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**SUPPLEMENTAL FIELD AND LITERATURE INVESTIGATION
OF THE UPPER CRETACEOUS AUSTIN GROUP (CHALK) OF TEXAS
WITH REGARD TO ITS POTENTIAL FOR RADIOACTIVE-WASTE ISOLATION**

**Dr. Serge Gonzales
Earth Resource Associates, Inc.
Athens, Georgia 30605**

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**Final Report
Submitted To**

**Office of Waste Isolation
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**By
Dr. Serge Gonzales
Earth Resource Associates, Inc.
Athens, Georgia 30605**

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INTRODUCTION

This report provides regional information about the stratigraphic and lithologic character of the Upper Cretaceous Austin Group (Chalk) as found in southeast, east-central and northeast Texas. As such, the commentary presented here supplements an earlier report by Gonzales (1975). Although the field data discussed here were obtained during the final week of 1975, completion of this study has been delayed due to the author's continued involvement in several other projects for the Office of Waste Isolation.

Information contained in this report was secured from the following sources: (1) study of numerous exposures of the Austin Group (Chalk), and adjoining strata, along a northeast-trending outcrop belt from San Antonio to Dallas, Texas; (2) visits to several cement and crushed-stone quarries developed within this carbonate sequence, and contacts with personnel at these facilities; (3) discussions with geologists at Baylor University in Waco, Texas; (4) meeting with Mr. Ed Garner of the Texas Bureau of Economic Geology in Austin, Texas; and, (5) additional literature secured from these sources in Texas. Also discussed here is the recent emergence of the Austin Group (Chalk) as a revitalized producer of crude oil in southeast Texas.

Concluding this report is an evaluation of the regional potential of the Austin Group (Chalk) as a possible carbonate host rock for radioactive-waste storage. Although this assessment tends to be negative, and leads to the recommendation that additional studies of this stratigraphic interval are not

critical at this time, this analysis should not be construed to negate other chalk sequences, especially the Selma Group, from further consideration and study.

An inventory of the sites where the Austin Group (Chalk) was observed and studied is listed below, beginning with the southwestern extent of the outcrop belt:

1. San Antonio Portland Cement Company quarry, Cementville, Bexar County
2. Capitol Aggregates, Inc., Capitol Cement Division quarry, near Wetmore, Bexar County
3. Kaiser Cement and Gypsum Corporation, Longhorn Cement Division quarry, northeast of San Antonio, Bexar County
4. Robert A. Welch Hall excavation, University of Texas, Austin, Travis County
5. Walnut Creek (several outcrops), north of Austin, Travis County
6. Blunn Creek (several outcrops), south of Colorado River, Austin, Travis County
7. Rinard Creek at Turnersville Road, south of Austin, Travis County
8. Onion Creek near the Williamson Creek Sewage Plant, south of Austin, Travis County
9. J. K. Ross quarry near Pilot Knob, south of Austin, Travis County
10. United States Steel Corporation, Universal Atlas Cement Division quarry, southwest of Waco, McLennan County
11. Route 6 Highway outcrop, near Bagby Avenue, south Waco, McLennan County
12. Lakeshore Drive (several outcrops), Waco, McLennan County
13. Cameron Park, north Waco, McLennan County
14. Gifford-Hill and Company, Inc., Gifford Hill Portland Cement Company quarry, Midlothian, Ellis County
15. Lake Waxahachie spillway, near Waxahachie, Ellis County

Although the Austin Group (Chalk) is exposed further to the northeast of Dallas, and is brought to the surface by several salt domes within the East Texas Basin, duration of available field time did not permit visits to these

widely separated areas. Inasmuch as 300 miles of the outcrop belt were reviewed and the portion studied included the type sections of all the stratigraphic divisions, those sites actually visited provided an adequate understanding of the Austin Group (Chalk).

REGIONAL STRATIGRAPHY

The following generalized comments about the regional stratigraphy and related lithologies of the Austin Group (Chalk) seem appropriate to set the tone for subsequent discussion of specific areas or sites:

1. Stratigraphic divisions and lithologies recognized in the type area near Austin, Texas can only be traced to either the southwest or northeast by means of a significant reliance on faunal evidence. Thus, the "formations" of Durham (1957) are more biostratigraphic than lithostratigraphic. Furthermore, the Austin Group (Chalk) within the subsurface cannot be divided into the units recognized at the surface from the type area (Garner, 1975, personal communication).
2. The Austin Group (Chalk) contains a sizeable number of lithologies which are not true chalks (micritic, coccolith-rich) or chalky limestones; in some areas, the limestones and marls appear as normal bedded carbonates atypical of other massive chalk sequences. Chalk as a chemical phase (calcilutite) is nevertheless abundant in most stratigraphic sections.
3. Present too are intervals characterized by apparent solution porosity, while some subsurface sections contain open-fracture systems. Both features are fairly uncommon for typically fine-grained chalk sequences.
4. Throughout its outcrop belt, the Austin Group (Chalk) disconformably overlies the Eagle Ford Group or its equivalents; in most outcrops, the underlying lithology present is a dark shale-mudstone.
5. Although the literature cites the stratigraphic term "Lower Taylor Marl" as succeeding the Austin Group (Chalk), several different, local stratigraphic names have been applied to the marly-chalky-clayey units which overlie the Austin Group (Chalk). There has furthermore been considerable controversy about the position of the Austin-Taylor boundary and the possibility that some Tayloran strata may in part be Austin in age (Durham, 1957). There is also argument about the extent of the disconformity represented by this contact in certain areas.

Stratigraphic investigations of the Austin Group (Chalk) can be traced back to Roemer (1852), who identified outcrops from this interval in Comal County as Upper Cretaceous in age. Shumard (1860) enlarged the geographic range of the unit to McLennan and Grayson Counties and called it the Austin Limestone. Proper

placement of this Cretaceous sequence above the Eagle Ford Group and below Tayloran-age strata is attributable to Hill (1887); at that time, however, each of the adjacent units carried stratigraphic names different from those in current use, and Hill referred to the chalk-bearing sequence in question as the Dallas Limestone.

Other workers, namely Taff (1893) and Adkins (1933), subdivided the Austin interval into upper and lower, and upper, middle and lower, sequences respectively. The latter investigator was also responsible for the formal naming of the Burditt chalk marl, although he assigned it as the upper division of the Austin Chalk. To the north in Dallas County, Shuler (1918) recognized three units, to which a thin basal unit was later added by the Dallas Petroleum Geologists (1941).

Over the years, there has developed some confusion regarding the term Austin in that it has held both rock-stratigraphic and time-stratigraphic status. In terms of the former, the Austin Chalk in its type area near Austin has essentially been considered a group, divisible into upper and lower sequences, and in turn into several formations (Durham, 1957; Murray, 1961). As originally proposed by Durham (1957), the formations from oldest to youngest are the: Atco Chalk; Vinson Chalk (this unit changes laterally into a marly facies, named the Bruceville marl); Jonah Limestone (to the north, this unit is represented by a facies called the Hutchins Chalk, which due to erosional truncation near Waco, was previously not extended further to the south); Dessau Chalk; Burditt Chalk Marl; and, Big House Chalk. Of these, only the terms Dessau (Durham, 1955) and Burditt (Adkins, 1933) can be considered acceptable stratigraphic terms; the others are technically invalid due to the informal manner in which they were presented in the literature. In essence, the Atco-Jonah interval of Durham is equitable to the lower Austin Chalk of the older literature, while the Dessau-Big House interval, which disconformably overlies the Jonah, is equivalent to the upper Austin Chalk of earlier

workers, although there is some disagreement in regard to which specific units of previous investigators should be included there. In terms of equivalence with the tri-part division by Shuler (1918), and the Dallas Petroleum Geologists (1941) for exposures in the general Dallas region, the lower chalk equals the Atco Formation, the middle chalk marl is represented by the Bruceville-Vinson interval and the upper chalk is equated to the Hutchins Chalk (in turn equivalent to the Jonah Formation north of the type area).

More recent work in the Austin, Texas type area by Young and others (1975) and Garner and Young (1976) has established the following in regard to the Austin Group (Chalk): (1) consideration of the sequence as a group; (2) retention as formational names of certain previously named subdivisions, namely the terms Atco, Vinson and Jonah; (3) use also as formations of the valid terms Dessau and Burditt, although the latter is more restricted than in previous usage; (4) establishment of the Pflugerville Formation as the youngest unit within the Austin Group; (5) identification of a beach-rock facies, called the McKown Formation, in the immediate vicinity of Pilot Knob, southeast of Austin (this unit is locally equivalent to the Burditt and Pflugerville Formations); and, (6) designation locally of the overlying Tayloran-age clays and marls as the Sprinkle Formation. The term, Big House Chalk of Durham, has been discarded.

If Durham (1957) is correct in his interpretation about the regional stratigraphy of the Austin Group (Chalk), then his Dessau-Big House interval (equal to the Dessau, Burditt, Pflugerville and McKown Formations as now recognized in the type area) is actually equivalent to various clays and marls exposed north of Waco and referred to by previous workers as Lower Taylor. These Tayloran, possible Austinian equivalents, overlie the eroded Hutchins Chalk in the general Dallas region.

As observed by both Durham (1955, 1957) and Young and others (1975), correlation of the various type-area stratigraphic units is possible through the use of closely spaced, measured sections and a few distinctive lithologies, but in large measure certain index fossils and faunal zones are necessary to establish accurate correlative relationships. To this end, various indicator fossils include several ammonites, oysters, and to a lesser degree, certain terebratulid brachiopods. No attempt has been made in this report to discuss the paleontologic data. Reliance on faunal evidence, however, casts serious doubt that the formations of the Austin Group (Chalk) are truly valid mappable units which can be correlated regionally based solely upon their lithologic expressions. In other words, the divisions of the Austin Group as now recognized throughout the type area of Travis and Williamson Counties are to a large degree biostratigraphic.

LOCAL STRATIGRAPHY

Although the Austin Group (Chalk) extends southwest and west of San Antonio into Uvalde County and hence to the Rio Grande Valley southeast of Del Rio, Texas, this investigation began in the general Bexar County area near San Antonio. Throughout Bexar, and Comal and Hays, Counties to the northeast, the Austin Group (Chalk) and other Cretaceous-age units are severely affected in surface exposure by faulting known as the Balcones Fault Zone. Adding to the situation is that one such faulted unit is the Pecan Gap Chalk, which in northeast Texas lies above the Austin Group (Chalk), but is mapped together with the Austin Group (Chalk) toward adjacent Medina County to the southwest because stratigraphic separation is not possible (Texas Bureau of Economic Geology, 1974b). Above the Pecan Gap, where it is identifiable, and the Austin-Pecan Gap interval where the chalk units are combined, is the Anacacho Limestone. The latter generally appears as an argillaceous limestone with interbeds of marl and clay, and its more characteristic alternation of bedding allows some distinction from the poorly bedded Austin Group (Chalk).

At the San Antonio Portland Cement Company quarry, the Austin Group (Chalk) appears brecciated, solutioned, recrystallized and rubbly (Fig. 1); the absence of bedding appears due to these factors and not to a massive expression which characterizes typical chalk lithologies (Gonzales, 1975). Represented here is most likely the Dessau Formation although that designation is not definite. According to personnel of the cement firm, to the west of the point shown in the figure is an up-to-the southeast fault which has brought the Austin Group (Chalk)

Figure 1. Austin Group (Chalk) exposed in the quarry of the San Antonio Portland Cement Company at Cementville, Texas. The sequence here is largely unbedded, solutioned-recrystallized and brecciated due to local faulting. Scale: Post in lower left is 4 inches square.

into contact with the Anacacho Limestone, which is also rubbly, and less well bedded than normal. The geologic map for this area (Texas Bureau of Economic Geology, 1974b), however, shows the unit in fault contact with the Austin Group (Chalk) to be the Pecan Gap Chalk. Although neither unit here resembles chalk per se, the bedded nature of the other unit suggests that the Anacacho Limestone may be the preferred designation.

Due to its fractured, brecciated and porous nature, the Austin Group (Chalk) at this location does not exhibit the characteristics of typical chalks. Based on the recent upsurge of exploratory drilling for crude-oil prospects in the Austin interval downdip from Bexar County, Scott (1977) has also questioned whether the term chalk is correctly applicable. In the subsurface, the Austin Group (Chalk) is characterized as a dense, hard, micritic limestone lacking the typical pelagic, foraminiferal-coccolithic composition of other chalks. Fracture porosity is also a key to exploration success (Long, 1976); open fractures at depth are also uncommon in fine-grained chalks.

Between the San Antonio-Bexar County and Austin-Travis County areas, the San Marcos Arch has produced a pronounced thinning in the Austin Group (Chalk). For example, the oldest unit, or Atco Formation, has been estimated to be nearly 400 feet thick near Del Rio, but is only 40 feet near San Marcos in Hays County (Durham, 1957). To the north of the Arch, this unit thickens to nearly 100 feet near Austin and then to 240 feet in the general Waco region. The Jonah Formation is totally absent over the Arch; this fact may reflect both erosion and truncation through non-deposition. Northward from the north flank of the Arch, the Dessau Formation likewise expands from less than 15 feet of development to nearly 75 feet in Travis County.

Within the general Austin area of Travis County, the Austin Group (Chalk)

more closely resembles a true chalk sequence. Much of the city of Austin is developed upon this stratigraphic unit even though currently inactive faults of the Balcones fault zone have produced a number of vertical offsets (Garner and Young, 1976). The University of Texas campus is also largely constructed upon the Austin Group (Chalk) which here consists of chalks, soft chalky limestones and minor marly interbeds (Fig. 2) which typify the Dessau Formation. Massive, poorly stratified chalk units can also be found in the Pflugerville Formation (Fig. 3), which is the uppermost, locally persistent division. Adjacent to and southeast of the outcrop shown in Figure 3 occur remnants of altered volcanic tuff from nearby Cretaceous-age vulcanism, as well as several fault slices which place Taylor-age shales into contact with this upper unit. The Pflugerville Formation is also exposed to the north and northeast of Austin where it attains a thickness of approximately 40 feet.

The Burditt Formation lies stratigraphically between the Dessau and Pflugerville Formations and consists of up to 15 feet of chalky marls and clays which tend to be more gray in color and richer in their content of clay than the chalk lithotypes within the adjacent units (Fig. 4). Durham (1955) has contended that the Burditt Formation lies disconformably upon the Dessau Formation, although he ascribed much more significance to the erosional break at the base of the Dessau.

Within the general region to the south and southeast of Austin, a number of intrusive plugs and explosive craters, which represent the northern extent of a series of Upper Cretaceous volcanic events (Young and others, 1975), also occur. One such feature is Pilot Knob, exposed adjacent to Bergstrom Air Force Base, southeast of the city. Acting as a submarine volcanic island, Pilot Knob modified sedimentation within the Austin Group (Chalk) so that a porous, shell-fragment, beach-rock phase was locally deposited (Fig. 5). This reef-like limestone is

Figure 2. Well developed Austin Group (Chalk) with thin interbeds of marl as exposed in a new foundation excavation for Welch Hall, University of Texas campus, Austin, Texas. Unit represented is the Dessau Formation. Exposure is approximately 15 feet high.

Figure 3. Typical massive, non-bedded chalk showing characteristic spalled weathering surfaces. Iron staining from decomposed pyrite nodules. Exposure of Pflugerville Formation is located along Blunn Creek, near East Riverside Drive in Austin, Texas. Scale is given by geology hammer.

Figure 4. Rubbly, burrowed and iron-stained chalky limestone, chalk and marls of Dessau Formation (cream-colored units) overlain by grayer marls of Burditt Formation. Some marls of the Pflugerville Formation at top. View is upstream along Rinard Creek at Turnerville Road crossing, 4 miles from Creedmoor, Texas, southeast of Austin. Exposure is approximately 25 feet in thickness.

Figure 5. Panoramic view of the J. K. Ross limestone-aggregate quarry, by Burleson Road adjacent to State Route 183, southwest of Austin and near Pilot Knob. The Austin Group (Chalk) is represented here by the McKown Formation, which is a porous reef-like limestone adjacent to the Pilot Knob igneous intrusion. Downtown Austin is in the distance.

closely associated with pyroclastic debris, altered tuff (now largely nontronite) and volcanic-mudflow deposits. Several of these non-limestone units occur at the stratigraphic position of the Dessau Formation. This localized, porous limestone phase has been termed the McKown Formation, and is overlain by the Pflugerville Formation in some areas and by the Taylor-age Sprinkle Formation in others. The McKown Formation represents a facies of portions of both the Burditt and Pflugerville Formations.

Several other igneous structures, named Thrall, Elroy, Kimbro, Lytton Springs and Hilbig, are only known from subsurface data, but are surrounded by similar reefal beach rock and pyroclastics developed within the Austin interval. These localized features are of additional significance in that the associated zones of porous limestone and volcanic debris are productive petroleum reservoirs.

As now subdivided, the Austin Group (Chalk) attains a total thickness of approximately 420 feet. As previously noted, the Austin Group (Chalk) thins toward the San Marcos Arch so that the total thickness along the Travis-Hays County line is approximately 325 feet.

Northeastward from Austin, the Austin Group (Chalk) initially experiences thickening, and then due to erosional truncation in the lower units, thinning within the Waco-McLennan County area (Durham, 1957). According to the Baylor Geological Society (1972), the Austin Group (Chalk) varies in thickness uniformly across McLennan County from 195 feet in the south to 295 feet in the north. As shown in Figure 6, the lithologies, especially the chawks and chalky limestones, show a much more evenly bedded appearance. These units are interbedded with thin, more blue-colored marls and minor bentonite units. The percentage of marl appears to increase in an upward direction, although the bedding remains thick and regular. The outcrop shown in Figure 6 represents the thickest section of continuously

Figure 6. Distinctly and persistently bedded chalky limestones forming the high cliffs under Cameron Park, in north Waco, Texas. Exposure is slightly more than 100 feet in height. Bluffs to the right of this point show faulting from the Balcones Fault Zone.

exposed Austin Group (Chalk) in the Waco region (Baylor Geological Society, 1972); shown there are rock strata assigned to the Atco Formation and the Vinson-Bruceville Formation. Missing here due to truncation is the Hutchins Chalk (equivalent to the Jonah Formation to the south), although it is present to the north in southern Ellis County and northward into the Dallas region.

Well-bedded, laterally persistent chalks and chalky limestones characterize the Atco Formation throughout the Waco region. As described by Durham (1957), the type section (Fig. 7) occurs in the Universal Atlas Cement Company quarry at the old Atco Siding, 9 miles southwest of Waco. The more chalk-like lithologies, although lacking a typical massive, non-stratified appearance, are interbedded with thin layers of marl and clay. Throughout the Waco region, the Atco Formation attains a thickness of 240 feet; nearly 65 feet of this interval is exposed in the main cement-plant quarry at Atco. By the Dallas region, the unit has thickened to nearly 300 feet.

The Atco Formation rests disconformably upon the Eagle Ford Formation (here called the South Bosque Shale member), and the nature of the unconformable contact, characterized by small extensions of chalk down into the eroded and bored shale, is apparent in outcrop (Fig. 8). According to Durham (1957), the Atco Formation maintains its characteristic thick-bedded appearance throughout most of its extensive outcrop belt.

The Austin Group (Chalk) thickens toward Dallas and reaches a maximum thickness of 500 to 600 feet north of there in Collin and Grayson Counties. Throughout the immediate Dallas metropolitan area, the unit varies between 300+ and 500 feet in thickness. The "lower chalk" of the Dallas Petroleum Geologists (1941) consists primarily of thick bedded chalks and chalky limestones with thin interbeds of marl and clay, and equates to the Atco Formation of Durham (1957).

Figure 7. Thick, regularly bedded chalky limestones and thin marl interbeds of the Atco Formation at the latter's type section. Location is the Universal Atlas Cement Company quarry, adjacent to U. S. Route 87, 9 miles southwest of Waco, Texas. Scale: Large blocks in foreground are approximately 3 feet in average dimension.

Figure 8. Contact between the Austin Group (Chalk) and Eagle Ford Shale in the Universal Atlas Cement Company quarry southwest of Waco, Texas. Chalky limestones of the Atco Formation are both distinctly bedded and jointed. Exposure is approximately 35 feet in thickness.

The "middle chalk" is really expressed as thinly bedded marls with a few thick chalk beds, and is equivalent to the Bruceville Formation of Durham (1957). The more locally developed Hutchins Chalk, which was originally called the "upper chalk," carries a lithologic expression similar to the Atco Formation, although the bedding is not so consistently thick. These lower Austin units are disconformably overlain by Lower Taylor marls, which Durham (1957) has contended are facies of the upper Austin units recognized from the type area (Fig. 9).

To the north of the city of Dallas, the Austin Group has been divided into several other stratigraphic units (Texas Bureau of Economic Geology, 1967). By the latitude of the Grayson-Fannin County line and the cities of Sherman and Bonham, the Austin Group has developed a more argillaceous, and in some intervals an arenaceous, character. From oldest to youngest, the stratigraphic units as mapped by the Bureau and their approximate thicknesses are: Ector Chalk (35 feet); Bonham Marl (400 feet); Blossom Sand (20 feet); Brownstown Marl (80 feet); and, the Gober Chalk (400 feet). Locally to the east, the Gober Chalk in part grades laterally into a thin, dense limestone called the Roxton Limestone which contains abundant marine megafossils.

Although there are differences of opinion about the stratigraphic relations involved in this northeast Texas area, and no study has definitively resolved the situation, the following statements appear to hold:

1. The Ector Chalk is an eastward thinning tongue equivalent to part of the Atco Formation;
2. The Bonham Marl-Blossom Sand interval is stratigraphically equivalent to the Bruceville-Vinson and Hutchins Formations recognized to the south; this interval may also be equivalent to the lower portion of the Dessau Formation, and could conceivably be a partial facies of the Atco Formation;
3. The Brownstown Marl is a lateral equivalent of either the Burditt Formation, or portions of both the Dessau and Burditt Formations;

(after Murray, 1961)

4. The Gober Chalk represents the remainder of the type-section Austin Group, but may be in part equivalent to Taylor-age marls as identified near Dallas and to the south;
5. All workers recognize that the Pecan Gap Chalk here is stratigraphically younger than the Austin Group, but disagreement persists on the equivalency of the Anacacho Limestone, with which the Pecan Gap Chalk is mapped in some areas to the southwest as undifferentiable.

Several of these stratigraphic divisions of the Austin Group can be traced as far east as the Texas-Arkansas state line, or north and northwest of Texarkana, Texas (Texas Bureau of Economic Geology, 1966). Missing this far east, however, are the Ector Chalk and the Roxton Limestone member of the Gober Chalk.

In summary, the Austin Group (Chalk), although it can be mapped from Mexico northeastward to nearly Oklahoma, illustrates some significant stratigraphic variations due to differences in original sedimentation that produced lithologic changes as well as the effects of erosion-truncation and non-deposition. The stratigraphic divisions now delineated in the type area of Travis and Williamson Counties cannot be exclusively recognized far to the southwest or northeast. Reliance on paleontologic data to accomplish regional correlation lends credence to the view that the formations of the type area are really biostratigraphic units. An inability to recognize subdivisions within the Austin Group (Chalk) in the subsurface also suggests that lithologically variable formations cannot be utilized.

STRUCTURAL GEOLOGY

In outcrops from south of San Antonio in Bexar County to north of Waco in McLennan County and into Ellis County, the Austin Group (Chalk) is affected at the surface and in the shallow subsurface by faulting of the Balcones fault zone (Texas Bureau of Economic Geology, 1970, 1974a, 1974b, 1974c; Baylor Geological Society, 1972, 1975; Garner and Young, 1976). Movement involved in this regional structural feature is believed to have been concentrated in the mid-Tertiary (Oligocene-Miocene) according to Weeks (1945).

Most faults in the Balcones trend strike between $N40^{\circ}E$ and $N45^{\circ}E$ and are of the dip-slip, normal variety. Downtown blocks occur principally on the southeast. Individual displacements vary from 10 to several hundred feet, but the majority are less than 100 feet. According to Garner and Young (1976), the total displacement across the Balcones fault zone in the Austin, Texas area is 1200 feet. Sellards and others (1935) estimated the throw in Bexar County to be 1700 feet, although Weeks (1945) contended the amount was only 1200 feet.

Several areas, especially from Travis County northward to Ellis County, reveal fault slices that have placed Taylor-age marls into contact (Fig. 10) with chalky lithologies of the Austin Group (Chalk). Some faults, such as the Bullhide Creek Fault which is exposed north of Waco and has a displacement that ranges from 150 to 400 feet, extend for several tens of miles (Baylor Geological Society, 1975). Shuler (1918) was early to observe that several of these fault slices, especially ones in which overlying Taylor-age strata are involved,

Figure 10. Small normal fault (locally called the Bishop Fault) which has placed younger Taylor-age marls into contact with chalky lithologies of the Austin Group (Chalk). Outcrop is adjacent to State Route 6, near Bagby Road in south Waco. Small hill is approximately 15 feet high.

represent small grabens. These features appear more numerous in Ellis and Dallas counties.

Slickensides, drag along fault surfaces and associated joint sets are additional structural manifestations of the Balcones fault zone (Fig. 11). Other faults, such as the one well exposed along the spillway below Lake Waxahachie in southern Ellis County, do not parallel the prominent northeast trend of the Balcones zone, but appear complimentary to this regional fault system. Small faults, which may be extensions of the Balcones trend, have also been reported by Sellards and others (1935) as far north as Collin County.

The Austin Group (Chalk) is also affected in the subsurface by two other regional fault systems, known as the Luling and Mexia zones. Both lie downdip from the Upper Cretaceous outcrop belt and form arcuate zones of structural disturbance within the Gulf Coastal Plain. Faults of the Luling zone are primarily downthrown on the northwest side, and extend from Zavalla and Frio Counties southwest of San Antonio, through southeastern Bexar County, northward to Bastrop and Williamson Counties northeast of Austin. Characteristics of the Luling zone include (Weeks, 1945; Murray, 1961): (1) high-angle faults with average dips of 45° ; (2) individual fault displacements up to 500 feet; and, (3) total throw or displacement of 1500 to 2000 feet across the zone. Productive oil fields, such as Luling, Darst Creek and Lytton Springs, are related to this system, and hydrocarbon-entrapping closures (including rollover structures) have developed as a result of this faulting.

Further to the southeast is the Mexia fault zone, whose fault slices are typically grabens of varying width. Downthrown blocks occur along either southeast or northwest sides. This fault system exhibits two contrasting geographic patterns: (1) from Limestone County, which is due east of Waco, a narrow zone

Figure 11. Atco Formation of the Austin Group (Chalk) as exposed in Gifford-Hill Cement Company quarry, near Midlothian, south of Dallas. Along left side of photograph is a small, slickensided fault. Slickensides and joint surfaces are prominent at this location. Outcrop is 25 feet in height.

of faults extends northeastward to Hunt County, and then turns east to border the East Texas Embayment along this basin's northern margin; and, (2) southwest of Limestone County, the pattern of faulting extends far into south Texas (Karnes, Live Oak and Duval Counties), but does so in a series of en echelon offsets (Weeks, 1945). The Mexia fault zone thus exhibits an extent of nearly 500 miles. The tectonic map of the Gulf Coast region, however, designates several separate fault-system names to the southernmost extensions of the Mexia trend (American Association of Petroleum Geologists, 1972). Akin to the Luling system, several petroleum fields, such as Mexia, Powell, Talco and Pewitt Ranch, occur associated with faults of this structural trend.

Even though the Balcones, Luling and Mexia zones of faulting are all distinct structural features, Weeks (1945), using both field and subsurface data, has postulated that all are the same general age, or mid-Tertiary. Balcones faulting primarily influences the Austin Group (Chalk) at or near the surface; Luling and Mexia faults, although they are developed at the surface, cut the Austin Group (Chalk) in the subsurface.

Salt domes in the Northeast Texas Basin (East Texas Embayment) have also structurally influenced the Austin Group (Chalk). Geologic maps (Texas Bureau of Economic Geology, 1964; 1968) of the Tyler and Palestine areas show that blocks of this Cretaceous interval have been brought to the surface on both the Brooks and Palestine domes. Data summarized by Anderson and others (1973) show that salt diapirism at Keechi, Bethel, Mount Sylvan, Whitehouse, Bullard and Steen domes has either upwarped the Austin Group (Chalk) into an inclined flank position or brought the unit much closer to the surface. Netherland, Sewell and Associates (1976), in mapping the thickness and structural attitude of the Austin Group as part of a study about salt domes in the East Texas basin, demonstrated

similar relationships on these domes.

MINERAL RESOURCE DEVELOPMENT

As noted by Gonzales (1975), the Austin Group (Chalk) is utilized at several sites in Texas as a raw material in the manufacture of portland cement. At present, seven (7) plants, distributed within Bexar (3), McLennan (1), Ellis (2) and Dallas (1) counties, operate surface facilities where the chalks and chalky limestones of the Austin Group (Chalk) are quarried and converted to portland cement. At several sites, the underlying Eagle Ford shale is also mined to provide a source of clay-rich feedstock.

Central Frio County, which lies to the southwest of San Antonio, is the site of the 43-year-old Pearsall oil field. Within the past three years, extensions made to this field have precipitated an accelerated drilling and production stimulation-program from the Texas-Mexico border northeastward for 150 miles to Lee and Milam counties, northeast of Austin (Long, 1976a, 1976b). The prospective target for this new exploration play is the Austin Group (Chalk); drilling generally has ranged from 5000 to 7500 feet in depth.

Much of the prospective area coincides with where faults of the Mexia fault zone (and possibly the Luling in certain areas) have cut the Austin interval in the subsurface. Fracture zones within the Austin Group (Chalk) are extremely important in locating more productive reservoir zones, and Scott (1977) believes the presence of these open fractures is due to the same basin tectonics which gave rise to the Mexia fault zone.

Although the depths within this prospective trend are too great to consider

for a repository, the expanded significance of the Austin Group (Chalk) as an oil reservoir and the increased number of exploratory boreholes drilled into this unit are nevertheless important factors.

In the more updip portions of the Austin Group, several small oil fields, as noted in the previous section on local stratigraphy, are also to be found in the coarser-grained calcarenitic, reefal phases associated with buried volcanic centers. Most of these fields are near the general Austin area, and only sustain production typical of stripper wells.

Water obtained from the Austin Group (Chalk) throughout the general Austin area is largely limited to stock-watering and irrigation because it commonly contains enough oil and/or methane to render it otherwise unusable (Garner, personal communication, 1975). Significant amounts of hydrogen sulfide gas were also noted several years ago at the Capitol Aggregate quarry after a period of flooding (Gary Burgess, personal communication, 1975). Both these examples point to the fact that organic matter deposited within the Austin Group (Chalk) has generated hydrocarbons and related gases to a significant degree in certain areas.

No underground-storage facilities have been developed within the Austin Group (Chalk). In fact, Garner (personal communication, 1975) indicated that in the construction of the storm-sewer system for Austin, difficulty was encountered in keeping excavations from collapsing. Working faces within subsurface openings could not exceed 30 feet, and cement grouting was necessary to stabilize the relatively weak chalk units of this stratigraphic sequence.

EVALUATION OF REPOSITORY POTENTIAL

The Austin Group (Chalk) appears to be the least promising of several widespread, Cretaceous-age chalk sequences evaluated at a preliminary regional level (Gonzales, 1975). Potential obstacles to the utility of the Austin interval as raised in that earlier report were: (1) a greater level of structural deformation; (2) variations in thickness and the thinnest sequence of the three intervals evaluated; and (3) a large number of exploratory boreholes that have been drilled into or through the interval.

Based upon the supplemental information obtained from the literature and field observations as discussed in this report, there are several specific factors which appear to limit the potential of the Austin Group (Chalk) for future consideration as a repository medium to isolate high-level radioactive wastes.

These aspects include:

1. Unlike other chalk sequences, much of the Austin Group (Chalk) is regularly bedded and lacks thick, massively-bedded and impermeable chalk zones. Several intervals are largely marls and clays, and even those dominated by chalky lithotypes exhibit numerous interbeds, and show significant bedding alternation. Even the Atco Formation, which contains the most persistent and thickest chalks, appears normally bedded in outcrop. Movement of fluids along bedding surfaces could thus prove to be a problem.
2. In addition to these bedding characteristics, the Austin Group (Chalk) contains both porous-brecciated intervals in some areas and open fractures in others. The latter feature is involved in the accumulation of petroleum hydrocarbons and is an indication of the more brittle nature of certain carbonate lithologies found within the Austin sequence.
3. There is good evidence within the Austin Group (Chalk) of erosion, truncation and lateral variation in sedimentation patterns. Coupled with the fact that several facies changes can be recognized, this suggests

that the Austin Group (Chalk) is neither lithologically or stratigraphically as persistent as other chalk sequences even though it exhibits an extensive outcrop belt.

4. At least three separate systems of regional faulting have cut the Austin Group (Chalk), and have produced significant offsets or regional displacements. Smaller faults, fractures and joint sets also affect the interval, and appear related to the fault-system tectonics. These openings have obviously not been subsequently sealed, and even now serve as conduits for the migration of fluids.
5. The Austin Group (Chalk) has become the target for an extensive program of petroleum exploration which seeks to find crude oil in fracture-controlled reservoirs. Not only does this eliminate from future consideration much of the sequence where active drilling is underway, it also means that the Austin-stratigraphic sequence elsewhere may contain hydrocarbons, either in troublesome or commercial quantities. The drilling involved here also only adds to the number of boreholes which have encountered this unit in the subsurface.
6. Where the Austin Group (Chalk) has been affected by salt-dome tectonics, utility of the interval is also suspect because of conflicting competition in terms of petroleum fields and use of the domes for various purposes. Faced with the difficulty of evaluating certain salt domes as tectonically and hydrologically stable for possible repository consideration, utilization of the Austin Group proximal to domes in the East Texas Basin seems unlikely at this time. Effects of uplift by salt diapirism, dome-related faulting and associated hydro-dynamic systems probably exclude the Austin interval near any salt dome.
7. As opposed to the Selma Chalk in west-central Alabama, no experience or knowledge has been gained with regard to the Austin Group (Chalk) in terms of underground mines or subsurface-storage facilities. In shallow civil-engineered excavations within the Austin interval, however, the record of stability has not been favorable.

In summary, the above factors, in the writer's opinion, significantly minimize the potential of the Austin Group (Chalk) as a potential repository horizon. There may, however, be some areas within this extensively distributed interval that lack many, and even most, of these limitations. Inasmuch as few subsurface data have been reviewed and evaluated, further examination in this area may be potentially valuable. Although the following studies are not viewed as critical, and their adoption is not being urged here, inclusion of them below provides a measure of future direction, should additional information about the Austin Group (Chalk) be desired by the Office of Waste Isolation. Any future studies should concentrate

on non-faulted terrains where reasonable borehole data are available to permit acceptable analysis. Possible investigations might study:

1. The regional isopachous nature of the total stratigraphic unit;
2. The nature of the carbonate lithologies within the unit as they occur in the subsurface, based on available well cuttings and cores (provided the latter exist);
3. Lithotype-ratio mapping to discriminate thick, persistent chalk zones if the results under 1 and 2 prove encouraging.

More promising still would be serious consideration of similar studies directed toward the Selma Group in western Alabama and eastern Mississippi, inasmuch as this interval already lacks most of the restrictive features noted here for the Austin Group (Chalk).

REFERENCES CITED

- Adkins, W. S., 1933, The geology of Texas: Part II, The Mesozoic systems in Texas: Univ. Texas Bull. No. 3232, p. 239-518.
- American Association of Petroleum Geologists, 1972, Tectonic map of Gulf Coast Region, U. S. A.: Scale: 1:1,000,000.
- Anderson, R. E., Eargle, D. H., and Davis, B. O., 1973, Geologic and hydrologic summary of salt domes in Gulf Coast region of Texas, Louisiana, Mississippi, and Alabama: U. S. Geol. Survey Open-file Rept. 4339-2, 294 p.
- Baylor Geological Society, 1972, Urban geology, I-35 growth corridor: Waco, Texas: SW Assoc. Student Geol. Socs. Field Trip Guidebook, 130 p.
- _____, 1975, Structural geology of central Texas: Waco, Texas: SW Assoc. Student Geol. Socs. Field Trip Guidebook, 102 p.
- Dallas Petroleum Geologists, 1941, Geology of Dallas County, Texas: Field and Lab, v. 10, no. 1, p. 1-134.
- Durham, C. O., 1955, Stratigraphic relations of Upper Cretaceous volcanics in Travis County, Texas: Corpus Christi Geol. Soc. Ann. Field Trip Guidebook, p. 55-61.
- _____, 1957, The Austin Group in central Texas: New York, Columbia Univ., unpubl. Ph.D. dissertation.
- Garner, L. E., and Young, K. P., 1976, Environmental geology of the Austin area: an aid to urban planning: Texas Bur. Econ. Geol. Rept. Inv. No. 86, 39 p.
- Gonzales, S., 1975, Geologic feasibility of selected chalk-bearing sequences within the conterminous United States with regard to siting of radioactive-waste repositories: prepared for Union Carbide Corporation, Nuclear Division, Oak Ridge National Laboratory, Y/OWI/SUB-4310/2 (November 1975).
- Hill, R. T., 1887, The Texas section of the American Cretaceous: Amer. Jour. Sci., series 3, v. 34, p. 287-309.
- Long, M., 1976a, Austin chalk drilling surges in South Texas: Oil and Gas Jour., v. 74, no. 11, p. 62-63.
- _____, 1976b, Austin chalk play spreads far to northeast in Texas: Oil and Gas Jour., v. 74, no. 36, p. 60-64.
- Murray, G. E., 1961, Geology of the Atlantic and Gulf Coastal Province of North America: New York, Harper and Bros., 692 p.

- Netherland, Sewell and Associates, 1976, Geologic study of the interior salt domes of Northeast Texas Salt-Dome Basin to investigate their suitability for possible storage of radioactive waste material: prepared for Union Carbide Corporation, Nuclear Division, Office of Waste Isolation, Y/OWI/SUB-76/99939 (May 1976).
- Roemer, F., 1852, Die kreidebildungen von Texas und ihre organischen einschliesse: Bonn, Germany, Adolphus Marcus Publ., 100 p.
- Scott, R. J., 1977, A 1974 Austin Cretaceous discovery opened new frontiers in south Texas: Oil and Gas Jour., v. 75, no. 20, p. 200-204.
- Sellards, E. H., Adkins, W. S., and Plummer, F. B., 1935, The geology of Texas; Volume 2, Structural and economic geology: Univ. Texas Bull. 3401, 884 p.
- Shuler, E. W., 1918, The geology of Dallas County, Texas: Univ. Texas Bull. No. 1818, 54 p.
- Shumard, B. F., 1860, Observations upon the Cretaceous strata of Texas: St. Louis Acad. Sci. Trans., v. 1, p. 582-590.
- Taff, J. A., 1893, Report on the Cretaceous area north of the Colorado River: Texas Geol. Survey 4th Ann. Rept., pt. 1, p. 241-354.
- Texas Bureau of Economic Geology, 1965, Geologic atlas of Texas, Tyler sheet: Austin, Texas, scale: 1:250,000.
- _____, 1966, Geologic atlas of Texas, Texarkana sheet: Austin, Texas, scale: 1:250,000.
- _____, 1967, Geologic atlas of Texas, Sherman sheet: Austin, Texas, scale: 1:250,000.
- _____, 1968, Geologic atlas of Texas, Palestine sheet: Austin, Texas, scale: 1:250,000.
- _____, 1970, Geologic atlas of Texas, Waco sheet: Austin, Texas, scale: 1:250,000.
- _____, 1972, Geologic atlas of Texas, Dallas sheet: Austin, Texas, scale: 1:250,000.
- _____, 1974a, Geologic atlas of Texas, Austin sheet: Austin, Texas, scale: 1:250,000.
- _____, 1974b, Geologic atlas of Texas, San Antonio sheet: Austin, Texas, scale: 1:250,000.
- _____, 1974b, Geologic atlas of Texas, Seguin sheet: Austin, Texas, scale: 1:250,000.
- Weeks, A. W., 1945, Balcones, Luling, and Mexia fault zones in Texas: Amer. Assoc. Petroleum Geol. Bull., v. 29, no. 12, p. 1733-1737.
- Young, K. P., Barker, D. S., and Jonas, E. C., 1975, Stratigraphy of the Austin

Chalk in the vicinity of Pilot Knob: Geol. Soc. America, South-Central Sect.,
9th Ann. Meeting Field Trip Guidebook, 28 p.