0.75-1.50 km from the granite contact. Attitudes of quartz veins are not especially modified, although a hint of small-circle deformation about an axis trending NNW is present. Diagram B represents a strip 0-0.75 km from the granite contact. Here, the great-circle pattern of Diagram A has been scattered to some extent but has not been tilted.

granite contact out to a distance of 1.5 km. The belt itself stretches from 1.5 km east of the Gwinnett County line, west, then south to 1 km southeast of the western tip of the pluton. Two strips, 0-0.75 km and 0.75-1.50 km distant from the pluton, were plotted separately; each contains about 100 points. The more distant strip shows the same orientations as seen in areas A, B, and C, of figure 3. The strip adjacent to the granite shows scattering of this orientation, but the major great circle is easily recognized and has not been systematically tilted or folded.

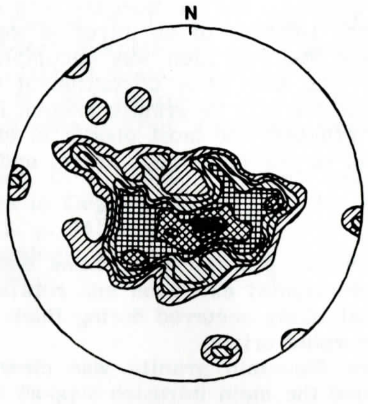
Figure 5 shows a separate plot of conformable quartz veins for all regions save the tilted area D of figure 3. Only 102 measurements were made. Results show a single subhorizontal maximum in the center of the diagram, with some east-west extension. This maximum probably constitutes the major central portions of the girdles in the other diagrams, although a few quartz veins of shallow dip are discordant.

GEOLOGICAL AND STRUCTURAL INTERPRETATIONS

Several lines of evidence clearly show that the vast majority of quartz veins formed before intrusion of the Stone Mountain granite. These are:

1) Quartz veins are rare within the granite itself.
2) At common intersections, quartz veins are virtually always cut by granite and pegmatite dikes and sills derived from Stone Mountain granite.
3) Distribution patterns of quartz veins are unrelated to proximity of any igneous intrusion.

Stereonet diagrams A, B, and C of figure 3 show emplacement of quartz veins in a regional stress field with subhorizontal extension oriented N 60-70°W and rotation about a subhorizontal axis oriented N 20-30°E. This pattern is compatible with possible



102 POINTS

Figure 5. Plot of attitudes of all conformable quartz veins, save for those from the area of near-vertical foliation (area D of figure 3). The diagram shows some E-W extension but is essentially a featureless single maximum.

WNW transport of nappe structures in the Inner Piedmont. With regard to the five deformational episodes of Atkins and Higgins (1980), most quartz veins appear to be related to the Buck Branch or Klondike episodes. Fold axes of both these episodes trend northeast, parallel to girdle axes of areas A, B, and C. Younger generations of folds have axes of different orientations.

It is not possible to decide whether orientations of quartz veins reflect Buck Branch or Klondike deformation. Subhorizontal extension is more compatible with the flat-lying axial planes of Buck Branch folds than with the variable, often reclined axial planes of Klondike folds. On the other hand, the fact that most quartz veins are discordant and that conformable quartz veins (figure 5) are not extensively rotated would seem to rule out ages earlier than the waning stages of Klondike folding. Later periods of deformation (Elijah Mountain, Scott Creek, and Tara) involve gentle to open folding and apparently caused little modification of pre-existing patterns. Hints of such deformation include broadening of the major girdle in area C of figure 3, possibly by Elijah Mountain deformation, and perhaps slight tendency toward formation of small circles about axes trending NNW, possibly during the Scott Creek episode (Strip 1 of figure 4).

It is recognized that a few quartz veins are of somewhat later date. Indeed, a very few examples are known in which quartz veins cut granitic and pegmatite dikes derived from the Stone Mountain pluton, and such veins are not totally absent from the granite itself. However, in a structural analysis of this sort, inclusion of this handful of later veins has little or no effect on structural patterns formed during the major phases of quartz-vein formation. Thus the structural patterns of quartz-vein attitudes may be used as convenient markers to determine the effect of intrusion of the Stone Mountain pluton in adjacent country rocks.

The area of near-vertical foliation south and southeast of Stone Mountain (area D of figure 3) was clearly tilted without major internal folding after emplacement of quartz veins. The axis of tilting appears to have been oriented E-W and not far from the horizontal. In this region the granite intrusion displays conspicuous flow foliation and granitic banding whose orientations dip under the contact. It is likely that this area represents the greatest blister of a phaco-laccolith and the greatest original thickness of the intrusion. This is supported by the fact that deformation is more ductile here (implying a greater reservoir of heat) than elsewhere.

Along the western and northwestern margins deformation seems to have been somewhat more brittle. Numerous faults of limited displacement cause slight shifting and rotation of previous structures, but apparently not into any new preferred orientation. In this region, the granite itself is massive, and shows little or no development of flow structures (Grant and others, 1980). Brittle deformation within country rock and lack of structure within granite suggest a lesser reservoir of heat and perhaps lesser thickness of granite. Rather than the site of a large blister, this area appears to resemble more the top side of an intrusive wedge.

To the east, it appears that intrusion was accomplished by emplacement of a number of semiconformable sills with little disruption of country rock. Perhaps the most likely point of entry for the bulk of granite magma is along the southern margin where deformation was the greatest and most plastic in character. From this region the granite may have spread to the northwest, north, and east.

CONCLUSIONS

A study of quartz veins in country rock shows emplacement in a stress field consisting of N60-70°W subhorizontal extension and rotation about an axis N20-30°E, also subhorizontal. This most likely occurred during Buck Branch or Klondike folding. Quartz veins have a metamorphic origin.

Intrusion of the Stone Mountain granite was clearly later. Observations of country rock structures around the main intrusion support the hypothesis of Grant and others (1980) concerning a phaco-laccolith shape of the intrusion, with the greatest blistering in approximately the region now covered by the monadnock of Stone Mountain. Deformation to the south was relatively plastic, and involved tilting of an area of country rock, 0.5-1 km wide and about 6 km long, into subvertical position. Deformation to the north and west was brittle, involving much local faulting but little overall displacement of country rock. Little deformation occurred to the northeast and east. Areas near the southern contact probably received the greatest volume of granite; granitic magma may have spread from this area into other parts of the intrusion.

ACKNOWLEDGEMENTS

The M.S. thesis of Mohr (1965) upon which this paper is based was conducted at the Department of Geology, Emory University, under the very helpful direction of Willard Grant. I also appreciate constructive reviews of the original manuscript to this paper by Robert Atkins, Willard Grant, and James Whitney.

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SEDIMENT IN A DELTA STREAM

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ABSTRACT

Erosion and sedimentation studies were conducted on a Mississippi Delta watershed during a 3-year period. Nearly all of the sediment removed from fields and transported in the stream was clay-size material. Measured sediment yield from cultivated field-size areas was about 0.17 t/ha/yr per cm of runoff. This was about 4 times greater than the estimated suspended sediment yield for the 440 km^2 watershed indicating that about 75% of the sediment eroded from fields is deposited before it reaches the major streams. For 30 cm of annual runoff the estimated suspended sediment yield for the watershed was about 1 t/ha/yr, a modest amount for an intensively cultivated delta watershed.

INTRODUCTION

Recent studies indicate that erosion on delta fields may be much greater than previously assumed. Erosion studies during the last decade have shown that sediment eroded from cultivated fields in the Mississippi Delta may exceed 20 metric tons per hectare (t/ha) during years of abnormally high rainfall (Dendy, 1981; Murphree and others, 1976). Sediment deposits in some delta lakes also indicate comparatively high erosion rates in the area (Ritchie and others, 1979).

This paper summarizes the results of a 3-year study of sediment in Bear Creek, a Mississippi Delta stream. Information is given on sediment deposits and suspended sediment concentrations in Bear Creek, sediment inflow rates and amounts from cotton fields adjoining the stream, and the particle size distribution of sediments in the system.

STUDY AREA AND METHODS

The Bear Creek drainage area, about 440 square kilometers in size, is totally within the Mississippi Delta in north central Mississippi (figure 1). The stream begins with flow from Blue Lake, a spring-fed lake near the town of Itta Bena. It meanders in a southerly direction for about 80 kilometers to the confluence with the Yazoo River near Belzoni. The channel (thalweg) slope is less than 0.2 meters per kilometer in the upper reaches and essentially flat in the lower reaches (figure 2). Six in-stream lakes occur along the channel. They range in surface area from 3 to 142 hectares. All of the lakes are large enough to greatly reduce flow velocities thus providing additional time for sediment deposition. They have a combined surface area of about 286 hectares.

About 73% of the drainage area is cultivated in row crops. The remainder is composed of pasture, forest, and miscellaneous uses. Conventional tillage for the major clean-tilled crops, cotton and soybeans, usually consists of extensive disking and seedbed preparation in the early spring, planting in April or May, periodic cultivation during the summer, a period of little or no cultivation in the late summer and fall, crop harvest in the fall, and finally disking or chisel plowing in the late fall or early winter. Disking or chisel plowing in the fall leaves the soil in a disturbed condition which is highly susceptible to erosion during the winter and early spring, normally a period of high rainfall. In recent years some farmers have discontinued fall plowing. This leaves crop residue on the land which reduces erosion.

Data collection began in January 1976 and continued for about 3.5 years at 11 sites along Bear Creek (figure 1). Bi-weekly measurements were made of water stage and depth and dip samples were taken to determine the suspended sediment concentration at or near the water surface. Water stage recorders provided a

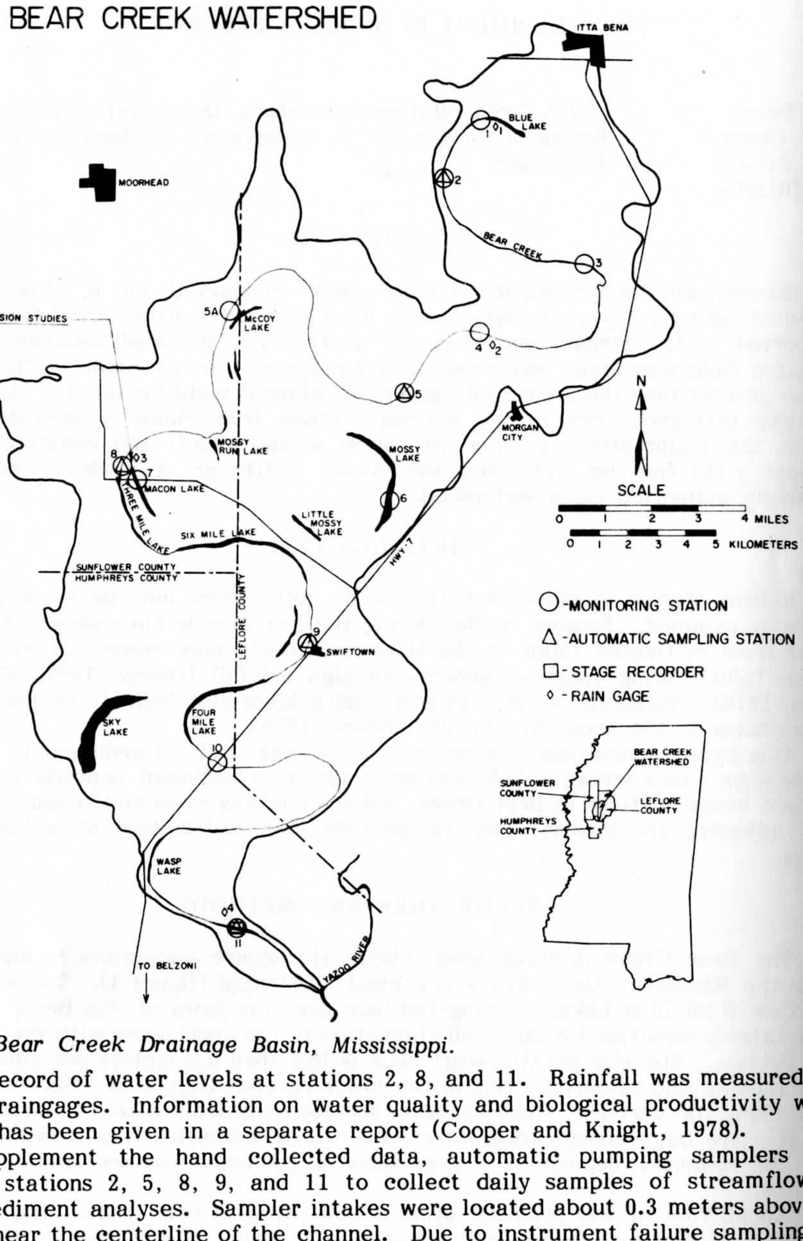

Figure 1. Bear Creek Drainage Basin, Mississippi.

continuous record of water levels at stations 2, 8, and 11. Rainfall was measured with 4 recording raingages. Information on water quality and biological productivity within the system has been given in a separate report (Cooper and Knight, 1978).

To supplement the hand collected data, automatic pumping samplers were installed at stations 2, 5, 8, 9, and 11 to collect daily samples of streamflow for suspended sediment analyses. Sampler intakes were located about 0.3 meters above the stream bed near the centerline of the channel. Due to instrument failure sampling was intermittent during part of the study.

Additional runoff and sediment data were obtained on a storm basis on two small cotton watersheds (fields) located near station 8 (figure 3). The smaller watershed, 2.59 hectares in size, drains directly into Bear Creek. The larger, 7.25 hectares, drains into Macon Lake, an off-stream lake which drains into Bear Creek at high water levels. Both watersheds were shaped to a uniform slope of 0.2% several years before the studies began, and both were cultivated in cotton with conventional tillage and pest control practices. Parshall flumes, water stage recorders, and pumping type samplers were used to measure and sample runoff. A recording raingage was used to measure rainfall. Samples of runoff were collected at 20-minute intervals during storm runoff and subsequently analyzed for sediment concentration. Selected samples were analyzed to determine the particle size distribution of the sediment.

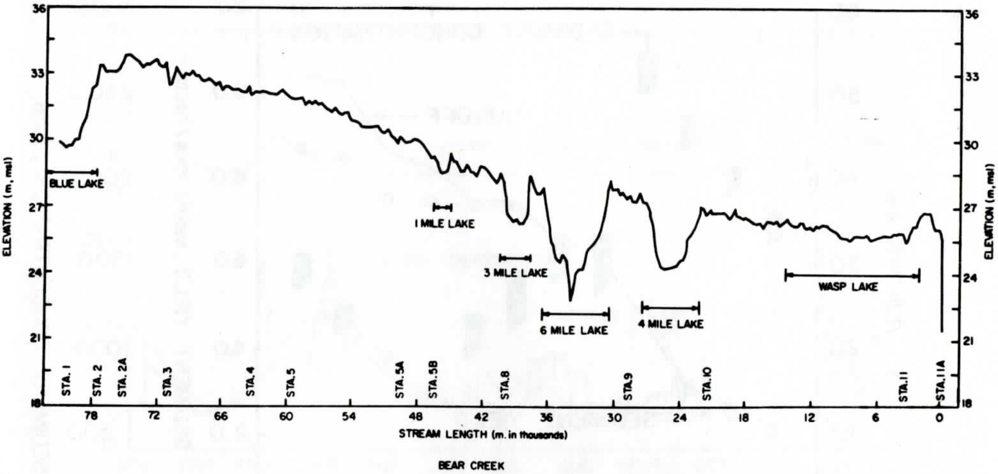

Figure 2. Profile of Bear Creek (Thalweg) Channel.

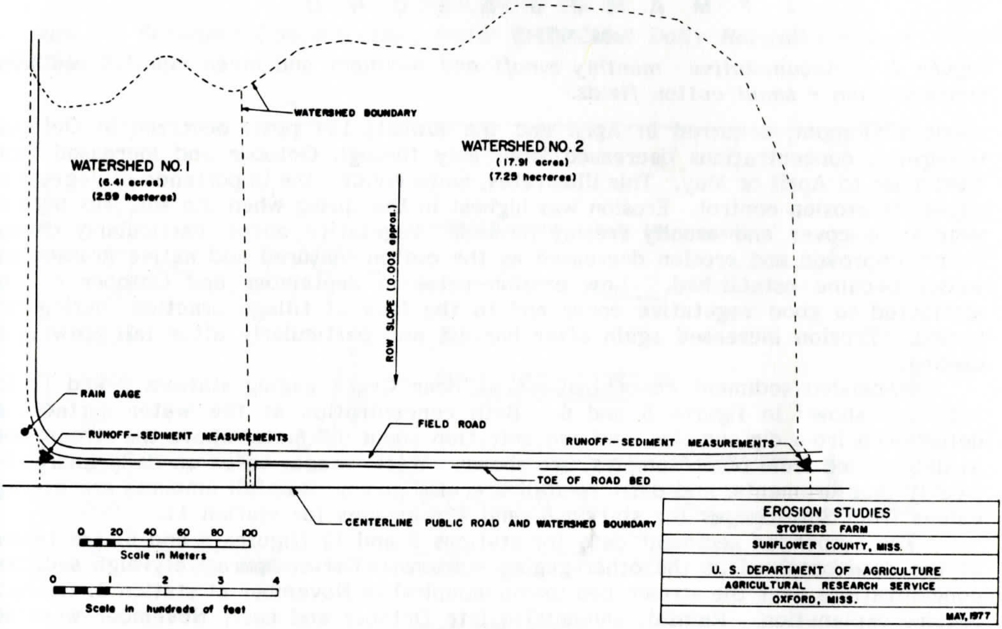

Figure 3. Field Layout for Erosion Studies on Cultivated (Cotton) Field in the Bear Creek Watershed.

RESULTS AND DISCUSSION

The erosion studies on the small cotton watersheds provided information on the sediment production potential of cultivated lands in the Bear Creek basin. Accumulative average monthly runoff and sediment yields for a 33-month period are shown in figure 4. Average annual rainfall for the study period was 143 cm, about 10 cm above normal. Average annual runoff was 52 cm and average annual sediment yield was about 8.7 metric tons per hectare (t/ha/yr).

Suspended Sediment Concentrations

Average monthly suspended sediment concentrations in runoff from the cotton watersheds varied widely with season (figure 4). The highest monthly concentration,

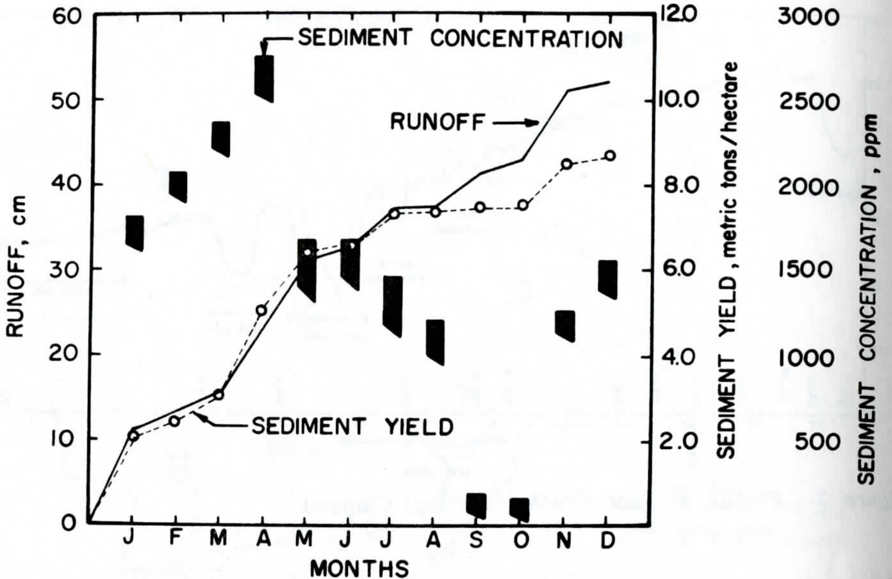

Figure 4. Accumulative monthly runoff and sediment and mean monthly sediment concentration - small cotton fields.

about 2750 ppm, occurred in April and the lowest, 164 ppm, occurred in October. Generally, concentrations decreased from May through October and increased from November to April or May. This illustrates, quite vividly, the importance of vegetative cover for erosion control. Erosion was highest in the spring when the soil was bare of vegetative cover and usually freshly plowed. Vegetative cover, particularly canopy cover, improved and erosion decreased as the cotton matured and native grasses and weeds became established. Low erosion rates in September and October can be attributed to good vegetative cover and to the lack of tillage practices during this period. Erosion increased again after harvest and particularly after fall plowing or disking.

Suspended sediment concentrations at Bear Creek gaging stations 8 and 11 for 1977 are shown in figures 5 and 6. Both concentration at the water surface, as determined from dip samples, and concentration about 0.3 meter above the stream bed, as determined from pump samples, are shown. Water stage, based on daily and/or bi-weekly measurements, and daily rainfall are also given. Rainfall amounts are average values from 3 raingages for station 8, and 4 raingages for station 11.

The suspended sediment data for stations 8 and 11 (figures 5 and 6) are typical of the data obtained at the other gaging stations. The comparatively high sediment concentrations near the stream bed (pump samples) in November at station 8, figure 5, require explanation. Rainfall amounts in late October and early November were not large enough to explain the large increase in concentration. Neither was there a corresponding increase in concentration at the water's surface (dip samples). Further study of the data indicated that these increases in concentration were not inorganic sediments but were particulate organic matter. Similar phenomena have been reported previously (Wetzel, 1975, 1972). These abnormally high concentrations, which resulted from biological activity, were not used in the computations of mean monthly sediment concentrations in Bear Creek.

Generally, suspended sediment concentration in Bear Creek ranged between 300 and 1500 ppm, and concentrations at the surface were nearly always less than concentrations near the stream bed (figures 5 & 6). The vertical concentration gradient, frequently several hundred ppm's, was usually greater immediately after storm runoff. This indicated that some relatively coarse sediments (silt-size) reach the channel and that deposition occurs in the channel and particularly in the in-stream lakes. Data acquired by Ritchie and others, 1979, showed deposition rates in both off-stream and in-stream lakes ranging from 1.4 to over 5.6 cm/yr. And while

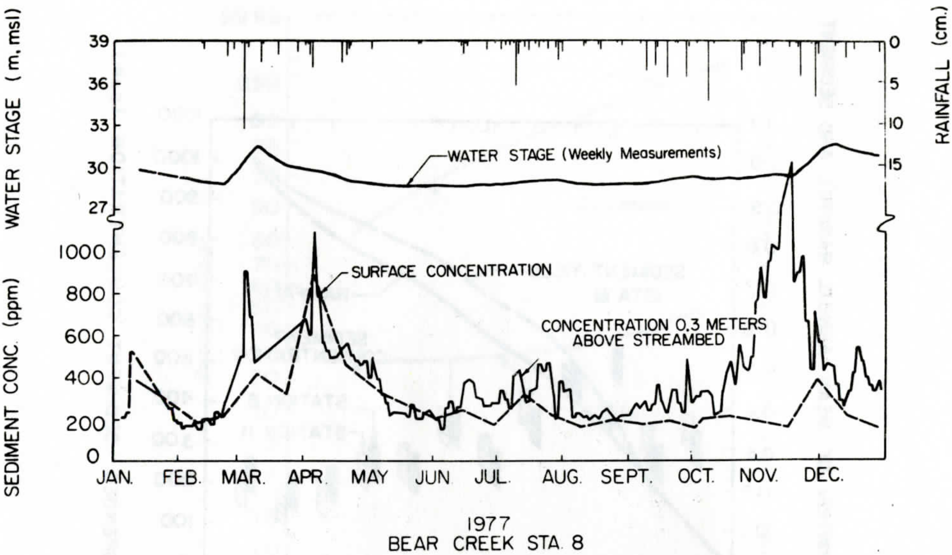

Figure 5. Sediment Concentration, Water Stage, and Daily Rainfall for Bear Creek Station 8.

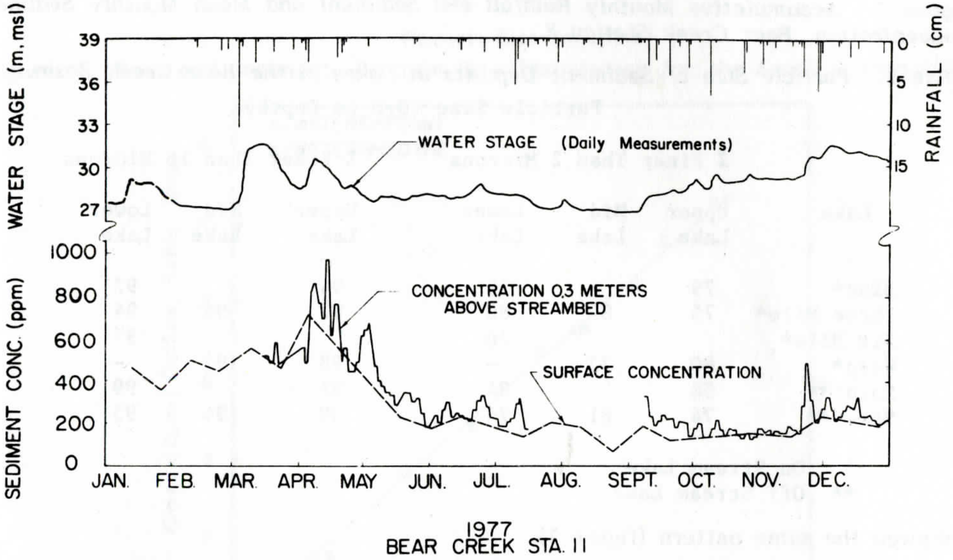

Figure 6. Sediment Concentration, Water Stage, and Daily Rainfall for Bear Creek Station 11.

concentrations usually increased in response to rainfall and runoff, water stage was not closely correlated with concentration. Instead, concentration appeared to be more nearly seasonally correlated.

Mean monthly suspended sediment concentrations at stations 8 and 11 for the 3-year period, 1977-79, (two year averages for Jan., Feb., Oct., Nov., and Dec.) were computed by averaging the mean daily concentrations (figure 7). Daily concentrations were computed by averaging the concentration at the water surface and the concentration 0.3 meter above the stream bed. Since only weekly or bi-weekly measurements of surface concentration were available, the change in surface concentration from one sampling time to another was assumed to vary linearly with time. Monthly suspended sediment concentrations in Bear Creek were generally much less than those in runoff from the small cotton watersheds, but variation with season

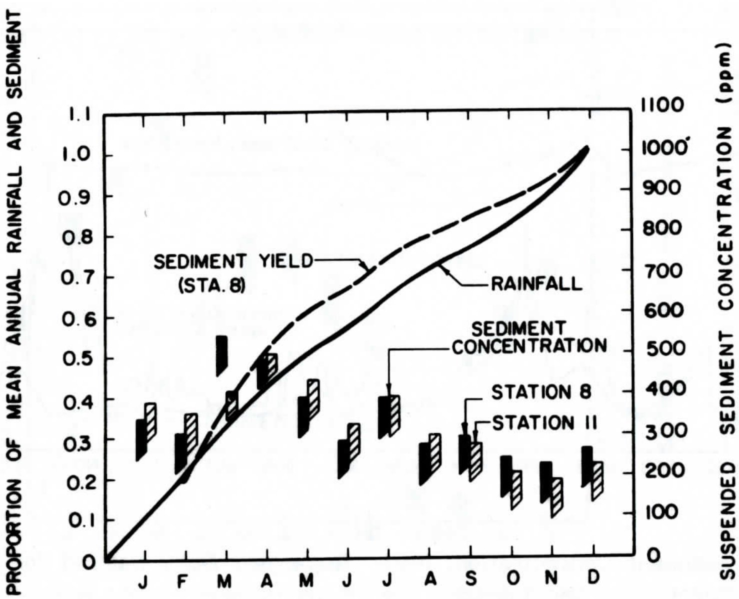

Figure 7. Accumulative Monthly Rainfall and Sediment and Mean Monthly Sediment Concentration, Bear Creek Station 8.

Table 1. Particle Size of Sediment Deposits in Lakes in the Bear Creek Basin.

Particle Size (0-8 cm Depth)

	% Finer Than 2 Microns			% Finer Than 16 Microns		
Lake	Upper Lake	Mid Lake	Lower Lake	Upper Lake	Mid Lake	Lower Lake
Blue*	79		75	94		97
Three Mile*	75	82	80	97	98	94
Six Mile*			76			97
Wasp*	80	73	-	98	97	-
Macon**	58		84	91		99
Mossy**	74	81	74	99	96	95

* On Stream Lake
** Off Stream Lake

followed the same pattern (figure 7).

Sediment Particle Size

Sediment particle size data obtained from the erosion studies on the cotton watersheds show that most of the sediment removed from fields in the Bear Creek basin, and particularly that portion which reaches the major streams, is fine material. Even though the soils were composed of approximately 24% clay (< 2 μm), 23% silt (> 2 < 53 μm), and 53% sand (> 53 μm), most of the sediment removed from the fields was clay particles (figure 8). Particle size analyses of sediment outflow samples showed that about 83% was clay, < 2 microns, and 98% was <16 microns. Essentially no sand particles were measured at the flume sites.

Figure 9 shows the relationship between clay outflow and total sediment outflow for 6 selected storms. The clay portion was about the same for all runoff rates and for both large and small storms. Peak runoff rates ranged from 0.5 to 3.6 cm/hr and runoff volumes from 1.4 to 10.5 cm. The selected storms occurred in January, April,

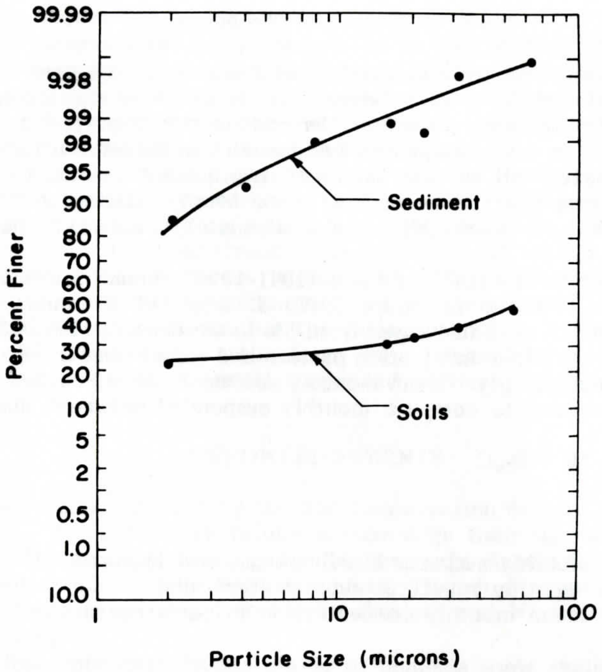

Figure 8. Soils and Sediment--Particle Size Distribution for the Small Cotton Fields.

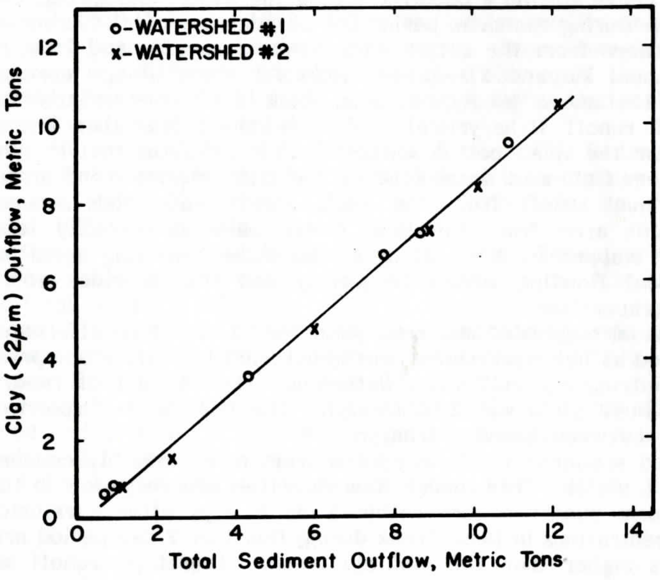

Figure 9. Sediment-Clay Relationship on a Storm Basis for the Small Cotton Fields.

August, and November so they represented a wide range of vegetative cover and ground surface conditions.

Sediment deposits in Bear Creek lakes also indicate that most of the sediment entering the stream is fine material. Samples showed that 75 to 80% of the top 8 cm of sediment deposits in both in-stream and off-stream lakes was finer than 2 microns and nearly all was finer than 16 microns (table 1).

Sediment Discharge

While the mean monthly suspended sediment concentrations in figure 7 are only approximately correct, they may be used to estimate suspended sediment discharge from the Bear Creek basin. Most of the sediment transported in Bear Creek is fine silt and clay which is easily suspended and remains in suspension for long periods. This indicates that nearly all of the sediment transported in the channel is suspended material. And since fine sediments tend to be evenly distributed throughout the flow, a single point sample each day should adequately represent the daily mean concentration.

Monthly distribution of long-term (1941-1970) annual rainfall at nearby Greenwood, Mississippi is shown in figure 7 (U. S. Dept. of Commerce, 1978). Monthly proportions of annual rainfall ranged from 5% in October to 12% in March. Runoff was assumed to have the same distribution pattern and annual runoff was apportioned to the various months accordingly. Mean monthly sediment concentrations and mean monthly runoff were then used to compute monthly suspended sediment discharge as follows:

$$Q_s = 10^{-6} Q_w C$$

where

Q_s = monthly suspended sediment in metric tons
Q_w = monthly runoff in cubic meters, and
C = mean monthly concentration in parts per million.

Monthly values were summed to obtain annual suspended sediment yield. About 61% of annual runoff and 68% of annual suspended sediment discharge from the drainage area above station 8 occurred during the winter and spring, December through May (figure 7). During the same period the percentages of measured annual runoff and sediment discharge from the cotton watersheds were 62% and 75%, respectively.

Mean annual suspended sediment yield for the drainage area above station 8, computed by the above procedure, was about 0.036 metric tons per hectare per centimeter of runoff (t/ha/yr/cm). This is much less than the measured 0.166 t/ha/yr/cm from the small cotton watersheds. It indicates that only about 1/4 of the soil eroded from field-size areas reaches the main channels and streams.

Mean annual runoff from the small cotton watersheds was about 52 cm/yr. Runoff per unit area from the Bear Creek basin is probably less because large quantities are trapped in lakes, sloughs, and other low-lying areas within the basin. Temporary local flooding occurs frequently and this provides additional time for seepage and evaporation.

Mean annual suspended sediment yield for 30 cm of runoff from the Bear Creek basin, computed as indicated above, was about 1.08 t/ha/yr, a comparatively low yield rate for an intensively cultivated watershed. For 60 cm of runoff the estimated suspended sediment yield was 2.16 t/ha/yr. The true mean suspended sediment yield is most likely between 1 and 2 t/ha/yr.

Suspended sediment yields computed from mean monthly concentrations tend to be below actual yields. Even though flow velocities are very slow in the delta, a major portion of storm runoff occurs within 1 or 2 days after a rainstorm. Suspended sediment concentrations in Bear Creek during this 1 or 2 day period are usually several hundred ppm's higher than the monthly mean. Therefore, runoff weighted concentrations would be higher than the mean monthly values used in the computations.

CONCLUSIONS

There were distinct seasonal variations in sediment concentrations in runoff from the small cotton watersheds and in suspended sediment concentrations in Bear Creek. Vegetative cover appeared to be the predominant factor causing these variations. Mean monthly sediment concentration in the cotton field runoff varied from about 2750 ppm in April when there was essentially no vegetative cover to 164 ppm in October when cover was good. Suspended sediment concentration variations in Bear Creek followed a similar seasonal pattern but were much less in magnitude.

Most of the suspended sediment transported in the Bear Creek drainage system is fine material. About 83% of the sediment removed from the cotton watersheds and 75 to 80% of recent deposits in Bear Creek lakes were less than 2 microns in size, and nearly all, 95 to 98%, was smaller than 16 microns. This indicates that nearly all sediment transported in the stream is suspended material.

Estimates of annual suspended sediment discharge in Bear Creek, based on mean monthly suspended sediment concentrations and an assumed monthly distribution of annual runoff, were quite low for an intensively cultivated basin. Suspended sediment yield per cm of runoff for the Bear Creek basin was about .04 t/ha/yr, about one-fourth as much as the measured sediment yield (0.17 t/ha/yr) from the small cotton watersheds. This indicates that approximately 75% of the sediment eroded from field-size areas is deposited before it reaches the main channel.
For 30 cm of runoff, a reasonable estimate of annual runoff for a central Mississippi Delta watershed, the estimated annual suspended sediment yield was only about 1 t/ha/yr.

ACKNOWLEDGEMENTS

This study was funded in part by the Soil Conservation Service and the U.S. Army Corps of Engineers. The authors gratefully acknowledge their support and the support of J. R. McHenry, the principal investigator for the study, Arnold Champion and Wayne Sansom who collected most of the field data, Kathy Roush, Warren Slayden, and John May who analyzed the samples and to Sandra Sanders and Winfred Cook who helped prepare the manuscript.

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A NEW OCCURRENCE OF TELLURIDE MINERALS IN SOUTH CAROLINA

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ABSTRACT

Study of drill cores from the Haile gold mine, South Carolina has revealed grains containing large amounts of tellurium with various combinations of lead, silver and gold in pyrite. Although these have not been identified mineralogically, they are clearly telluride minerals. The nearby Brewer mine on the basis of chemical evidence also contains telluride minerals. The probable telluride localities in South Carolina are expanded to three significantly increasing the few reports of telluride minerals from the gold deposits of the southeastern Piedmont, many of which are now considered volcanogenic deposits. The occurrence of telluride minerals in gold ore from the Haile-Brewer area may help to explain the divergence in gold-silver ratios reported in chemical analyses of drill core, ore samples and production records. Tellurium, in addition, may be useful in geochemical exploration programs in the southeastern piedmont including programs using heavy mineral concentrates derived from stream alluvium.

INTRODUCTION

During examination of drill core samples of gold ore from the Haile mine, Lancaster County, South Carolina, we identified grains containing large amounts of tellurium with various combinations of lead, silver and gold. Although these have not been identified mineralogically, it seems clear that these are telluride minerals (figure 1).

The most common associations found in samples from the Haile mine are lead-tellurium followed by nearly equal occurrences of silver-tellurium both of which are more abundant than gold-tellurium or gold-silver-tellurium. These minerals are possibly altaite (Pb Te), hessite (Ag_2 Te), krennerite (Au Te_2) and sylvanite (Au Ag Te_4). As such they expand the described occurrences of tellurium-bearing minerals in South Carolina to two, York County and the Haile mine (this study). The Brewer mine in Chesterfield County, on the basis of chemical evidence presented here, is also thought to contain tellurides.

The presence of undetected silver and gold-silver tellurides in gold ores of the southeast, however, may help to explain a divergence in gold to silver ratios between production records and bullion assays on one hand and chemical analyses of drill core and ore samples on the other hand. Production records for the Haile-Brewer area commonly show gold-silver ratios greater than one and in bullion a ratio of gold to silver of 4.3 is reported by Newton, Gregg and Mosier (1940, table 6). Chemical analyses of drill core and other ore samples usually show ratios of gold to silver of less than one, with a large sample of ore from the Haile mine having a ratio of gold to silver of 0.311. Although the divergence in ratios is probably the result of several factors, including the method of ore refining and analytical procedures at least some of the divergence may be due to undetected abundance of gold- and silver-tellurides which were not recovered in previous chlorine, cyanide and amalgam milling processes.

GEOLOGIC SETTING

The Haile and Brewer mines are important former gold producers in the Carolina Slate belt. These mines are in greenschist facies metamorphic rocks and are in the upper part of a predominantly felsic volcaniclastic unit near its contact with overlying thick units of argillite (Bell, 1982). The mineralized rocks at the two mines have many similarities. The Brewer mine characterized by intensely silicified and brecciated rocks containing gold, topaz, enargite and small massive pyrite bodies may represent a higher temperature center of deposition than the Haile mine. Massive pyrite bodies and gold

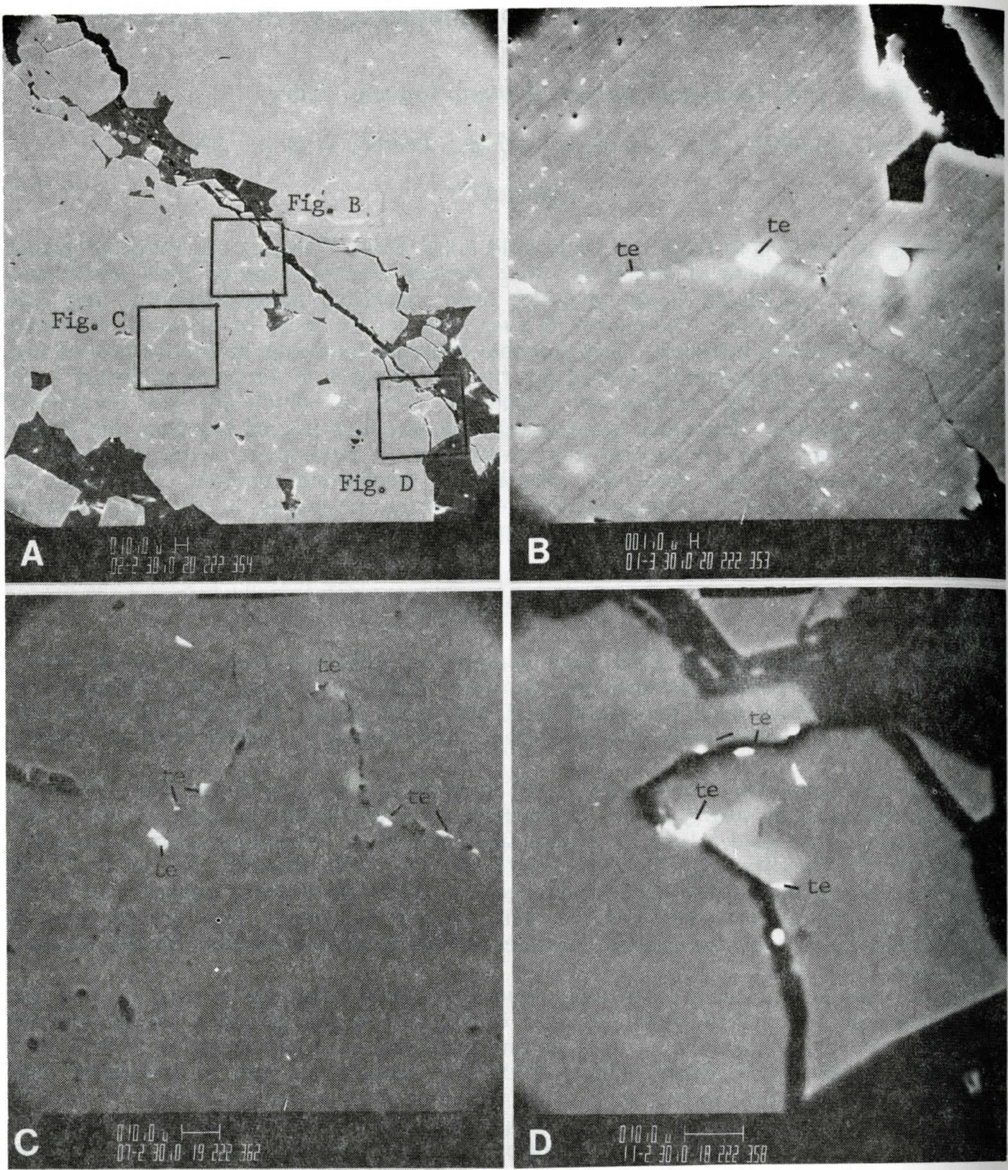

Figure 1. Scanning electron microscope images of tellurium-rich grains in pyrite from the Haile mine, South Carolina. A: Secondary electron detector image showing location of figures B, C, and D. The latter are backscattered electron detector images.

ore containing significant amounts of molybdenite occur at the Haile mine. The very siliceous, fine grained and thinly bedded gold horizon there suggested to Spence and others (1980), "the siliceous sinter apron of an ancient hot spring system."

Tellurium minerals as described in text books and compendiums (Ramdohr, 1960; Boyle, 1979) are commonly found in gold ore, although usually in small amounts, and are especially associated with volcanogenic ore deposits. In spite of this common association, reports of telluride minerals in the numerous gold deposits of the southeast Piedmont in general and South Carolina in particular are remarkably scarce even though many of the deposits are now considered to be volcanogenic (Bell, 1982; Bell and others, 1980; Spence and others, 1980; Worthington and Kiff, 1970).

OTHER TELLURIDE OCCURRENCES

Pardee and Park (1948, p. 37) list tetradymite as the most common telluride occurring in 13 gold mines, in the southern Piedmont. Butler (1964) describes an occurrence of tetradymite at the Hull prospect in the Smyrna district, York County, South Carolina. Bismuth minerals occur at the Brewer mine (Mount, 1963), but neither tetradymite nor other tellurium minerals have been identified there. Grab samples, however collected at equally spaced intervals through a 1000 feet long, deep drainage tunnel show tellurium values ranging from 10 ppm, the lower limit of detection, to 33 ppm in 10 of 65 samples (Bell, 1984). The results of semiquantitative spectrographic analyses for 34 elements and for tellurium, gold, silver, bismuth, tin and fluorine by various other chemical methods are shown in table 1. Simple Pearson correlation coefficients were calculated using the analyses for tellurium, gold, silver, bismuth, tin and fluorine from the tunnel samples (fig. 2). The results show that tellurium is correlated with silver and gold in the order anticipated but also rather surprisingly, tellurium is more closely correlated with tin than with bismuth.

METHODS AND PROCEDURES

The tellurium-bearing grains were discovered by means of the scanning electron microscope (SEM). The samples used for analysis were polished thin-sections one inch in diameter fastened to specimen mounts, called stubs, and coated with a thin layer of carbon in a vacuum evaporator. Polished sections as well as loose grains from heavy mineral concentrates were also examined, but in less detail.

SEM photographs (fig. 1) were made of pyrite grains in polished thin-sections using both the secondary electron detector and the backscattered electron detector. In general, areas underlain by minerals with high atomic weight were located by scanning the samples quickly with the backscattered electron detector at a medium magnification (approximately 2000x). In the backscattered mode the areas with higher average atomic weight are distinguished from areas with lower atomic weight by higher contrast (areas of increased brightness on the SEM viewing screen). This technique makes it possible to rapidly find areas of suspected heavy minerals in a sample. The elemental composition of each grain located by this procedure was determined using the SEM energy-dispersive X-ray detector. The SEM was operated at 30Kv making it possible to determine lead and gold by L and M series X-ray lines. Silver and tellurium were identified using the L series X-ray lines.

E. Y. Campbell (U.S. Geological Survey, Analytical Laboratories) analyzed by a graphite furnace atomic absorption technique two specimens from which tellurium-bearing thin-sections had been prepared. The samples contain 15 and 1.1 parts per million tellurium. Other samples from the Haile mine are five pyrite separates in which tellurium ranges from 1.1 ppm to 79 ppm (table 2).

DISCUSSION

The tellurides in the samples from the Haile mine all occur in pyrite crystals and along fractures apparently confined to the pyrite crystals or crystal aggregates. These sites seem to confirm the generally recognized position of telluride minerals as a late phase in ore paragenesis.

The samples of pyrite analyzed for tellurium are splits from the samples used by LeHuray (1983) for sulfur isotope analyses and include pyrite from several generations recognized in the Haile mine gold ore as having different histories or origins. These include fine-grained "submassive" pyrite, disseminated euhedral pyrite, and large zoned cubes of pyrite. Table 2 shows the results of analyses for tellurium, sulfur isotopes and ore values for the drill core interval in which the tellurium-bearing pyrite crystals were found. If the tellurium-bearing grains are in some way related to the formation of the pyrite cubes by partitioning or fractionation during crystallization of a tellurium-bearing, sulfur-rich, ore-forming solution, as seems likely, then the similarity to many volcanogenic gold deposits is enhanced. The values for $\delta^{34}S$ from the pyrites in the Haile gold ore suggested to LeHuray (1983) a strong magmatic sulfur component and an environment dominated by fresh water rather than Paleozoic seawater.

Table 1. Chemical analyses of tellurium-bearing samples from drainage tunnel, Brewer mine, South Carolina.

Sample numbers	13-HB-29 ABY-819	13-HB-30 ABY-820	13-HB-35 ABY-825	13-HB-37 ABY-827	13-HB-41 ABY-831	13-HB-52 ABY-842	13-HB-57 ABY-847	13-HB-58 ABY-847	13-HB-64 ABY-854	13-HB-65 ABY-855
Spectrographic analysis[1/]										
Percent										
Fe	1.5	5	G	5	1.5	.1	7	3	.5	2
Mg	.01	.007	.005	.003	.015	.01	.005	.002	.003	.003
Ca	.03	.01	.01	.01	.03	.03	.007	.007	.001	.0003
Ti	.2	.2	.1	.2	.2	.3	.3	.2	.2	.3
Parts per million										
Mn	10	20	100	2	70	10	3	15	7	20
Ag	.3	N	1.5	N	.5	N	2	.5	N	.5
Ba	1000	300	50	300	200	100	50	50	10	20
Bi	30	N	30	7	20	70	20	20	N	7
Co	N	7	30	N	N	N	N	N	N	3
Cr	5	15	10	N	15	10	5	N	N	N
Cu	15	50	300	30	100	30	50	30	15	70
La	N	N	N	30	50	150	N	N	N	N
Mo	20	3	20	5	5	15	100	50	15	50
Nb	N	5	7	5	5	5	7	5	5	7
Ni	N	10	20	N	10	N	N	N	N	N
Pb	100	30	30	70	200	15	15	15	N	N
Sc	10	10	7	10	10	10	10	7	7	7
Sa	7	7	200	7	20	30	30	20	15	30
Sr	200	100	30	150	700	150	15	15	N	N
V	30	30	10	20	50	15	15	10	5	7
Y	7	5	7	7	5	7	5	7	5	7
Zr	200	200	200	200	150	200	300	200	150	200
Other chemical analyses[2/]										
Parts per million										
Hg	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Te	17	10	14	11	13	16	33	16	12	11
Au	.2,.2	<.05	.3,.3	<.05	.1,.1	1.1,1.0	.4,.6	.4,.5	.2,.1	.4,.4
U	1.5	1.3	1.0	1.1	1.5	1.9	1.3	1.3	1.1	1.1
F	0.35	.011	.14	.25	.11	6.6	5.1	1.5	.82	.20

1/ Analyst: William B. Crandell, 1969
Fe, Mg, Ca, and Ti are reported in %; all others in ppm. Results are to be identified with geometric brackets whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, etc., but are reported arbitarily as mid-points of these brackets. 1., 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, etc. The precision of a reported value is approximately plus or minus one bracket at 68% or two brackets at 95% confidence.
Symbols used are: N = Not detected, at limit of detection or at value shown
2/ Mercury was determined by a combined penfield-dithizone technique. Analyst: J. J. Warr
Tellurium was determined by atomic absorption spectroscopy after extraction into MIBK from Br_2-HBR. Analyst: F. W. Brown.
Gold was determined by a combined fire-assay-atomic absorption technique and reanalyzed. All determinations are shown. Analyst: L. Mei.
Uranium was determined fluorimetrically: Analyst: J. Budinsky.
Fluorine was determined volumetrically using a fluoride specific-ion electrode to detect the end point after distillation as fluorsilicic acid. Analyst: J. Budinsky.

	Ag	Au	Bi	Sn	Te
Au	.606				
Bi	.331	.363			
Sn	.646	.480	.177		
Te	.434	.285	.064	.205	
F	-.066	.123	.057	.118	.024

Figure 2. Simple Pearson correlation coefficients for selected elements in samples from the Brewer mine, South Carolina.

Table 2. Gold, tellurium and $\delta^{34}S$ values in pyrite samples from the Haile mine, South Carolina. Adapted from LeHuray (1983).

	Type[1]	Au[2]	Te[3]	$\delta^{34}S$[4]	
1	D	.016	67	3.07	Medium grained cubes along bedding and fractures in siliceous bedded felsic tuff
2	D	.011	79	2.42	Fine-grained in siliceous felsic tuff
3	sub-M	.096	47	1.78	Fine grained and medium grained in felsic tuff
4	D	.007	18	2.07	Large zoned cube of pyrite
5	D	Y.001	1.1	2.58	Fine grained in fine grained felsic tuff

1) Pyrite characteristics: D = disseminated, sub-M = sub-massive

2) Gold values in ounces per ton from company drill-logs. Values are for 10 ft. intervals which include the pyrite sample, except no. 5 which is a 5 ft. interval.

3) Tellurium analyses; E. Y. Campbell, U.S. Geological Survey, by graphite furnace atomic absorption.

4) Sulfur isotope analyses by A. P. LeHuray, U.S. Geological Survey.

Analyses for tellurium on a variety of materials have been successfully used in geochemical sampling programs in the western states by Gott and co-workers (1966, 1969, 1973). Watterson and others (1977, p. 32-33) reviewing the use of tellurium as a guide to mineral deposits point out that, ". . . in the zone of weathering tellurium is usually immobile. The oxidation of pyrite-rich rocks and subsequent production of gossans, or leached cappings, usually prevent Te from migrating appreciably in the zone of weathering . . . ." Although telluride minerals are commonly very soft, they have very high specific gravity, ranging from about 7 to 9.5, and as a consequence may be expected to occur in heavy mineral concentrates, probably, close to their source rocks.

In the southeastern states where collection of heavy mineral concentrates from stream alluvium is a part of many exploration programs, analysis for tellurium and search for telluride minerals should be considered, because the occurrence of tellurides may be more common than previously suspected.

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NOTES ON COSUNA CORRELATION CHART FOR ATLANTIC COASTAL PLAIN

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ABSTRACT

AAPG's COSUNA Correlation Chart for the Atlantic Coastal Plain presents time-based correlation for about 200 units in common usage from New Jersey through South Carolina. The chart was compiled from the work of many stratigraphers and is a statement of current knowledge about the province. Historically, the techniques available and the styles of individual stratigraphers have influenced regional correlations in ways that make it difficult to reach broad general agreement. The regional display of the new chart aids in identifying prerift, synrift, and postrift sequences and the distribution in time and space of rock types and major unconformities. The establishment of relationships between Coastal Plain rocks and their offshore extensions offers promise for improved understanding of the history of the continental margin. A coordinated approach to regional stratigraphy, including especially the offshore, will provide advances beyond the benchmark established by the COSUNA chart.

INTRODUCTION

The Correlation of Stratigraphic Units in North America (COSUNA) Project began in 1977 under the sponsorship of the American Association of Petroleum Geologists. It will produce a set of 16 modern correlation charts and compilations of pertinent documentation in a computer-based system. The COSUNA Project was led by Orlo E. Childs, Project Director, Grant Steele, Steering Committee Chairman, and Amos Salvador, Technical Committee Chairman, and involved contributions by many organizations and individuals over a six-year period. Childs (1982) estimated that 450 geologists participated in the project and that their efforts will produce 550 stratigraphic columns and 17,500 data sheets. The columns will be distributed among the 16 regional correlation charts to be published over a span of several years.

One of the first charts to be published is that for the Atlantic Coastal Plain (Jordan and Smith, 1983). The purpose of this paper is to offer some additional explanation of the Atlantic Coastal Plain Chart and some observations on the status of stratigraphic knowledge and the practices of stratigraphers in the Province.

COSUNA PROCEDURES

Standardized conventions for all charts were established for COSUNA by the Steering and Stratigraphic Technical committees working with the Operations Committee, which included the Coordinators for each province. The basic format was inspired by the 1970 correlation charts of Canada (Douglas, 1970). Each COSUNA chart covers, roughly, a geologic province. Columns within each chart depict the stratigraphy within representative areas of each province. Printing considerations constrained the number of columns that could be accommodated on each chart and the amount of detail and variety of colors used. It is important to note that COSUNA charts are time-based correlation charts. Much attention was given to developing a standardized time column that incorporates worldwide units. The charts are not to be confused with cross sections.

Conventions were also evolved for graphic representation of stratigraphic relationships. Several compromises were required to meet the necessities of standardization and practicality which, in some cases, conflicted with the specific requirements of a particular chart or column.

The COSUNA provinces do not coincide exactly with geologic or physiographic provinces, but, rather, are approximations based on Committee on Statistics and

Drilling (Mayer, 1974) divisions established by AAPG to facilitate data organization. Some additional constraints on the boundaries of provinces were found necessary so as to distribute the many columns reasonably among the printed sheets.

The province coordinators selected for each COSUNA province, in turn, established province committees. The province committees normally consisted of those experts in the stratigraphy of particular portions of the provinces who served as authors of individual columns and who prepared the accompanying data sheets. The draft products were reviewed and compiled according to COSUNA conventions by the province coordinators and submitted for review to other geologists. Draft columns were displayed for comment at regional society meetings for additional review.

A fundamental principle guiding the COSUNA effort was that the result be practical. That is, that the charts incorporate the established units used by practicing geologists in the areas represented. Formal status was not a primary consideration, although the principles of the Code of Stratigraphic Nomenclature (ASCN, 1961; 1970) and the International Stratigraphic Guide (Hedberg, 1976) were generally applied. The objective was to usefully organize existing information, not to revise stratigraphic practices or create new stratigraphies. The charts, therefore, reflect consensus views as of the times of their compilation.

A significant, and easily overlooked, aspect of the COSUNA Project was the preparation of data sheets to document each entry in each column of every chart. The data sheets include such information as status, rank, relationships, lithologies, paleontology, authorship, and pertinent references that could not be portrayed graphically or in detail on the charts (Fig. 1). Authors and coordinators will testify that the preparation of the data sheets was a far more rigorous exercise than drawing columns. Preparation of the data sheets served as something of a test of the desirability of including specific units on the charts. Information from the data sheets has been entered under the COSU file at the University of Oklahoma and is a major resource resulting from the COSUNA Project. Retrieval from the data bank by various category headings should facilitate further research. Also, stratigraphers seeking justification for the representations on the charts may consult the data bank for documentation.

EVOLUTION OF THE ATLANTIC COASTAL PLAIN CHART

Research for the Atlantic Coastal Plain Correlation Chart was conducted by a 10-member Province Committee chaired by Jordan and Smith as Co-Coordinators. The members of the Province Committee plus five additional contributors prepared the columns and the data sheets. Twenty-eight geologists served as formal reviewers of the chart. All of these persons are identified on the chart and their work is gratefully acknowledged.

Throughout the preparation of the chart the Coordinators respected the technical judgments of the authors of the columns. Many modifications of draft materials were necessary in order to assure conformance with the COSUNA conventions. Otherwise, the Coordinators sought conventional stratigraphic practices and the resolution of problems by consensus.

The coverage area for the chart was determined by the administrators of the project to be the Coastal Plain from New Jersey through South Carolina as defined by the CSD map. The Coordinators included a representative section for the offshore Mid-Atlantic synthesized from data from five exploratory wells yielding information publicly available at the time of preparation of the chart. The COSUNA administration added columns for each of two wells from the Georges Bank Basin when it was discovered late in the editing process that they could not be physically accommodated on the New England chart.

In total, 595 separate entries appear in 38 columns of the Atlantic Coastal Plain Chart. Each entry is documented by data sheets, which total approximately 1,750 pages. Many names appear in several columns, so about 200 different stratigraphic units are involved. This may represent about a third of the names that have appeared in the literature, but includes those that were found by active stratigraphers to be in signicant use as of 1981 and which comply with the general COSUNA rules.

The units selected for the chart, and their correlations, will not meet with the

DATA SHEET FOR EACH STRATIGRAPHIC UNIT

ON CORRELATION CHART

1. REFERENCE #_______ 2. LOCATION #______ 3. CSD PROVINCE #______

4. COLUMN NAME:

5. CHART #__________ 6. COLUMN #__________

7. NAME OF STRATIGRAPHIC UNIT:

8. STRATIGRAPHIC RANK AND STATUS:

Group, Formation, Member, Bed,____________________

Formal, Informal,____________________________

9. AGE: System____________Series______________Stage____________

10. SURFACE, SUBSURFACE OR BOTH:

11. BOUNDING UNITS: Above________________Below________________

12. LITHOLOGY: Dominant__________________% ________________

Subordinant________________% ________________

13. THICKNESS (Metric)__________________(Range if necessary)

14. MAJOR UNCONFORMITIES: None Disconformable Angular

ABOVE:
WITHIN:
BELOW:

15. FOSSIL DATA:

16. RADIOMETRIC DATA:

17. ECONOMIC DATA:

18. OTHER DATA:

19. ORIGINAL REFERENCE:

20. MOST SIGNIFICANT REFERENCE:

21. AUTHOR(S) OF SHEET PREPARATION:

22: DATE PREPARED:

ADDITIONAL DATA (Amplification of above)

Figure 1. COSUNA Data Sheet. (Adopted from original.)

approval of all stratigraphers. Advances in the field are stimulated by attempts to resolve such differences of opinion. The base line established by the chart should be useful to many geologists and students. It is to be hoped that attention to the problems identified by the Atlantic Coastal Plain Chart will result in the improvements that will soon make it obsolete. The science is dynamic and the chart captures, according to its conventions, the status of our work at this stage of development.

EARLIER REGIONAL CORRELATIONS

Attempts to correlate stratigraphic units on the scale of the COSUNA Project are rare. The early "Correlation Papers" of the U. S. Geological Survey and the correlation charts of the National Research Council project published by GSA (Dunbar and others, 1942) are examples. Among the correlation papers, Dall and Harris' 1892 volume on the Neocene is pertinent to the Atlantic Coastal Plain, but there have been many changes in stratigraphic practice and much additional information generated in the past 90 years. Charts by Stephenson and others (1942) and Cooke and others (1943) appear generalized in comparison with the COSUNA chart as they depict seven and four Atlantic Coastal Plain columns, respectively, and contain less than one-third of the unit citations. Although annotated, the "GSA" charts do not have the associated documentation provided by the COSU data retrieval system.

Regional studies of the stratigraphy of the Atlantic Coastal Plain have been presented at irregular intervals, but with, perhaps, increasing frequency, since McGee's 1888 "Three Formations of the Middle Atlantic Slope." Significant examples include

Clark (1910), Richards (1945), Spangler and Peterson (1950), Dorf (1952), Loeblich and Tappan (1957), Murray (1961), Maher (1965), and Brown, Miller, and Swain (1972). There have also been regional studies specialized to particular portions of the column or Province such as the Quaternary work exemplified by Cooke (1930) and Oaks and DuBar (1974), and offshore studies by the USGS (for example, Schlee and others, 1976; 1981; Poag, 1979; Grow, 1981).

Each of these studies, together with the many stratigraphic investigations of subdivisions of the Province or specific units, has contributed to the understanding of Atlantic Coastal Plain stratigraphic correlation. "Correlation," however, has had a variety of meanings. Examination of the papers cited indicates the range of possibilities. Various authors have placed emphasis on correlation by a variety of lithologic properties, various macro- and micro-fossils, geophysical properties, and an array of other techniques. As suggested by Oaks and DuBar (1974) for the post-Miocene, stratigraphic practices might be catalogued by periods ranging from the very early emphasis on economic properties through macrofossils, trace mineralogy, sea level, microfossils, geophysical properties, and tectonics to a period when the art has been disciplined and formalized to some degree by the Stratigraphic Code (ACSN, 1961) and Guide (Hedberg, 1976).

In addition to the influences of the formalized rules of stratigraphic nomenclature, the greatest impact on Atlantic Coastal Plain stratigraphy appears to be the recognition of the importance of studies of the subsurface and the growing availability of subsurface information. This is linked to increasing knowledge of the continental margin and the exploration for oil and gas, particularly offshore.

Although it conforms to applicable conventions and plots, with few exceptions, lithostratigraphic units against time, the COSUNA chart reflects the varying styles of its authors as well as the variable status of knowledge in different parts of the Atlantic Coastal Plain. Its major deficiency lies in the inability to more completely characterize the deeper subsurface and offshore extensions of the Province where most of the volume of rock lies buried.

PERCEIVED STYLES OF STRATIGRAPHERS

Beyond objective matters of fact, disputes in stratigraphy stem largely from differences in the approaches of practitioners. Differences of opinion of this type are inherent in geology because so much of the subject matter cannot be studied directly and is masked in immaterial time. This stimulates the investigator, but also reinforces individualistic tendencies.

The Atlantic Coastal Plain is a "subsurface" province. Outcrops are comparatively rare and limited in thickness of contained section. Inevitably, differences of interpretation will result between studies of outcrops where great tangible detail may be obtained and the investigation of laterally constrained, but vertically more representative, well and geophysical data. Mappers of the surface and paleontologists specialized in macrofossils emphasize the outcrop. Investigators of ground water, petroleum, and other economic resources, geophysicists, and micropaleontologists emphasize the subsurface. The chart reflects these approaches in the detail shown on columns representing outcrop sections and near the tops of most columns. The more accessible units have been more frequently studied. Early correlations of Atlantic Coastal Plain units suffer from a tendency to force the details of the outcrop long distances into the subsurface. Others have extended the data from wells in the opposite direction, updip, and minimize the detailed information from outcrop. The two camps should meet more frequently in regional correlation studies.

It was not until 1961 that the Code of Stratigraphic Nomenclature (ACSN, 1961) stated that "Rock-stratigraphic units are essentially the practical units of general geologic work that serve as a foundation for describing and studying lithology, local and regional structure, stratigraphy, economic resources, and geologic history." The Code did not suggest that one type of unit is "better" or preferable to another, only that there are fundamental differences among them. As noted, the COSUNA chart attempts to locate rock stratigraphic units in time. Prior to codification of the definitions of various stratigraphic entities, few investigators took such distinctions into account. As with other provinces, the Atlantic Coastal Plain has historically established nomenclature based on a variety of criteria such that a compound problem is created when differently defined units are correlated by various techniques. These complexities cannot be overcome in a single correlation chart, but future investigators may be made more aware of the need to play by the rules or, at least, carefully specify their techniques.

The differences between investigators who "lump" or "split" their information become apparent whenever classification is employed. To some degree splitting is a concomitant of increasing data. McGee's (1888) three formations have now become more than 200. However, growth of data alone does not fully explain increasing tendencies towards splitting. For example, the concept of "formation" has changed since McGee's day and the concept of the province itself has expanded in depth and beyond the ephemeral shoreline. In general, the chart shows more units identified in areas of better exposure and longer study than in downdip and more recently investigated parts of the Province. The seemingly disparate approaches of lumpers and splitters have been reasonably integrated at this scale.

About 10 percent of the citations on the chart are informal, acknowledged as questionable, or used as "undifferentiated" compounds. The Code of Stratigraphic Nomenclature (ACSN, 1961) acknowledges and specifies the usage of informal nomenclature. In the case of the present chart, some key aquifers are included in keeping with the theme of practicality and informal "chronostratigraphic" units are retained because of their usage in the subsurface of North Carolina and Virginia. Names set in quotation marks or followed by "undifferentiated" indicate honest expressions of doubt or inadequate information. Some authors place greater value on informal nomenclature than others. It is a useful working tool; premature attempts to formalize nomenclature, apparently on the misguided assumption that it is "better," result in unnecessary confusion.

Examination of the chart will reveal that in some portions of the Coastal Plain, rock-stratigraphic units tend to follow time lines whereas other boundaries are time-transgressive. Undoubtedly, in some cases the selection of time and rock unit boundaries result in their coincidence. In others this reflects a style inherited from earlier stratigraphic practice. In general, units that have received intensive study are shown to be time-transgressive.

All geologists are familiar with the "state-line fault" which may bound any provincial investigation. Some of these lateral discontinuities are real as some political boundaries do follow significant natural features. Most, however, are artifacts of the histories of the investigations. The nomenclature used in the Coastal Plain does not appear to suffer unduly from state-line faults, but the ages of some units and the degree of certainty about the ages of many units vary according to the several authors. Regional correlation charts serve to clarify the possibilities for future studies to determine whether the differences are real or result from differing methodologies.

GENERAL ASPECTS OF COASTAL PLAIN STRATIGRAPHY

The limitations of conventions applied to this project and variable knowledge and styles do not prevent the general aspects of Atlantic Coastal Plain stratigraphy from being identifiable on the chart and, in fact, the regional portrayal enhances ability to detect certain themes. Bearing in mind that the COSUNA Project involves correlation charts, not cross sections, the magnitude of the Province, lithologic trends, and continuity of deposition may be examined.

The emergent portion of the Atlantic Coastal Plain from New Jersey to South Carolina covered by the correlation chart is about 700 miles northeast-southwest and averages roughly 100 miles from the Fall Line to the coast, an area of approximately 70,000 square miles. The emergent Coastal Plain extends to the east as the continental shelf and together these areas have a rather remarkably uniform width of about 175 miles.

Although the chart emphasizes the stratigraphy of the emerged Coastal Plain, sediments of the Atlantic margin are continuous to the east beneath the shelf, slope, and rise and should also be considered. Published estimates of the volumes of rock do not coincide with the area covered by the chart, but maximum thicknesses may reach 15 kilometers (Schlee, 1981) and the volume of rock involved is very great (for example, Gilluly, 1964). The region is one of the great sedimentary basins of the world. Although often portrayed as a simple homocline (for example, Anderson, 1951; Heezen and others, 1959), significant structure is present as noted, for example, by Murray (1961), Brown and others (1972), and Brown and others (1977). A continental margin of this magnitude with its subordinate system of basins and arches is dynamic although in current tectonic terminology, it is considered "passive."

Thirty-five of the chart's columns deal with the Coastal Plain and only three with its offshore extension as the continental shelf. Two of the offshore columns represent the section penetrated by COST wells on Georges Banks. The offshore Mid-Atlantic column incorporates data derived from five wells and interpretations based on seismic-reflection profiles. The slope and rise are not represented. This speaks to the limited availability of stratigraphic data from the major mass of rock in the basin to which the Coastal Plain belongs.

Lithologies are indicated in general terms by the limited colors allowed on the chart. Only the dominant lithology of each unit could be portrayed. The dominance of clastic rock is clear, divided about equally between sandstones and grouped shale, siltstone, and mudstone. Dominantly gravelly material appears in the Miocene-Pliocene of Virginia and in the Pliocene and Pleistocene of New Jersey. Predominantly carbonate rock is confined to the Carolinas (mainly Eocene and Oligocene) and is postulated to occur as a reef or bank deposit in the deep offshore (Jurassic and Lower Cretaceous). Aside from the basement complex, intrusive rocks are known only from the Triassic and Lower Cretaceous offshore. Although thin bentonites have been reported from the Coastal Plain in the Upper Cretaceous (Stevenson, 1936) and lowermost Tertiary (Jordan and Adams, 1962), the Province is remarkably free of volcanics.

The oldest rocks reported, aside from "basement," which is commonly difficult to interpret, are those of the Lower Triassic from South Carolina and from offshore. Nearly all columns include rocks of Holocene age. Considering the Province as a whole, rocks of all ages in between are shown to be present. Major gaps do, however, exist as shown by the fact that blank areas predominate over occupied spaces in the rock versus time plot of the correlation chart. Because of space limitations, the columns of the chart are arranged in two tiers. Workers wishing to check lateral continuity of units or gaps may wish to cut the chart between the tiers and arrange all the columns side by side.

The base of the Coastal Plain sedimentary section lies at a major nonconformity with Paleozoic and Precambrian crystalline rocks. The ages of the crystallines are poorly known and they are unnamed except in parts of Virginia and Maryland. Basement rocks are generally metamorphic, but more igneous material is present in Maryland, Virginia, and North Carolina than elsewhere.

Insofar as is presently known, sedimentary rocks of the Province were first deposited in a series of elongate, en echelon basins that began forming during the Triassic in response to regional crustal thinning, thermal expansion, and uplift (Falvey, 1974; Manspeizer, 1981). Sedimentation occurred in nonmarine to restricted marine environments and may range into the Early Jurassic (Gohn and others, 1978; Schlee, 1981). Certain wells of the emerged Coastal Plain and the Georges Banks COST wells have encountered rocks associated with initial deposition and a similar sequence, termed "prerift" or "synrift" sediments by Grow (1981), has been mapped on the basis of seismic reflection character in the submerged portion of the Province. The nonconformity separating basement rocks from the rift sequence encompasses the transition from Appalachian mountain building to the initial phase of Atlantic margin development.

The most continuous unconformity within the chart occurs during the Middle to Late Jurassic. Falvey (1974) termed this interruption in deposition the "breakup unconformity" and attributed it to a final pulse of regional uplift and erosion. The ensuing development of the Mesozoic and Cenozoic Atlantic margin is thought to be one of subsidence due to a combination of sediment loading and cooling lithosphere (Steckler and Watts, 1978). The sedimentary rock sequence deposited during this phase of overall margin subsidence has been termed "postrift sediments" by Grow (1981).

An extensive unconformity is centered about the Coniacian from New Jersey through Virginia with, apparently, the magnitude of the hiatus increasing from north to south. In contrast, this section is rather complete in North and South Carolina on both sides of the Cape Fear Arch. The units above are transgressive and may bear some angular relationship to those below. Rocks of Coniacian age are present downdip (Cape May, New Jersey, and Eastern Shore, Virginia) and offshore the mid-Atlantic. The unconformity represents the transition from an aggrading coastal plain (Jordan, 1983) in the northern Coastal Plain (Potomac Group) to the major transgression represented by the Magothy Formation.

Once established, marine sedimentation continued with little interruption from about the Campanian well into the Tertiary except in the Virginia portion of the Coastal Plain. Authors have debated the existence of an unconformity at the Cretaceous-Tertiary boundary (Olsson, 1960; Jordan, 1963; Minard and others, 1969). According to those preparing the chart, no unconformity is present in New Jersey and Delaware, but a small break exists in coastal Maryland and North and South Carolina and a larger gap elsewhere, from the Cenomanian to the Thanatian in parts of Maryland and Virginia.

Another major unconformity is shown in the Carolinas from about Bartonian (North Carolina) or upper Priabonian (South Carolina) to the Chattian or Burdigalian within largely carbonate rocks. To the north clastic deposition continued longer, but was interrupted during at least portions of the Oligocene. Given the uncertainties of dating, one extensive unconformity is probably present in mid-Tertiary.

Workers have found difficulty in the assignment of Pliocene or Pleistocene ages to the largely nonmarine units near the tops of the Coastal Plain columns. This applies even to the abundantly fossiliferous Yorktown Formation of the central Coastal Plain. Gaps in the record here are influenced by the vagaries of clastic deposition caused by climate and sea level changes as well as by problems of correlation. In aggregate the record may be more or less continuous than shown in the chart.

It may be noted that Jurassic, Paleocene, and Oligocene rocks have been "discovered" in the Atlantic Coastal Plain since publication of the last regional correlation charts by GSA. It seems likely that the major unconformities in the Coastal Plain section will be more precisely defined, and probably narrowed, as dating techniques progress and the deeper subsurface is further explored.

In highly generalized terms the Coastal Plain may be broken down into a few packages of sediment separated by regional unconformities. The prerift and synrift sequence of Triassic-Jurassic age is bounded by the Fall Zone unconformity below (Johnson, 1931) and the "breakup" unconformity above (Falvey, 1974). The postrift package contains largely nonmarine or marginal marine sediments up to a mid-Late Cretaceous unconformity. Major transgression initiated deposition of primarily marine units continuing into the mid-Tertiary. This package has a great time span and its faunal and outcrop characteristics have allowed detailed study, but it is relatively small in volume. Sporadic continental and marginal marine deposition continued thereafter in the late Tertiary and Quaternary.

Deposition along the Atlantic margin was necessarily controlled by tectonics and sea level. The relationships shown on the chart could, perhaps, be related to the epeirogenic history of the Appalachian source area (Johnson, 1931; Thompson, 1939), stages of overall Atlantic margin subsidence (Steckler and Watts, 1978), intramarginal tectonics (Brown and others, 1972), and fluctuations of sea level (Vail and others, 1977). These studies are beyond the scope of the present paper, but may be considered potentially productive areas of investigation by others in the future.

INFORMATION FROM OFFSHORE

If the stratigraphic record of the Coastal Plain is incompletely understood, the principal cause may be lack of information from more deeply subsided portions of the margin. The Coastal Plain is only the presently emergent portion of a volumetrically larger mass underlying the shelf, slope, and rise. Deep wells along the Atlantic margin are numbered in tens in contrast to the hundreds of thousands in and around the Gulf of Mexico. The motivation for deep drilling and accompanying geophysical studies is, of course, petroleum exploration. Interest in the thinner, onshore part of the margin has been modest, resulting in a few wells drilled in North Carolina, Virginia, Maryland, and New Jersey. Since Outer Continental Shelf Oil and Gas Sale No. 40 (1976) first opened the "frontier" areas offshore to exploration, thirty exploratory holes have been drilled. At the time of preparation of the Atlantic Coastal Plain Correlation Chart, data from only five of these wells were publicly available. Exploration has centered on bull's-eye prospects in the Baltimore Canyon trough. Correlation of information from these wells requires a jump of almost 100 miles to the nearest onshore control. Seismic profiling helps to transcend this gap, but the seismic lines also generally end tens of miles from the few deep onshore wells.

As data from offshore become available and as additional information is generated, much will be learned about the stratigraphy of the Atlantic margin. For example, the profound facies changes that might have been expected between the shore and the shelf edge are, in fact, only moderate and the downdip rocks should be readily related to those of similar ages under the Coastal Plain. Of course, new units have and will be described, especially in the buried rift basins and the deepest parts of the drift sequence. Some will lie buried beyond the reach of the drill. Correlation will take on new and exciting aspects as the offshore is joined to the emerged Coastal Plain. In part, at least, the information will be from new sources and in new forms: from the petroleum industry and with increased emphasis on seismic stratigraphy. Progress will depend largely on the ability of the traditional Coastal Plain stratigraphers to accommodate such new data and whether the petroleum industry will require and respect the work and workers preceding its arrival.

FUTURE STUDIES

A regional correlation chart might well be expected to raise many questions about the stratigraphy of and stratigraphic practices in a province. In part these will be in the form of specific challenges to its contents by those wishing to correct real and perceived wrongs. We urge the aggrieved parties to improve on the chart, for by such means is progress achieved.

Over 650 question marks appear on the correlation chart, making the query its most commonly used symbol. These indicate uncertainties of varying degrees about the ages of the contacts of the rock units. Refinement of time correlation is obviously desirable. Correlations along both strike and dip can undoubtedly be improved. Nomenclatural rules and accepted principles of practice should be more rigorously enforced. Perhaps the new Code of Stratigraphic Nomenclature (NACSN, 1983) will be generally adopted by workers and organizations dealing with the Coastal Plain; if so, improved classification and communication could result.

Most sediment comes to rest at the margins of continents. The vast mass along the eastern margin of North America must record the post-Paleozoic history of the Appalachians and the Atlantic Ocean, not insignificant features of the planet. Yet the data base is thin and relatively few workers have been drawn to the challenges of such fertile subject areas. Studies of broad scope performed by investigators capable of synthesizing highly varied information should prove rewarding.

An impediment to future studies is the segregation of investigators and data into various classes. There are litho-, bio-, chrono-, magneto-, seismic, and other stratigraphers affiliated with industry, governments, and academia, each tending to create valuable, but specialized, information not always transmitted to or understood by other practitioners. One of the pleasures of the COSUNA project has been to bring at least some of these elements together.

It is suggested that regional studies be continued. A unique model exists in the form of the work of the international committees that prepared "A Proposed Standard Lithostratigraphic Nomenclature for the Central and Northern North Sea" (Deegan and Scull, 1977). The objective of that work was "...to compile...a practical framework for the lithostratigraphic nomenclature of the central and northern North Sea. These areas are immature with respect to subsurface control from wells and seismic data, which tend to be unevenly distributed" (page 1). It is not known whether the colleagues who have contributed so generously and graciously to the present study would tolerate additional demands on their careers or whether others will be attracted to or flee from such ventures after examining the product, but we hope to have provoked consideration of the possibilities.

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SIGNIFICANCE OF TOURMALINE COMPOSITIONS

FROM THE INNER PIEDMONT GEOLOGIC BELT OF SOUTH CAROLINA

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ABSTRACT

Seven black tourmaline samples were collected from the Inner Piedmont geologic belt. Compositions were obtained through inductively coupled argon plasma (ICAP) spectrometry and ARL-SEMQ microprobe analysis. Three of the samples analyzed as dravite (Na>Ca, Mg>Fe), two as schorl (Na >Ca, Fe>Mg), one as a uvite (Ca>Na, Mg>Fe) and one as a calcian schorl (Ca>Na, Fe>Mg). Six of the seven samples are from a restricted geographic area in northwestern Cherokee County, South Carolina and represent a boron anomaly, marked by an extra ordinary concentration of magnesian tourmaline. This boron anomaly should be considered a valuable exploration guide for base and precious metals.

INTRODUCTION

The composition of tourmaline has recently received much attention in base- and precious-metal exploration. Magnesium tourmalines (dravites) are found in anomalous concentrations at the Sullivan mine (lead-zinc) in British Columbia, Canada (Ethier and Campbell, 1977), at the Passagem de Mariana gold deposit in Brazil (Fleischer and Routhier, 1973) and in association with copper mineralization in the northern Appalachians, USA (Slack, 1980, 1982). Slack states that the dravitic tourmalines of these classic mining localities "are unrelated to the iron-rich schorls typical of most felsic intrusive rocks." The boron anomaly then, marked by anomalous concentrations of dravitic tourmaline, can be a valuable indicator of metallic mineralization. Tourmalinites (massive, foliated quartz-tourmaline rocks) and other tourmaline-rich lithologies are common in these classic mining districts, but more significantly, are present in the Inner Piedmont geologic belt of South Carolina.

The Inner Piedmont belt consists of high-grade metamorphic rocks, interpreted as metasediments and metavolcanics (Overstreet and Bell, 1965). The Inner Piedmont core, the central zone as defined and delineated by Griffin (1971, 1977), represents a migmatitic assemblage of sillimanite-grade rocks. All of the tourmaline samples were collected from this core zone.

The tourmaline sampling sites were chosen on the basis of either an unusual tourmaline-bearing mineral assemblage or an anomalous concentration of tourmaline in the lithologies of an area. Four of the samples were analyzed by Technical Service Laboratories, Mississauga, Ontario, using inductively coupled argon plasma (ICAP) spectrometry. The ICAP method has a wide dynamic range, few matrix or inter-element effects and minimal line interferences. The resulting major-oxide analyses are considered extremely reliable. The other four sample analyses were provided by the U. S. Geological Survey and were performed by Paul Atelsek on the ARL-SEMQ at Reston, Virginia on April 11, 1983.

Herein, I provide these major-oxide analyses (Table 1), a short description of each sample/sampling site, and explain the significance of these tourmaline compositions as they define a boron anomaly.

TOURMALINE OCCURRENCES

SAMPLE 1 - A euhedral black tourmaline crystal was collected from the Boling mica prospect (Teague, 1949) near Paris Mountain State Park. This mica-bearing granitic pegmatite intrudes sillimanite-mica schist and sillimanite and biotite gneisses of the Inner Piedmont core as delineated by Griffin (1971, 1977). Tourmaline is a common constituent of the regionally metamorphosed lithologies of the area and so is

Table 1: Tourmaline compositions (Major-oxide analyses in weight percent) and tourmaline sample localities.

	1	2	3	4	5	6	7a &	7b
	schorl	dravite	uvite	schorl	dravite	dravite	calcian	schorl
SiO_2	36.73	36.75	34.23	34.94	36.59	35.93	35.63	34.76
Al_2O_3	40.09	40.21	37.28	35.33	34.61	35.87	29.08	29.77
* Fe_2O_3	9.98	4.93	6.24	7.55	4.73	5.43	12.61	11.11
CaO	.07	1.10	1.56	0.95	0.80	0.77	3.07	2.43
MgO	3.69	7.38	7.47	5.56	8.07	6.92	7.59	7.31
Na_2O	2.09	1.95	1.16	1.74	1.87	1.66	1.29	1.38
K_2O	.01	.04	.01	**	**	**	.25	**
TiO_2	.68	1.28	3.25	1.09	0.59	0.52	.86	0.88
MnO	.10	.02	.03	0.05	0.03	0.04	.08	0.12
P_2O_5	.07	.07	.05	**	**	**	.01	**
BaO	.02	.02	.01	**	**	**	.00	**
Cr_2O_3	.01	.00	.00	0.17	0.09	0.07	**	0.06
LOI	.66	1.56	3.93	**	**	**	.19	**
Total	94.20	95.31	95.22	87.38	87.38	87.21	90.66	87.82
Boron (B) %	5.45	3.54	3.53	**	**	**	4.60	**

* Total iron as Fe_2O_3

** Not reported

Samples 1, 2, 3 and 7a analyzed by Technical Services Laboratories, Mississauga, Ontario.

Samples 4, 5, 6 and 7b analyzed by the U.S. Geological Survey, Reston, Virginia.

Sample 1 - 1.2 miles N 6° E of the intersection of S.C. Highway 253 and County Road 344 (S-23-344) near Paris Mountain (Greenville County), from vacant lot on the east side of County Road 344.

Sample 2 - 2.95 miles N 9° W of the intersection of Interstate 85 and County Road 39 (S-11-39) in Macedonia (Cherokee County), on dirt road leading up to Thicketty Mountain.

Sample 3 - 3.55 miles N 1° W of the intersection of Interstate 85 and County Road 39 (S-11-39) in Macedonia (Cherokee County), in field north of S.C. Highway 11.

Sample 4 - 2.8 miles N 42° E of the junction of S.C. Highway 110 and S.C. Highway 11 (Cherokee County), on hillside south of County Road 60 (S-11-60).

Sample 5 - 3.2 miles due north of the intersection of Interstate 85 and County Road 39 (S-11-39) in Macedonia (Cherokee County), as float on road.

Sample 6 - Same location as Sample 5, but in power line cut.

Sample 7 - 2.9 miles N 76° E of the intersection of S.C. Highway 110 and U.S. Alternate 29 in Cowpens, on the south side of the unpaved portion of County Road 131 (S-11-131) in gully (Cherokee County).

not found only in the pegmatitic association. The anomalous occurrence of tourmaline in the rocks of the Paris Mountain area may constitute a boron anomaly. Analyses showed this sample to be schorl with Fe_2O_3/Fe_2O_3 + MgO = .73. This result was not unexpected considering the typical felsic intrusive association.

SAMPLE 2 - A thin layer (2-3 cm) of pure black tourmaline schist of limited extent is exposed on the northern slope of Thicketty Mountain in northwestern Cherokee County. The tourmaline occurs as small subhedral crystals in a thin, felted sheet within sillimanite-mica schists. When examined individually under the binocular microscope, the crystals are found to be amber to honey brown in color rather than opaque and black. This tourmaline is dravite with Fe_2O_3/Fe_2O_3 + MgO = .40.

SAMPLE 3 - A strongly foliated tourmalinite with alternating bands of black tourmaline and quartz with acicular sillimanite needles was found as float in a field north of Thicketty Mountain. A mineral separate from one of the tourmaline-rich bands was analyzed and showed this sample to be uvite with Fe_2O_3/Fe_2O_3 + MgO = .46.

SAMPLE 4 - A tourmalinite composed of broad bands (1-2 cm) of quartz and black tourmaline was found as float on a hillside near the North Carolina state line. Zoned tourmaline grains from this sample give an average composition of schorl with Fe_2O_3/Fe_2O_3 + MgO = .58.

SAMPLE 5 - Blades of black tourmaline occur in massive white mica. The sample was found as float on an unpaved county road. The analyses provided are the averages of the rims and cores of several grains. The tourmaline from this sample is dravite with Fe_2O_3/Fe_2O_3 + MgO = .37.

SAMPLE 6 - Sprays of black tourmaline are found in a coarse quartz-kyanite rock. Three-point averages of the rims, centers and cores of these zoned tourmaline crystals give a dravite composition with Fe_2O_3/Fe_2O_3 + MgO = .44.

SAMPLE 7 - A tourmaline-rich granitic pegmatite dike intrudes a biotite-quartz augen gneiss. The pegmatite dike is tabular and is exposed in a drainage gully. Euhedral black tourmaline crystals compose 9-10 percent of the rock. The dike mineralogy includes quartz, microcline and calcic plagioclase. Although this sample is calcian schorl, with Fe_2O_3/Fe_2O_3 + MgO = .60 - .62, it has a surprisingly large dravite component, particularly for a felsic intrusive rock. (Note: Samples 2 through 7 were collected in a restricted geographic area where the author has recognized a boron anomaly (Mittwede, 1983). Detailed geologic mapping is in progress in this area).

SIGNIFICANCE OF TOURMALINE ANALYSES

Of the seven black tourmalines analyzed, only two (Samples 1 and 7) are related to felsic intrusive rocks. Both of these samples are schorl. The five remaining samples (Samples 2-6) are from an assemblage of aluminous schists, massive sillimanite and kyanite, and garnet quartzite. This assemblage, found in the Thicketty Mountain area of northwestern Cherokee County, South Carolina, is interpreted as having undergone hydrothermal alteration (Mittwede, 1983). Magmatic and residual fluids, percolating through the sedimentary-volcanic pile in the paleoenvironment, caused base-leaching and thereby enhanced already aluminous sediments to form the aluminosilicate, tourmaline-bearing assemblage.

All of the tourmalines from the Thicketty Mountain area are magnesium-rich, with approximately 5.5 to 8 percent MgO. It is clear that the concentration of dravite and uvitic tourmaline in the rocks of this area is anomalous. This boron anomaly should be considered a valuable exploration guide for base and precious metals.

ACKNOWLEDGEMENTS

This paper is part of a South Carolina Geological Survey mineral resources investigation. Thanks to A. H. Maybin, III and Norman K. Olson for their discussion and encouragement. Special thanks to John Slack and Paul Atelsek of the U.S. Geological Survey for the microprobe data included in this report. Thanks also to Agnes Streeter for typing the manuscript.

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