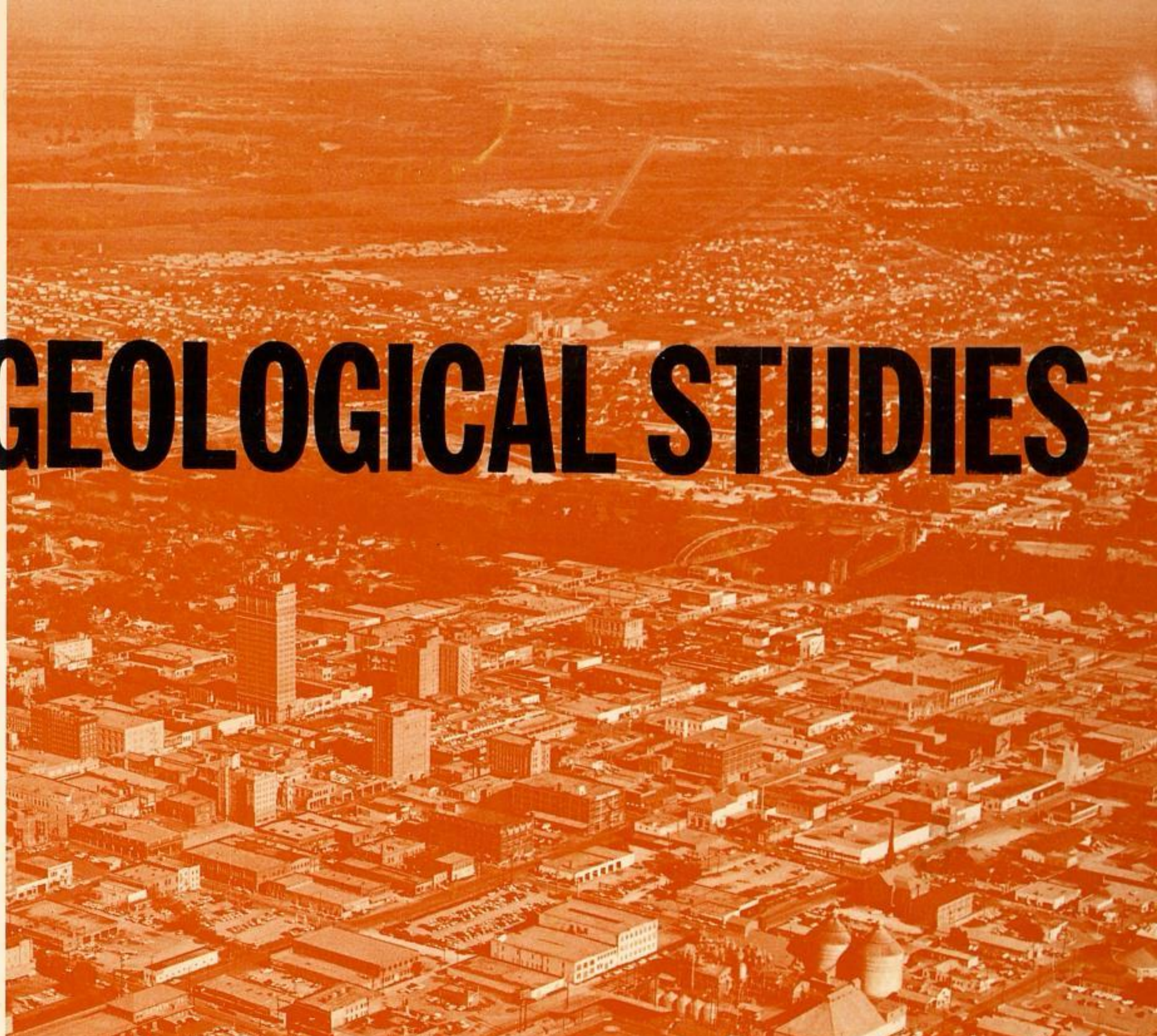
BAYLOR GEOLOGICAL STUDIES



SPRING 1970

Bulletin No. 12

BAYLOR UNIVERSITY - WACO, TEXAS
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URBAN GEOLOGY OF GREATER WACO
PART IV: ENGINEERING

Geologic Factors Affecting Construction in Waco

ROBERT G. FONT

EDWARD F. WILLIAMSON

Leon Byrd

"Creative thinking is more important than elaborate equipment--"

FRANK CARNEY, PH.D.
PROFESSOR OF GEOLOGY
BAYLOR UNIVERSITY
1929-1934

Objectives of Geological Training at Baylor

The training of a geologist in a university covers but a few years; his education continues throughout his active life. The purposes of training geologists at Baylor University are to provide a sound basis of understanding and to foster a truly geological point of view, both of which are essential for continued professional growth. The staff considers geology to be unique among sciences since it is primarily a field science. All geologic research including that done in laboratories must be firmly supported by field observations. The student is encouraged to develop an inquiring objective attitude and to examine critically all geological concepts and principles. The development of a mature and professional attitude toward geology and geological research is a principal concern of the department.

THE BAYLOR UNIVERSITY PRESS
WACO, TEXAS

BAYLOR GEOLOGICAL STUDIES

IN COOPERATION WITH COOPER FOUNDATION

A SERIES ON

URBAN GEOLOGY OF GREATER WACO

PUBLICATION SCHEDULE

Part I: GEOLOGY

Bulletin No. 8, Spring, 1965

Geology and Urban Development by Peter T. Flawn, Director, Texas Bureau of Economic Geology, Austin, Texas.

Geology of Waco by J. M. Burket, Professor of Geology, Tyler Junior College, Tyler, Texas.

Part II: SOILS

Bulletin No. 9, Fall, 1965

Soils and Urban Development of Waco by W. R. Elder, Field Specialist-Soils, Soil Conservation Service, Temple, Texas.

Part III: WATER

Bulletin No. 10, Spring, 1966

Surface Waters of Waco by Jean M. Spencer, Research Geologist, Department of Geology, Baylor University, Waco, Texas.

Bulletin No. 11, Fall, 1966

Subsurface Waters of Waco by H. D. Holloway, Geologist, Texas Water Development Board, Austin, Texas.

Part IV: ENGINEERING

Bulletin No. 12, Spring, 1967

Geologic Factors Affecting Construction in Waco by Robert G. Font, Geologist, Continental Oil Company, Lafayette, Louisiana and Edward F. Williamson, Staff Engineering Geologist, Dames and Moore, Consultants in Applied Earth Sciences, Seattle, Washington.

Part V: SOCIO-ECONOMIC GEOLOGY

Bulletin No. 13, Fall, 1967

Economic Geology of Waco and Vicinity by W. T. Huang, Professor of Geology, Baylor University, Waco, Texas.

Geology and Community Socio-Economics—A Symposium by authorities on Law, Appraising, Architecture, Public Works and other professions. Symposium Coordinator: R. L. Bronaugh, Professor of Geology, Baylor University, Waco, Texas.

Part VI: CONCLUSIONS

Bulletin No. 14, Spring, 1968

Urban Geology of Greater Waco—Summary and Recommendations by the Editorial Staff, Baylor Geological Studies, Baylor University, Waco, Texas.

FOREWORD

The development and early growth of Waco occurred primarily on the outcrops of the Austin Chalk and the Brazos Alluvium. Few geologically related problems appeared in the early development of the city, primarily because of the stable nature of the chalk and alluvium underlying most foundations in the city; the light weight and simplicity of most early structures; the relatively light loads on streets and roads; the uncomplicated nature of sewage and pipe systems; and the low demands of a small population for water, sand and gravel, sewage disposal and storm drainage.

During and after World War II, Waco expanded from these stable outcrop areas onto the outcrop of the unstable, incompetent shales of the Taylor Formation to the east and Eagle Ford Group to the west. This geographic expansion of Greater Waco during the past twenty years has been accompanied by many new urban problems of geological origin in addition to many existing problems which became critical with rapid urban population growth and expansion.

Among these important urban geological problems are those involving sand and gravel, which are lost to the area by unplanned city growth; foundation problems, which result in the failure of foundations in one area, over-design in another; soil problems involving corrosion of pipes, failure of foundations, variation in excavation costs and drainage problems; water supply problems, including surface and subsurface sources, utilization and pollution; and the quality, quantity and location of economic rocks and minerals in the Waco region.

These and many other problems cannot be solved adequately and economically without considering the role of the earth sciences. Responsible long-range urban development must also involve other geologically related aspects, such as problems of legal nature, property evaluation, city planning, recreation, beautification and development costs.

In recent years the Baylor Geology Department has received a growing number of requests for geological advice in the aforementioned areas of urban development. Although Baylor geologists have supplied free consultation as a public service, there has developed an apparent need for more comprehensive and accessible data on the total spectrum of earth science-urban relationships. The Baylor Geological Studies editorial staff decided in 1962 that a comprehensive publication on the Urban Geology of Waco should prove an asset to the city and its citizens.

Late in 1962 a thorough survey was made to ascertain sources of earth science data pertaining to the Waco area, as well as to locate published references on Urban Geology. Many city, state, and federal agencies, as well as interested individuals, were invited to cooperate in the project.

The Cooper Foundation, a private civic philanthropic foundation in Waco, was approached in January, 1963, for financial support to aid in the preparation and publication of a Waco Urban Geology report. A detailed, budgeted proposal was approved by the foundation to cover the proposed cost of publication and related expenses, totaling $7,000. Baylor University, through its press, accounting facilities, geology department, and Baylor Geological Studies budget accepted the responsibility for the remaining expense. The editorial staff of the Baylor Geological Studies provided free coordination, cartographic-field supervision, and editorial service.

Since the project was initiated early in 1963, it has evolved in concept and scope. The number and nature of contributions expanded as the project matured. The URBAN GEOLOGY OF GREATER WACO includes major contributions from the Baylor Geology Department, Texas Bureau of Economic Geology, U. S. Soil Conservation Service, U. S. Corps of Engineers, Texas Highway Department and Texas Water Development Board. Shorter contributions include papers by an architect, attorney, real estate appraiser, public works engineer and others.

In the spring of 1964, a series of eight public evening seminars were held at Baylor to provide contributors with an opportunity to present a summary of their reports for comments and discussion. A student seminar was conducted at the same time to explore all areas of urban activities which are related to the earth sciences.

Originally, the proposed Urban Geology report was scheduled to be released as a single volume. During preparation the various reports were expanded and complex illustrations were added; other papers were solicited to cover additional areas of importance. Because of the increased scope of the project, ten major and numerous shorter papers are included in the Baylor Geological Studies urban series.

Beginning with Baylor Geological Studies Bulletin No. 8 (Spring, 1965), seven successive semiannual Bulletins will include papers grouped according to Geology, Soils, Water, Geological Engineering, Socio-Economic Geology and Conclusions. Included in the series are multicolor geologic, soil, isopach and structure maps (on U.S. Geological Survey topographic base), charts, illustrations and tables of various types prepared by the Baylor Geological Studies student cartographic staff. Copies of Baylor Geological Studies Bulletins 8-14 (Urban Geology series) will be published and sold for $1.00 each. Sale of URBAN GEOLOGY OF GREATER WACO will be handled by Baylor Geological Studies in agreement with Cooper Foundation.

The editorial staff and contributors intend to provide a comprehensive series on Waco Urban Geology, which may also serve as a model for others interested in this vital area of geologic application and public service. No precise estimate can be placed on the value of information supplied by governmental agencies and individual researchers, or on the value of time donated by authors, editorial staff and interested geologists. The Cooper Foundation grant and the Baylor Geological Studies budget for the seven issues in the series will exceed $15,000—an amount which is conservatively estimated to be less than ten percent of the actual cost of the project if it had been contracted at regular professional and commercial rates.

The editorial staff appreciates this opportunity to provide a public service for the citizens of Waco. We sincerely thank the Cooper Foundation, Baylor University and the various State and Federal Agencies, as well as the many individuals, who made this series possible.

L. F. Brown, Jr., EDITOR, Bulletins 8, 9

Jean M. Spencer, EDITOR, Bulletins 10-14

Leon Byrd

BAYLOR GEOLOGICAL STUDIES

BULLETIN NO. 12

IN COOPERATION WITH COOPER FOUNDATION

A SERIES ON

URBAN GEOLOGY OF GREATER WACO

PART IV: ENGINEERING

Geologic Factors Affecting Construction in Waco

ROBERT G. FONT & EDWARD F. WILLIAMSON

BAYLOR UNIVERSITY
Department of Geology
Waco, Texas
Spring, 1967

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scheduled for Spring, 1967.

Baylor Geological Studies

The Baylor Geological Studies Bulletin is published semi-annually, Spring and Fall, by the Department of Geology at Baylor University. The Bulletin is specifically dedicated to the dissemination of geologic knowledge for the benefit of the people of Texas. The publication is designed to present the results of both pure and applied research which will ultimately be important in the economic and cultural growth of the State.

Cover photograph: Aerial view of Downtown Waco. Photograph provided through the courtesy of WINDY DRUM STUDIO, COMMERCIAL PHOTOGRAPHY, Waco, Texas.

Additional copies of this bulletin can be obtained from the Department of Geology, Baylor University, Waco, Texas 76703. $1.04 postpaid.

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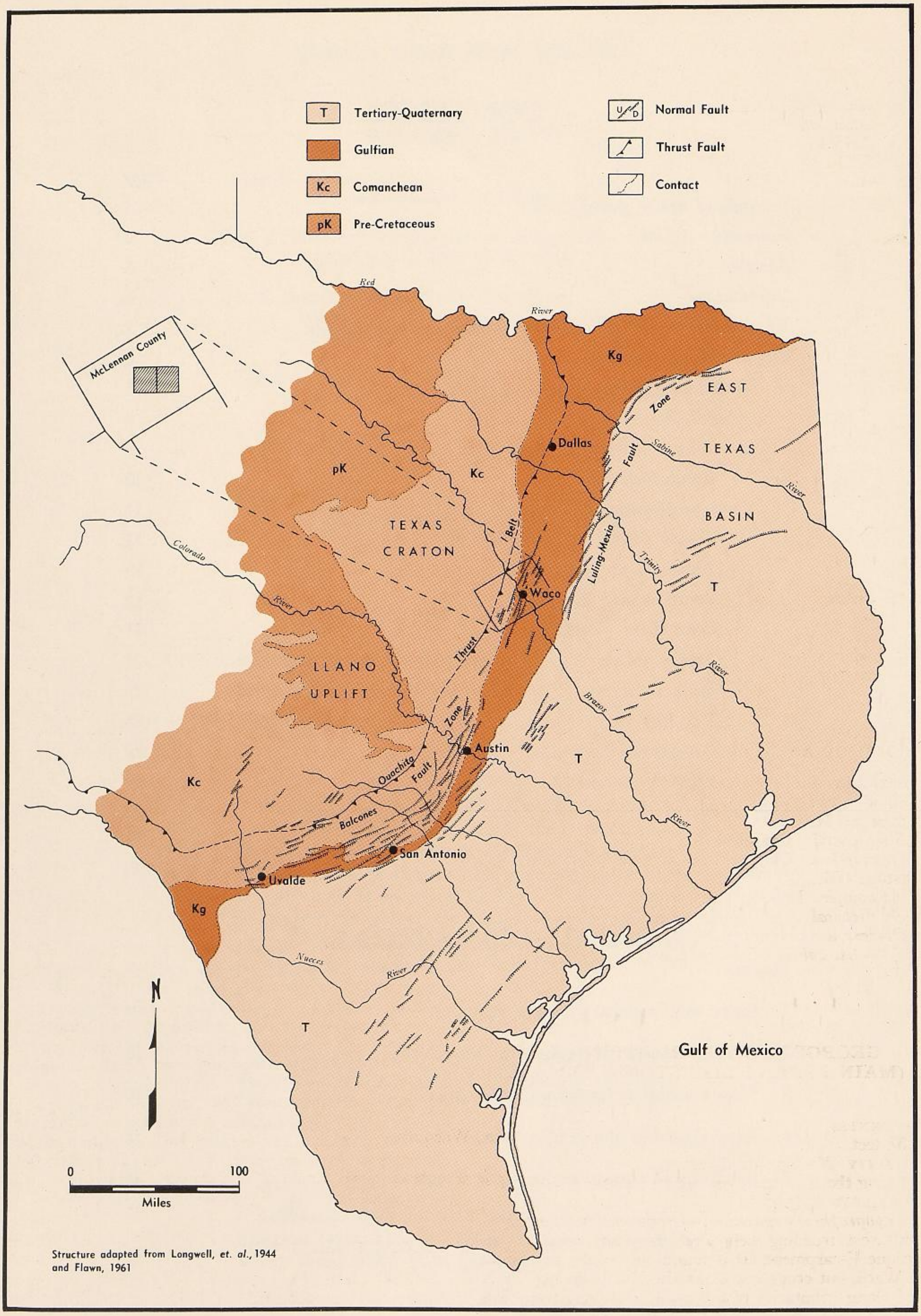


Fig. 1. Index and regional geologic map, Central Texas.

Geologic Factors Affecting Construction in Waco

Robert G. Font, Geologist, Continental
Oil Company, Lafayette, Louisiana

Edward F. Williamson, Staff Engineering Geologist,
Dames and Moore, Consultants in Applied Earth
Sciences, Seattle, Washington

ABSTRACT

Knowledge of its local geology is of vital importance to the development of a city. An understanding of the physical properties and behavior of local earth materials leads to better and safer construction and can prevent later failures. The purpose of this study is to make a systematic research of the geology of the city of Waco and adjacent areas as it applies to engineering problems which may be encountered in the future development of the city.

This report is designed for the use of engineers and city planners, as well as for geologists who are interested in the field of urban geology and city development.

Geologic factors affect the development and growth of a city. Earth materials, landscape, soils, and ground water are related to the geology of the area.

Waco is situated along the Bosque Escarpment which separates the Black and Grand Prairies of Texas. Most of Waco rests upon the Black Prairie. The Brazos River, with its major tributary the Bosque River system, constitutes the principal drainage near Waco. The city is underlain by eastward-dipping rock of the Gulf Coastal Plain. The structure of these beds is essentially homoclinal, but near Waco it is broken up by the Balcones fault system which bisects the city in a north-south trend. The fault patterns and the variety of rock types in the Waco area have resulted in problems involving drainage, septic sewage disposal, excavation, foundation design, etc.

The formations that crop out in the Waco area include in descending order: Quaternary Alluvium, Quaternary terrace deposits of the Brazos and Bosque rivers, and Cretaceous formations: Taylor Marl, Austin Chalk, South Bosque Shale, Lake Waco Formation, Pepper Shale, Buda Limestone, Del Rio Clay, and Georgetown Limestone. These surface formations are most significant to city growth, since they control the topography, engineering properties of rocks and soils, and hence construction and other urban problems. The Brazos and Bosque river alluvium occupies the lowest areas in Waco. These areas are occasionally flooded, thus introducing risk in development. Ground water from these alluvial deposits is polluted, although water is available in moderately large quantities.

The Brazos and Bosque terraces are composed of sands and gravels, produce limited amounts of seasonal ground water (usually polluted), and provide reservoirs for underground disposal of waste water. The Brazos River terraces provide excellent commercial siliceous gravels and sand, some polluted ground water, and stable foundation sites for light structures. The Bosque terraces provide limestone gravel with clay binder, limited amounts of polluted water, and modest underground disposal of waste water. They also furnish stable sites for light structures.

The Taylor Marl is a highly bentonitic, calcareous clay. Like most clays, the Taylor Marl becomes plastic when wet. Foundation failures are common in the weathered marl, because of the high shrink-swell ratio and the plastic nature of the material. Foundations should extend well into the unweathered part of the marl and excavations should be closed promptly to avoid swelling of the bentonitic clays. Septic tanks and other buried structures may be crushed by expansion of the clays. The Taylor Marl does not produce water and it will not absorb septic sewage effectively.

The Austin Chalk provides fewer problems for foundations and septic disposal systems. Nevertheless, it provides more difficulty in excavation than any other Cretaceous formation in the immediate Waco area. Soils derived from the Austin Chalk have a high shrink-swell ratio, and if sufficiently thick may provide foundation problems. The Austin Chalk supports steep cuts and banks, produces some polluted water, and absorbs moderate amounts of septic sewage.

The South Bosque Shale is a dark gray to black homogeneous shale. The upper 40 feet are essentially non-calcareous and are used in expanded aggregate production and in the manufacture of cement. The lower 120 feet are essentially calcareous. The South Bosque Shale yields no water in McLennan County, has a very low slope stability (especially in the upper 40 feet), has a low infiltration capacity, offers inadequate septic sewage disposal, has a low foundation support strength, and is readily excavated by light machinery.

The Lake Waco Formation has a greater range of support strengths than the South Bosque Shale, since the former has thin limestone beds in its upper and lower portions. The Lake Waco Formation supports steeper faces and heavier foundation loads than the South Bosque Shale. In limestone sections some fluid will be absorbed, but excessively large drainage fields are required for septic sewage disposal. Excavation is easier in the middle shale member and more difficult in the limestone sections.

The Buda Limestone is a hard to chalky, fossiliferous limestone averaging about 2 feet in thickness in the Waco area. The outcrop pattern of the limestone is too thin and discontinuous to affect the urban geology of the region. If thick enough, the limestone will support heavy foundation loads. The nature of the Buda Limestone insures difficulty in excavation.

The Pepper Shale, underlying the Lake Waco Formation, consists of a blue-gray, highly plastic, noncalcareous clay. This clay yields plastically under minimum loads, and the shale slumps readily even on very gentle slopes. It absorbs essentially no fluids and creates a corrosive environment for buried pipes.

The Del Rio Clay, which underlies the Pepper Shale, is composed of gray, calcareous, plastic clays with occasional discontinuous limestone stringers. The clay is highly plastic when wet, forms corrosive soils, and is impermeable to drainage and infiltration. In general the formation is easily excavated, although interbedded limestone and siltstone beds may present some problem. The clay fails by slumping even on gentle slopes.

The Georgetown Formation crops out west of Waco, on the west side of the Bosque Escarpment. It is composed of seven members, of which only the upper five are exposed within the mapped area. The uppermost member, the Main Street Limestone, has a high bearing capacity, supports steep slopes, has a low infiltration capacity due to its situation between impermeable shales, yields no free water except during wet seasons, and provides adequate septic sewage disposal except in periods of high saturation. Excavation in this member is difficult. Other members of the Georgetown Formation present within the area include in descending order: the Pawpaw Shale (directly beneath the Main Street Limestone), the Weno Limestone, the Denton Shale, and the Fort Worth Limestone. The limestone members exhibit properties similar to those of the Main Street Limestone. The shale members should be avoided, since they are thin and generally not suitable for engineering construction.

Rocks older than the Fort Worth Limestone Member of the Georgetown Formation occur in the subsurface within the mapped area.

The Edwards Limestone underlies the Georgetown Formation. Although it occurs in the subsurface within the mapped area, its engineering properties have been considered, since it crops out immediately west of the studied region. The Edwards Limestone is excellent for foundation and construction purposes. Excavation is difficult. Blasting may be required for excavation.

INTRODUCTION*

In an earlier Urban Geology of Greater Waco Bulletin (Baylor Geological Studies Bulletin No. 8), the geology of the Waco region was described, and the significance of geology to urban development was briefly reviewed.

As was indicated, considerable data exist on the engineering properties of rock and soils of the Waco area. These data have not been presented in readily useful and widely available form. Problems which can be encountered in the different soils and rocks in this area have been experienced by various individuals, but specific remedies and geological associations are not generally appreciated. If properties of local geological materials are understood and these materials are thoroughly tested at the building site, then potential problems can be anticipated and corrected before they become real.

This report is a compilation of geological engineering data for the Waco area, which emphasizes problem areas but does not provide design data for specific construction sites. Variations even in individual geological units, require that on-site inspection be utilized in all construction.

The principal purpose of this report is to identify geologically-related problems which may be encountered in the Waco area. Failure to recognize geologic factors in construction may result in shift and fracture, slumps, breaks in pipes and conduits, and seeps which cause flooding or other equally damaging failures.

*Manuscript received spring 1969.

The formations referred to in this report are those shown in figure 1 and on the geologic map accompanying Baylor Geological Studies Bulletin No. 8. Each geologic unit is discussed, and its engineering properties are emphasized.*

Formations exposed in the Waco area, include alluvial silts and clays, Brazos and Bosque River terraces (sands and gravels), the Lower Taylor Marl, Austin Chalk, South Bosque Formation, Lake Waco Formation, Pepper Shale, Del Rio Clay and Georgetown Limestone. Each formation possesses characteristics which affect construction of homes, small and large buildings, dams, bridges, streets and highways.

For example, foundation support strengths of the different geologic formations in this area vary with each formation, and frequently the bearing capacity within the same unit varies considerably. The Austin Chalk has been tested and found to have bearing capacity values ranging from 20 to 35 tons per square foot. In comparison, the South Bosque Shale, which is present directly below the Austin Chalk, has been found to have bearing capacities which range from 3.5 to 18 tons per square foot, depending upon depth.

Slope stability of each formation is directly related to the composition of the material and the amount of water present. As a general rule, the higher the shearing strength of a given type of material, the greater will be the slope angle. The Austin Chalk will support vertical slopes whereas the weaker South Bosque Shale will support only slopes less than 10 degrees under its own weight. If the overburden is too great on this shale, the angle of a stable slope will be lessened. Clays of the Lower Taylor Marl are so weak that when wetted a normally stable slope of 10 degrees will fail under its own weight, even if the overburden is a few feet thick.

Variations of equivalent magnitude occur in drainage properties, excavation difficulties, etc.

Data are presented for each of the geologic units exposed in the Waco area. For each unit, the following properties are considered: (1) thickness, (2) distribution in the Waco area (3) lithology and major physical properties (4) slope stability (5) excavation properties (6) drainage properties (7) soil parameters of associated soils and (8) economic values.

A glossary is also provided to define unfamiliar terms.

For most effective use of this report a proposed building site is to be first identified on the geologic map (Bulletin 8). This will serve to identify the formation or formations which will most directly affect construction at that site. The properties of the formations may then be determined from the appropriate section of this report.

However, it is emphasized that information presented in this report cannot substitute for on-site testing. The information in this study merely points out problem areas and possible solutions. It does *not* identify specific dangers at any one locality.

Appreciation is extended to R. L. McKinney of the Waco Division of the Texas Highway Department, for his help and valuable advice in the development of this project, as well as for allowing use of Texas Highway Department information and to J. M. Burket and W. R. Elder for their respective studies involving the geology and engineering characteristics of geologic formations and soils of the Waco area. Dr. O. T. Hayward was consulted during research and manuscript preparation.

Besides those already mentioned, many others have contributed to a better knowledge of the geology of the Waco area. The works of many of these individuals are listed in the reference section of this report. Also listed with the references are general engineering and structural geology studies which were invaluable to this engineering geology study.

INTRODUCTION TO SOIL PARAMETERS AND SHEARING STRENGTH DATA*

Some of the soils which develop throughout the Waco area can give rise to problems concerning foundation or pavement construction, if corrective measures are not undertaken. If subsequent drying or swelling of a particular soil occurs after pavements or foundations are placed on it, the volume change that can occur in the soil may result in the failure or cracking of the structure. On the other hand, if the soil beneath the structure is too dry, an additional absorption of moisture may result in its warping, as the soil mass increases in volume (Burket, 1959, p. 113). To control and avoid these problems, the soil beneath the structure should be compacted at the proper density and moisture content recommended for good structural performance. To insure better and safer construction, soil samples should be taken from the proposed foundation site and used to determine the material that should be employed in stabilizing the soil. It is usually advisable to have a higher moisture content, because in the Waco area soils tend to absorb moisture with time (McKinney, oral communication). With a lower moisture content, subsequent swelling may result.

Good results are obtained when a material having a low volume change (Plasticity index below 10) is used between the plastic soil and the subgrade and the base course of the foundation. If the foundation soil has

Editor's note: Geologic and structure maps accompany Urban Geology of Greater Waco, Part I: Geology by P. T. Flawn and J. M. Burket, Baylor Geological Studies Bulletin No. 8. Soil maps accompany Urban Geology of Greater Waco, Part II: Soils by W. R. Elder, Baylor Geological Studies Bulletin No. 9.

very high PI values, the addition of lime tends to reduce this value into the 20's (a more desirable figure) (Burket, 1959, p. 113). Soils having a plasticity index of 10 or less have practically no volumetric swell (McKinney, oral communication).

For each formation cropping out within the mapped area, values of Atterberg limits, and of the unconfined compressive strength (calculated from triaxial tests) of particular soils developing on them, are given in the section dealing with soil parameters. Part of these data was made available by the Waco Division of the Texas Highway Department. The values given are considered representative for soils of the Waco area. These should give the reader an idea of the type material under consideration, but these values might change from one locality to another which makes on-site testing necessary to insure safety. Soil parameters herein discussed include Liquid Limit (LL), Plasticity Index (PI), Shrinkage Limit (SL), Linear Shrinkage (LS), Shrinkage Ratio (SR), and Potential Vertical Rise (PVR). The unconfined compressive strength values given were calculated from triaxial tests at given lateral pressures of 3, 5, 10, and 15 pounds. The desirable density (Dfc in $lbs./ft^3$) and moisture content (Dmc in %) for compaction are also given. In some instances, the average volumetric swell (Avs in %) is listed.

ENGINEERING PROPERTIES

QUATERNARY SYSTEM

ALLUVIUM (Qal)

THICKNESS

0 to 35 feet.

LOCALITY WHERE MEASURED

Within the Waco area.

DISTRIBUTION

Topographic expression. In "bottom" land. Mainly in the flood plains of the Brazos and Bosque rivers, and Tehuacana, Williams, and Tradinghouse creeks. A narrow strip extends into the channel area of Waco, Cottonwood, and other creeks located within the mapped area.

DESCRIPTION

Lithologic name. Calcareous silts and clays.

Color. Fresh: brown to black. Weathered: Buff to tan to red.

Bedding. Loosely compacted.

Description. Brown to black, calcareous, silts and clays; loosely compacted. Organic content is generally high.

BEARING CAPACITY

DESCRIPTION

Low.

Qualifications. Varies with: 1) thickness, 2) moisture content, 3) clay-silt composition, and 4) nature of underlying formation.

BEARING CAPACITY

0.7 to 1.8 $tons/ft^2$.

SHEARING STRENGTH

Low.

POTENTIAL SWELL

2 to 7 percent by volume; PVR of 20 feet of clay is usually 6 to 8 inches, and over 12 inches in some areas.

PROBLEMS RELATED TO BEARING CAPACITY

Bearing capacity may vary greatly in an area of a few square yards.

CORRECTIVE MEASURES IN FOUNDATION DESIGN

1. Stabilizers, such as $CaCO_3$ should be employed to improve the low shearing strength of the material by developing moisture barriers and by acting as bonding agents.
2. On-site testing is necessary.

SLOPE STABILITY

DESCRIPTION

Unstable.

Qualifications. Usually high moisture content.

MAXIMUM NATURAL SLOPE ANGLE

Irrelevant.

SLOPE RETENTION IN EXCAVATIONS

1. Shoring and cribbing are often necessary to maintain open cuts.
2. Dangerous material when unsupported.

Shallow (less than 6 feet). Because of the usually high water content of the sediment, the material is unstable. Either gentle slopes (3½ : 1*) or wall supports should be provided.

CAUSES OF SLOPE FAILURE

1. Plasticity of the material (emphasized when wet).
2. High moisture content and porosity.

Recommendations. Particularly heavy structures should be supported below grade to insure permanence.

EXCAVATION PROPERTIES

DESCRIPTION

Readily excavated with light machinery.

NATURE OF EXCAVATED MATERIAL

Silt.

EXCAVATION DESIGN PROBLEMS

Slope retention. Shoring and cribbing are necessary to support open cuts. Dangerous material when unsupported.

Drainage. 1) High porosity, 2) moderate to low permeability.

Disposal of material. Large drainage fields may be required for septic sewage disposal. Additionally intro-

*Horizontal : vertical.

duced fluid is not readily accepted because of the high moisture content of the material.

Causes of Excavation Problems
When moisture content is high, the material may be difficult to manage.

NATURE OF MATERIAL WHEN USED AS FILL

Description
Unstable.

Qualifications. When used as compacted grade fill, the material should be stabilized with lime or other suitable agents and compacted to a density of 90 lbs/ft^3 or more, depending on the type of construction.

Slope Stability of Compacted Fill
Low to moderate.

Permeability
Low to moderate.

Erosion Properties
Erodes easily.

Problems in Use as Fill
Alluvial silts and clays should not be employed as loose fill on exposed slopes or large excavations.

DRAINAGE PROPERTIES

Infiltration Capacity
Low.

Qualifications. 1) High porosity, 2) because of normally high moisture content fluids are not readily accepted.

Soil Parameters by Soil Name

Sample of Alluvial clay. LL=30, PI=15, LS=8.9, SL=12.8, SR=1.87, PVR=6.12 inches.

Alluvial soils (undifferentiated). LL=24.6, PI=4.0, LS=2.2, SL=2.04, SR=1.63, Dmc=7%, Dfc=103 $lbs./ft^3$.

Catalpa clay. LL=46.8, PI=29.3, SL=14.6, LS=14.2, SR=1.83, Dmc=24.5%, Dfc=97$lbs./ft^3$, PVR=1.72 inches.

Asa silt loam. LL=26.4, PI=8.0, SL=17.3, LS=5.0, SR=1.82, Dmc=12.9%, Dfc=118 $lbs./ft^3$, PVR=0 inches.

Shearing Strength

Catalpa clay.

T.B.L.P.	U.C.S. ($lbs./in^2$)
at 3 lbs.	17.58
at 5 lbs.	22.83
at 10 lbs.	33.00
at 15 lbs.	38.62

Asa silt loam.

T.B.L.P.	U.C.S. ($lbs./in^2$)
at 3 lbs.	73.20
at 5 lbs.	81.80
at 10 lbs.	103.87
at 15 lbs.	123.58

Alluvial soils undifferentiated.

T.B.L.P.	U.C.S. ($lbs./in^2$)
at 3 lbs.	28.2
at 5 lbs.	35.1
at 10 lbs.	52.2

Problems Encountered in Infiltration Drainage
Large drainage fields may be required for septic sewage disposal. Additionally introduced fluid is not readily accepted due to the normally high moisture content of the material. During particularly wet seasons, this problem is emphasized.

Free Water
Moderate.

Qualifications. 1) High porosity, 2) moderate to low permeability (because of originally high water content).

Nature of Occurrence of Free Water
Some water at shallow depths.

Quality. Probably polluted.

Problems Involving Free Water. 1) Pollution, 2) large drainage fields.

SOIL PARAMETERS

Soils Developed on This Unit
Alluvial soils; Asa: very fine sandy loam; Catalpa series; Miller clay; Norwood soils; Yahola silt loam.

Relation of these soils to slope. Well drained soils of the Brazos bottomlands and soils of the Brazos River flood plain.

Problems With Soils on This Unit
Since these alluvial soils occur in the flood plain of the Brazos River and other major creeks in the Greater Waco area, any type of foundation or construction will be subjected to the danger of flooding.

Corrective Measures
On-site sampling is required for effective soil evaluation.

ECONOMIC ASPECTS

Horticultural Values
Excellent farm lands.

Value as Material

Description. Major source of sand and gravel for various construction purposes.

As aquifer. Some water at shallow depths (probably polluted).

As disposal site. Large drainage fields may be necessary (see drainage properties).

Present use. Some gravel pits; major source of sand and gravel for various construction purposes.

Potential value. Exploitation of sand and gravels.

BRAZOS TERRACES (Qbrt)

Thickness
Ranges from 1 to 25 feet.

Locality Where Measured
Throughout the Waco area.

Distribution (local)

Topographic expression. East of the Brazos River and throughout southeast Waco; west of the river in south and north Waco.

Lithologic name. Sands and gravels.

Mineralogic composition. Quartz, quartzite, jasper, chert, and limestone gravels.

Description. Sand and gravel from bedload deposits of the river from earlier stages of river flow. Composed of quartz, quartzites, jasper, chert, and limestone gravels.

BOSQUE TERRACES (Qbot)

THICKNESS
From 1 to 25 feet.
LOCALITY WHERE MEASURED
Throughout the Waco area.
DISTRIBUTION (LOCAL)
Topographic expression. Along the Bosque Rivers and on the north and west sides of Lake Waco.
DESCRIPTION
Lithologic name. Sand and gravel.
Mineralogic composition. Limestone and shell gravels with varying amounts of reddish-brown clay.
Description. (See mineralogic composition.)

TERRACES

BEARING CAPACITY

DESCRIPTION
Low to intermediate.
Qualifications. Bearing capacity values in this material are dependent upon cohesiveness, water content, depth, etc.

BEARING CAPACITY
Brazos sands. 1.1 to 2.5 tons/ft^2.
Compacted sands. 4 to 8 tons/ft^2.
Gravel. 2.5 to 8.5 tons/ft^2.

SHEARING STRENGTH
Brazos terraces. Low.
Bosque terraces. Intermediate.

POTENTIAL SWELL
None in the parent material itself. This is not true for some of the soils which develop on them.
PROBLEMS RELATED TO BEARING CAPACITY
Testing is required at each specific site. Values for bearing capacity may be quite different in different sites.

CORRECTIVE MEASURES IN FOUNDATION DESIGN
Shallow foundations or slab construction will encounter minimum bearing capacities due to lack of confining pressure.

SLOPE STABILITY

DESCRIPTION
Stable.

Qualifications. The Bosque terraces can maintain steep slopes due to the existence of clay binder. Also, $CaCO_3$ cementation of the gravel has resulted in the development of durable conglomerates that will maintain low vertical faces.

MAXIMUM NATURAL STABLE SLOPE ANGLE
Normally supports slopes greater than 10° without shoring (see qualifications above).

SLOPE RETENTION IN EXCAVATIONS

Shallow (less than 6 feet). Groundwater may be encountered in excavations in the low terraces.

CAUSES OF SLOPE FAILURE
In uncemented sands and gravels it is safer to keep gentle slopes (10° to 15°) to insure stability of the slopes. Sometimes shoring is required to maintain steeper slopes in this material.

EXCAVATION PROPERTIES

DESCRIPTION
Readily excavated with light equipment (draglines, back hoe, front-end loaders, etc.).
Qualifications. Where cementation of the gravels has produced dense, hard, conglomerates, it may be necessary to blast or rip.
NATURE OF EXCAVATED MATERIAL
Disaggregated.
EXCAVATION DESIGN PROBLEMS
Slope retention. Generally good, especially in indurated, dense, cemented, conglomerates.
Drainage. Good. (See drainage properties).
Disposal of material. Excellent. (See drainage properties).
CAUSES OF EXCAVATION PROBLEMS
Shallow groundwater is frequently encountered in excavations in the Brazos terraces. On the lower terraces, water is generally encountered at a depth of about 10 to 15 feet.

NATURE OF MATERIAL WHEN USED AS FILL

DESCRIPTION
Poor to excellent.
Qualifications. Brazos sands and gravels—poor when used as above-grade fill, due to the lack of clay binder; very good as below-grade fill. Bosque terrace material —excellent above-grade fill, except when an excessive amount of clay binder is present, or when much of the clay binder has been lost in washing.
SLOPE STABILITY OF COMPACTED FILL
Generally fair to good.
PERMEABILITY
High.
EROSION PROPERTIES
Moderate to resistant to erosion.
PROBLEMS IN USE AS FILL
Brazos River terrace material should have additives, such as clay or cement to stabilize it when used as above-grade fill. When used as below-grade fill, as drains, or as bedding beneath foundations, the material is stable under very heavy loads.

DRAINAGE PROPERTIES

INFILTRATION CAPACITY
High.
Qualifications. Lower terraces pose problems in excavations due to shallow water table.
NATURE OF PERMEABILITY
High-terrace sands and gravels readily accept infiltration of fluid.
PROBLEMS ENCOUNTERED IN INFILTRATION DRAINAGE
Although the terraces are excellent material for septic sewage disposal, care should be taken not to contaminate shallow wells throughout the area. The high perme-

abilty of this material insures that sewage will find its way into shallow wells.

FREE WATER

Abundant.

Qualifications. High permeability.

NATURE OF OCCURRENCE OF FREE WATER

1. Abundant in low terraces.
2. Less abundant and seasonal in high terraces.
3. Bosque terraces are generally less productive than the Brazos terraces.

Quality. Mostly polluted, although usable water is generally present in the Brazos terraces.

PROBLEMS INVOLVING FREE WATER

Septic sewage disposal in this material normally will contribute to contamination of shallow producing wells throughout the area.

SOIL PARAMETERS

SOILS DEVELOPED ON THIS UNIT

Axtell, Bell, Irving and Lewisville soils. Also, Travis sandy loam.

RELATION OF THESE SOILS TO SLOPE

Develop on high and low river terraces.

SOIL PARAMETERS BY SOIL NAME

Axtell clay. LL=52.2, PI=36.1, LS=16.8, SL=13.8, SR=1.82, PVR=1.12 inches, Dmc=18%, Dfc=103 lbs./ft^3, Avs=4.5%.

Bastrop soils. LL=no definite limits, PI=4-12, Dmc=7-12%, Dfc=105-110 lbs./ft^3, Avs=negligible.

Bell soils. LL=56.5, PI=38.5, LS=21.4, SL=8.2, SR=2.01, PVR=2.11 inches, Dmc=25%, Dfc=95 lbs./ft^3, Avs=3.8%.

Irving series. (Fine sandy loam) LL=29.3, PI=13.0, LS=7.9, SL=14.3, SR=1.83, PVR=1.20 inches, Dmc=12.5%, Dfc=117.5 lbs./ft^3, Avs=negligible.

Irving series. (Clay loam) LL=34, PI=19.1, LS=10.5, SL=12.9, SR=1.87, PVR=0.93 inches, Dmc=15.5%, Dfc=110 lbs./ft^3, Avs=3.8%.

Lewisville series. LL=53.6, PI=35.0, SL=9.1, LS=19.2, SR=2.01,PVR=1.60 to 2.28 inches, Dmc=21%, Dfc=98 lbs./ft^3, Avs=5.5%.

Travis sandy loam (0-1 feet depth). LL=16.9, PI=4, SL=12.6, LS=2.6, SR=1.84, PVR=1.24 inches, Dmc=9%, Dfc=125 lbs./ft^3, Avs=negligible.

SHEARING STRENGTH

Normally low for Brazos terraces; medium to high for Bosque terraces.

Axtell clay.

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	16.8
at 5 lbs.	18.4
at 10 lbs.	25.5
at 15 lbs.	32.5

Bastrop soils.

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	24.7
at 5 lbs.	34.7
at 10 lbs.	48.2
at 15 lbs.	68.9

Bell soils.

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	18.6
at 5 lbs.	20.1
at 10 lbs.	25.6
at 15 lbs.	34.1

Irving series.

1. Fine Sandy Loam

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	81.9
at 5 lbs.	91.7
at 10 lbs.	121.2
at 15 lbs.	136.5

2. Clay Loam

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	20.6
at 5 lbs.	23.3
at 10 lbs.	33.7
at 15 lbs.	39.7

PROBLEMS WITH SOILS ON THIS UNIT

See section on soils.

CORRECTIVE MEASURES

Soil cover is usually thin. In this case, the soil layer should be removed, and foundations should be placed in bedrock.

ECONOMIC ASPECTS

HORTICULTURAL VALUES

Good farm soils.

VALUE AS MATERIAL

Description. Brazos terraces—constitute the principal source of construction sand and gravel for the Waco area. Bosque terraces—grade A base material for street and highway construction because of the abundant clay binder.

As aquifer. Shallow groundwater in low Brazos terraces.

As disposal site. Excellent, although septic sewage disposal should be discouraged to avoid contamination of the shallow ground water in this material.

Present use. Gravel pits, fill, and road material.

Potential values. Lower terraces produce some water for irrigation and domestic use.

CRETACEOUS SYSTEM

TAYLOR MARL (Kta)

THICKNESS

250 feet.

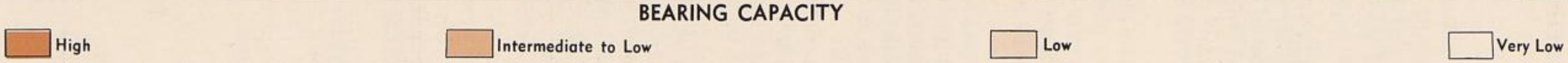
LOCALITY WHERE MEASURED

At the J. L. Myers & Sons, No. 1 Pardo Well.

DISTRIBUTION (LOCAL)

Topographic expression. The Taylor Formation is

BEARING CAPACITY



Very low and low bearing capacity require that heavy structures be largely supported by means of piers or floating foundations. If piers are employed, they must be sunk into adjacent, more resistant units.

Very low bearing capacity exists in the Pepper Shale.

Low bearing capacity exists in alluvial deposits in Brazos terrace sands; in the upper 30 to 50 feet of the South Bosque Shale; in bentonitic portions of the Lower Taylor Marl and Wolfe City Sand; and in the middle, noncalcareous, portion of the Del Rio Clay.

Intermediate bearing capacity allows significant portions of the foundation load of heavy structures to be supported by footings or beams. In some instances pier support may be necessary to insure stability.

Intermediate bearing capacity exists in Brazos and Bosque terrace deposits; in certain portions of the Lower Taylor Marl and Wolfe City Sand; in the lower portion of the South Bosque Shale; in the Lake Waco Formation; in the upper and lower, calcareous portions of the Del Rio Clay; and in shaly sections of the Weno and Denton members of the Georgetown Formation.

High bearing capacity allows heavy structures to be supported by conventional footings and grade beams. No pier or caisson support is generally required in these areas, although local jointing, faulting, etc., modify these conditions.

High bearing capacity exists in the outcrop areas of the Austin Chalk; Main Street Limestone; and in limestone sections of the Weno and Denton members of the Georgetown Formation.

This map applies only to foundations resting below weathered and soil zone.

Fig. 2. Bearing capacity of formations, Waco area.

divided into four members. In descending order these are: the Upper Taylor Marl, the Pecan Gap Chalk, the Wolfe City Sand, and the Lower Taylor Marl. Of these members, only the Lower Taylor Marl and the Wolfe City Sand are found in the Waco area. In the J. L. Myers & Sons No. 1 Pardo Well, the Lower Taylor Marl is about 250 feet thick. The Wolfe City Sand Member of the Taylor Formation crops out in eastern McLennan County. It conformably overlies the Lower Taylor Marl. The contact between these members was observed in those areas of the Axtell, Elk and Riesel quadrangles which were mapped. The Wolfe City Member is a dark to light gray or brown sandy, silty marl with interbedded thin sandstone lenses from 0.1 inch to 1.5 feet thick (mostly ranging from 1 to 2 inches in thickness). The sandstone lenses are cemented with finely to coarsely crystalline calcite. On weathered exposures, the Wolfe City Member is light brown to buff with a greenish cast in some of the marls.

Description

The younger, overlying members of this formation crop out in eastern McLennan County and in the western portions of Limestone County. The Lower Taylor Marl has been eroded off in most of the area west of the alluvial valley of the Brazos River. It is now exposed chiefly in the area east of the Brazos River.

Generally the properties of the Wolfe City Member are similar to those of the lower marl. Whenever the two members differ in some specific property, the difference has been pointed out (see drainage properties for example). The presence of interbedded, thin, sandstone beds and lenses gives the Wolfe City Member a slightly better slope stability and bearing capacity than that of the lower marl. In some areas, the PVR in the Wolfe City Member may be low due to a high sand content, but in others it may be comparable to that of the lower marl due to its high content of bentonitic clays. On-site testing is, therefore, highly recommended to avoid later failures.

Description

Lithologic name. Shale and marl.

Color. Fresh: blue-gray. Weathered: buff-tan.

Bedding peculiarities. Fissile where the $CaCO_3$ cement is leached.

Megascopic description. Fresh: blue-gray, blocky. Surface: buff to tan, friable.

Mineralogic composition. Clay minerals, chiefly illite and montmorillonite (Beall, 1964, pp. 16-19) compose approximately 69 to 70 percent of the Lower Taylor Marl. Calcium carbonate cement and minor amounts of silt, calcite, pyrite, hematite, glauconite, and calcium phosphate compose the remaining 30 to 40 percent of the marl.

Microscopic character. Abundant megascopic and microscopic fossils.

BEARING CAPACITY

Description

Variable; usually intermediate to low.

Qualifications. Bearing capacity increases with depth because of increasing confining pressure and natural clay stabilization below the weathered soil zone.

Bearing capacity in tons/ft^2. 3.5 tons/ft^2 at a depth of 10 to 15 feet; 15 tons/ft^2 at a depth of 40 to 50 feet.

Shearing Strength

Low. A remolded specimen tested at 0 pounds of lateral pressure revealed a shearing strength of 3.79 lbs./in^2. At 15 lbs. of lateral pressure the same material recorded a shearing strength of 29.15 lbs./in^2.

Potential Swell

Very high. The potential vertical rise usually reaches 8 to 12 inches.

Problems Related to Bearing Capacity

Values of bearing capacity can vary widely at a single construction site. Testing is required at each site.

Corrective Measures in Foundation Design

For protection against damage from swelling clays, the following measures should be taken: 1) Sealing of the ground from moisture fluctuation; 2) excavation and back fill with non-swelling material; 3) deep footings extending to the unweathered zone and below the zone of moisture penetration; 4) isolation of curtain walls and veneers from ground surface; 5) the use of particularly heavy beams and foundations.

SLOPE STABILITY

Description

Low.

Qualifications. Fails when wet in slopes less than 10°. Excavations require continuous shoring.

Maximum Natural Stable Slope Angle

Ten degrees. Throughout the outcrop area of the Lower Taylor Marl (in the East Waco quadrangle), northwest-facing slopes are usually steeper than southeast-facing slopes. This is probably due to climatic conditions and differential erosion. This relation also holds true in those areas where the marl crops out immediately adjacent to Waco (including the Elm Mott, Robinson, Axtell, Elk, and Riesel quadrangles. Northwest-facing slopes are usually 2 to 4 degrees steeper than southeast-facing slopes.

Slope Retention in Excavations

Usually low. When adequately compacted and stabilized, the Taylor Marl will support low embankments and reasonably heavy loads.

Shallow (less than 6 feet). During dry periods, the material may stand near vertical, but minor slumping can occur. If the excavation is to remain open for a long period of time, wall supports should be provided or slopes (not more than 10°) maintained. The size of the excavation may be a critical factor regarding wall supports. If excavations are dug beside previously existing structures, sheeting or bracing should be employed to maintain vertical faces. Shoring is necessary to support the existing structures.

Deep (more than 6 feet). If the excavation must remain open for a relatively long period of time, slopes should be stabilized. Depending on the size and character of the excavation, wall supports or gentle slopes (about 3½ : 1) should be kept. During wet periods danger of slumping in excavations is imminent. Sealing against moisture penetration is advisable.

Maintenance of Artificial Slopes

1. Retaining walls.
2. Proper compaction and stabilization.
3. Maintenance of gentle slopes (not more than 10°).

Causes of Slope Failure

1. Oversteepening of natural slopes.
2. High moisture content.

EXCAVATION PROPERTIES

Description

Easy. Readily excavated by light machinery.

Qualifications. Easily evacuated, but excavations require continuous shoring.

Nature of Excavated Material

Unweathered material is generally blocky, contrasting with the friable, weathered material. The blue-gray, unweathered Taylor Marl weathers buff to tan.

Excavation Design Problems

Slope retention. Low; the Taylor Marl fails when wet in slopes less than 10°. Adequately compacted and stabilized, it will support low embankments and reasonably heavy loads.

Drainage. The low permeability of the formation and the high proportion of bentonitic clays cause the marl to swell on wet surfaces, thus resisting further fluid infiltration.

Disposal of material. Sewage disposal requires large drainage fields. When the drainage field becomes saturated (generally during rainy weather) sewage will find its way to the surface.

Causes of Excavation Problems

Steep slopes cause failures, especially in the loosely compacted Taylor Marl fill. This fill is highly plastic, and when wet it will slump on very low angles. Footings are required to extend into the unweathered marl to avoid foundation failures. Excavations for footings and piers should be filled quickly, since bentonitic clay beds in the marl can be altered rapidly through exposure to water and air.

NATURE OF MATERIAL WHEN USED AS FILL

Description

Usually unstable.

Qualifications. When wet or oversteepened, the material fails readily. Proper compaction and stabilization minimizes the problem.

Slope Stability of Compacted Fill

During periods of high saturation (during rainy weather), the material fails readily in slopes less than 10°.

Permeability

Intermediate or moderately permeable when dry; impermeable when wet.

Erosion Properties

Easily eroded.

Problems in Use as Fill

1. Low support strength.
2. High Potential Vertical Rise.
3. Even when the clays are effectively sealed, during periods of high saturation (wet periods), the waste water introduced into the marl promptly rises to the surface to become surface pollution.

Corrective Measures

1. Sealing against moisture penetration.
2. Proper stabilization of slopes when they must support loads or maintain steep slopes.

DRAINAGE PROPERTIES

Infiltration Capacity

Low.

Qualifications. Impermeable when wet. Moderately permeable when dry.

Nature of Permeability

Taylor clays and soils are moderately permeable when dry; during wet periods they become saturated and impermeable. This low permeability of Taylor clays and soils facilitates the storage of surface water. Effective surface storage ponds can be constructed and maintained along the Lower Taylor Marl outcrop.

Problems Encountered in Infiltration Drainage

The Taylor Marl, because of its low permeability and high content of bentonitic clays, tends to swell and seal when wet, thereby resisting further fluid infiltration. Because of this fact, sewage disposal requires large drainage fields. During periods of high saturation the sewage may find its way to the surface. In areas of high population density, where septic systems are in use, the Taylor soils will tend to become contaminated during periods of high saturation.

Free Water

Moderate to none.

Nature of Occurrence of Free Water

The Wolfe City Sand Member of the Taylor Formation, which crops out in the eastern part of McLennan County, yields moderate amounts of potable water at shallow depths. The Lower Taylor Marl yields no potable water within the studied region.

Quality. No potable water is present in the Lower Taylor Marl. Some potable water can be found at shallow depths in the Wolfe City Sand Member in the eastern part of McLennan County.

Problems Involving Free Water

In those areas where terrace gravels overlie the Taylor Marl, water from the terraces may cause foundation and excavation problems. This can result in failure of slopes and swelling of the Taylor clays. Where terrace gravels are several feet thick, below the footings of a foundation, the swelling in the Taylor clays is generally absorbed in the sands and gravels of the terraces.

SOIL PARAMETERS

Soils Developed on This Unit

Among the soils developing on this unit are those belonging to the Houston series and the Sumter clay.

Relation of These Soils to Slope

Soils in the Houston series are similar to those in the Houston Black series, but are less dark, generally darkened to less depth, and more sloping and susceptible to erosion. Sumter series soils: about ¾ strongly sloping and ¼ moderately sloping.

Soil Parameters by Soil Name

Houston series. (Calcareous clay soils of the Blackland Prairie; it will be grouped into two depths for engineering purposes.)

1. 0 to 1 ft.: LL=44, PI=24.5, SL=12.5, LS=15.5, SR=1.87, PVR=2.33 inches, Dmc=18.5%, Dfc=100 lbs./ft^3, Avs=6.5%.
2. 1 to 4 ft.: LL=65.1, PI=42.5. SL=12.3, LS=21.0, SR=1.93, PVR=2.33 inches, Dmc=25%, Dfc=95 lbs./ft^3, Avs=14%.

Sumter series. (Calcareous, characteristically found on the Taylor Marl. The shallow soil has almost developed to a Houston soil in most areas.) LL=77.8, PI=55.9, SL=12, LS=23.9, SR=1.93, PVR=1.73 inches.

SHEARING STRENGTH

Houston Series.

1. 0 to 1 ft.

T.B.L.P.	U.C.S.(lbs./in²)
at 3 lbs.	18.4
at 5 lbs.	24.1
at 10 lbs.	31.3
at 15 lbs.	36.9

2. 1 to 4 ft.

T.B.L.P.	U.C.S.(lbs./in²)
at 3 lbs.	11.9
at 5 lbs.	14.5
at 10 lbs.	19.5
at 15 lbs.	27.8

Sumter series. No triaxial data available.

PROBLEMS WITH SOILS ON THIS UNIT

1. High swelling of the clays.
2. Soil becomes sticky and difficult to manage when wet.

CORRECTIVE MEASURES

Foundations should extend, if possible, into the unweathered marl.

ECONOMIC ASPECTS

HORTICULTURAL VALUES

Good farm soils.

VALUE AS MATERIAL

Descriptive. Montmorillonitic, illitic, bentonitic clays may contain some marginal economic ceramic clays.

As aquifer. Only the Wolfe City Member, which crops out in the eastern part of the county yields some potable water at shallow depths.

As disposal site. Inadequate for disposal, even in periods of moderate saturation. In periods of high saturation sewage may find its way to the surface.

Present use. None.

Potential values. May contain some marginal, economic ceramic clays.

AUSTIN CHALK (Kau)

THICKNESS

120 feet.

LOCALITY WHERE MEASURED

Lovers' Leap, Cameron Park, Waco.

DISTRIBUTION (LOCAL)

Topographic expression. The Austin Chalk crops out in a belt four to five miles wide from Sherman south to San Antonio and then westward. The formation thins southward through the Waco area. It is exposed along the crest and slopes of the Bosque Escarpment in West Waco.

DESCRIPTION

The Austin Chalk is composed of alternating beds of white chalk and blue-gray marl. Each individual bentonitic marl zone occurs approximately 50 feet above the base of the formation.

Lithologic name. Chalk and alternating marl beds.

Color. Chalk. Fresh: blue-gray. Weathered: buff to white.

Bedding peculiarities. Alternating beds of chalk and marl.

Mineralogic composition. The chalk beds within the formation contain about 85 percent $CaCO_3$, including microcrystalline calcite, as well as aluminum and magnesium mostly in the form of clay minerals.

Microscopic character. The layers of blue-gray marls contain less $CaCO_3$ and have higher clay mineral content than the chalk beds. Pyrite nodules are common in surface sections. Pelecypods and foraminifers are abundant within the formation.

BEARING CAPACITY

DESCRIPTION

High.

Qualifications. The support strength of the Austin Chalk varies from 14 to 25 tons/ft² in those areas where chalk and marl beds crop out. Support strength, especially on the few thin, clay-rich zones in the lower 50 feet of the formation may be much lower on the outcrop site.

BEARING CAPACITY

Fourteen to 25 tons/ft². In those areas or places where the Austin Chalk is just a few feet thick (especially along the scarp north and west of the city of Waco), the bearing capacity of the limestone may appear to be high, but it may be too thin to support the proposed loads.

SHEARING STRENGTH

High. Bearing capacity is higher in those areas where clay content is low, and lower in those areas where it is high. At zero pounds lateral pressure, the Austin Chalk showed a shearing strength of 9.75 lbs./in². At 15 pounds lateral pressure it averaged a shearing strength of 109.5 lbs./in².

POTENTIAL SWELL

The PVR in chalk beds is usually very low and causes no great problems. The potential swell of marl beds within the formation and of thick soils developed on it may be much higher and cause foundation problems.

PROBLEMS RELATED TO BEARING CAPACITY

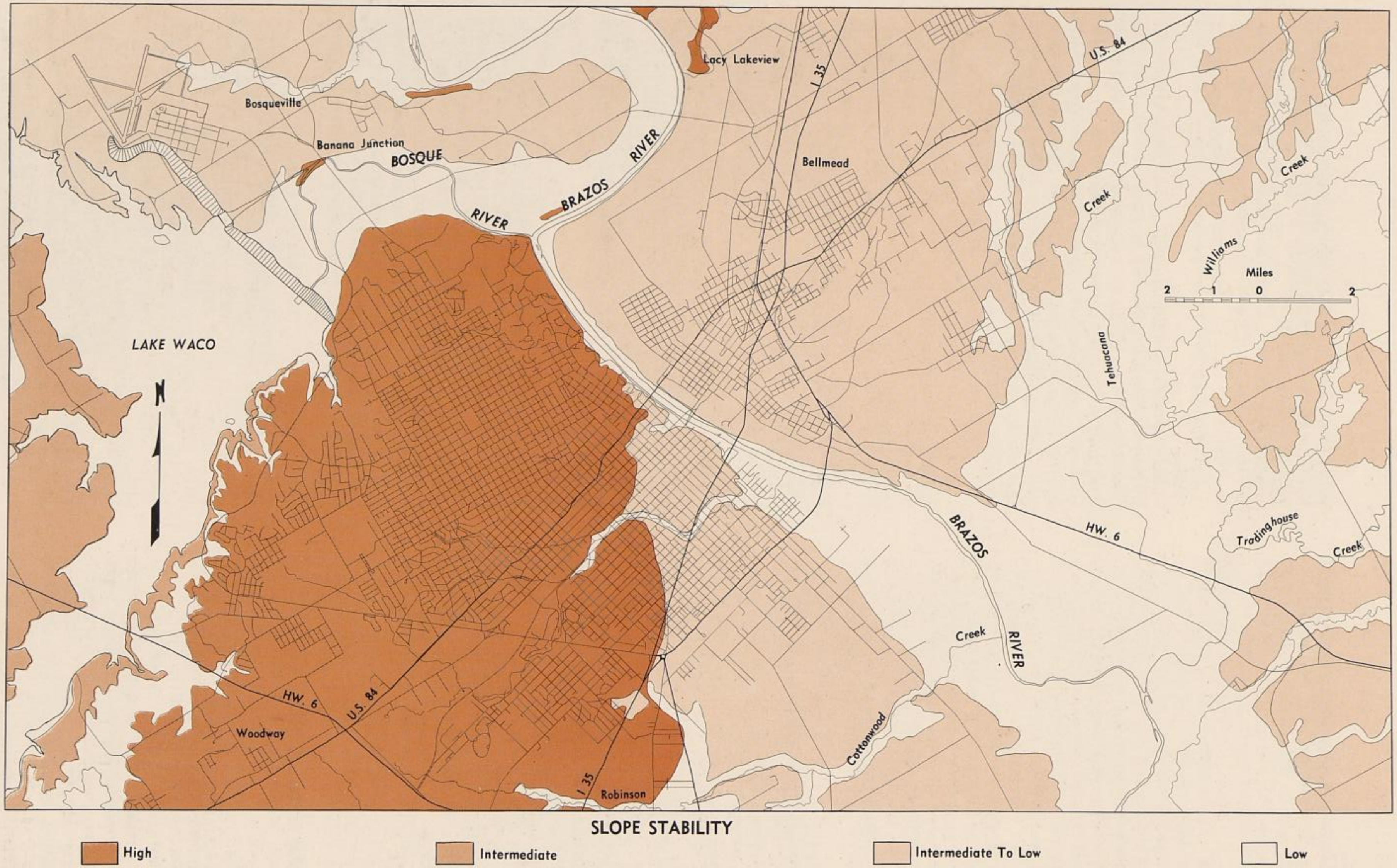
The bearing capacity of the Austin Chalk is generally high. Where the formation is thin, the bearing capacity of the limestones may seem high, but the bed may be too thin to support the proposed loads. In those areas where the South Bosque Shale is exposed beneath the Austin Chalk, the chalk may fail because of slope failure of oversteepened shale slopes.

CORRECTIVE MEASURES IN FOUNDATION DESIGN

The Austin Chalk normally presents no foundation problems. Most failures occur in those areas where the foundations rest on soil rather than on bedrock.

RECOMMENDATIONS

1. Foundations should extend to bedrock.
2. Thin soil coverings should be removed at the foundation site.



Low slope stability characterizes earth materials in which excavations require continuous shoring. These materials when saturated may fail in slopes less than 10°. When wet, or when natural slopes are oversteepened slope failure is imminent.

Low slope stability exists mainly in alluvial deposits; in the Lower Taylor Marl and bentonitic portions of the Wolfe City Sand; in some Brazos terrace deposits; in the upper 30 to 50 feet of the South Bosque Shale; in the Pepper Shale; in the middle, noncalcareous portion of the Del Rio Clay; and in clayey sections and shale members of the Georgetown Formation.

Intermediate slope stability is typical of earth materials which can normally support slopes greater than 10°, and less than 45° without shoring. Low vertical embankments may be supported, at least temporarily, in these materials.

Intermediate slope stability exists mainly in the Brazos and Bosque terrace deposits; in the Wolfe City Sand; in the lower portion of the South Bosque Shale; in the Lake Waco Formation; and in the upper and lower portions of the Del Rio Clay.

High slope stability characterizes earth materials which can support slopes greater than 45° without shoring. Usually, vertical slopes can be maintained in shallow and deep excavations without the need of artificial supports.

High slope stabilty exists in the Austin Chalk; in thick sections of the Buda Limestone; and in the Georgetown Limestone.

This map applies only to materials below soil zone.

Fig. 3. Slope stability of formations, Waco area.

3. In areas of thick soil accumulation all foundations should extend to bedrock either by deep excavations or by the use of piers.

4. Testing at particular sites is necessary for large structures.

SLOPE STABILITY

Description

High.

Qualifications. This material can support slopes greater than 45° without shoring. Shoring is necessary near the basal contact.

Maximum Natural Stable Slope Angle

North and northwest-facing slopes (mainly those along the Bosque Escarpment) are generally much steeper than the natural southeast-facing slopes developed on the outcrop area of the Austin Chalk. This slope configuration is largely fault controlled. Nevertheless, for engineering purposes, the Austin Chalk may be considered to have high slope stability, capable of maintaining vertical faces without any need of artificial support.

Slope Retention in Excavations

Very high.

Shallow (less than 6 feet). The Austin Chalk supports steep slopes without shoring. Slope retention in deep and shallow excavations is very high in this formation; the material can easily stand vertically without the need of artificial supports. Excavations dug near the basal contact of the Austin Chalk with the South Bosque Shale should be undertaken with caution. Failure of this shale will remove support from under the Austin Chalk and cause it to fail.

Maintenance of Artificial Slopes

The nature of the Austin Chalk insures the maintenance of steep slopes without support. Shoring is necessary near the basal contact.

Causes of Slope Failure

The Austin Chalk usually fails near the basal contact with the underlying South Bosque Shale. This shale will fail during periods of high saturation or when the natural slopes are disturbed. When wet, the shale will fail in slopes less than 10°. Failure of the shale removes support from the overlying Austin Chalk which will then slump in large blocks.

EXCAVATION PROPERTIES

Description

Difficult.

Qualifications. The Austin Chalk is the most resistant formation in the immediate Waco area. Excavation is difficult, but the friable nature of the chalk permits excavation by mechanical means. Weakness along joint and fault planes permits easier excavation by blade or ripper when the direction of force is applied at right angles to the dominant north-south fracture system.

Nature of Excavated Material

Friable.

Excavation Design Problems

Slope retention. High. Excavation openings in the Austin Chalk do not require internal support.

Drainage. Adequate. Drains excavated in chalk beds and properly bedded with gravels normally dispose of moderate amounts of fluid.

Disposal of material. Drainage fields of adequate proportions can be installed on lots of 100-125 feet for private homes. Effective drainage can be attained during periods of high saturation if drainage fields are located in valleys or scarp faces. Drainage fields extending into thicker marl beds encounter problems similar to those encountered in the Taylor Marl.

Causes of Excavation Problems

The superior resistance of the chalk beds within the formation makes excavation difficult. Excavation by mechanical means is suitable in this formation. Fault and joint systems in the formation serve as mechanical wave guides conducting seismic energy for great distances. Foundation damage can occur to structures parallel to the fracture system at considerable distances away from blasting sites. Little or no damage occurs to nearby structures at right angles to the fracture system. The tendency of weathered marls within the Austin Chalk to spall causes banks to slump or cave after prolonged exposure.

Recommendations

1. Structures and foundations should be constructed at right angles to the fracture alinements.

2. Exposed banks in marl beds within the formation should be sloped or capped by a properly anchored surface seal.

NATURE OF MATERIAL WHEN USED AS FILL

Description

Excellent.

Qualifications. Chalk beds in the Austin Chalk make excellent fill material. Marl beds within the formation have a high PVR and should, therefore, be avoided.

Slope Stability of Compacted Fill

Very high.

Permeability

Moderate. Fractures such as faults and joints offer planes through which water that percolates into the formation can travel freely.

Erosion Properties

Fairly resistant to erosion.

Problems in Use as Fill

The fill should be sealed against infiltration, since water tends to decompose the chalk. Settlement of the foundation will occur if free water percolates through the fill.

DRAINAGE PROPERTIES

Infiltration Capacity

Moderate.

Qualifications. The Austin Chalk provides adequate sewage disposal, except in periods of prolonged saturation.

Nature of Permeability

Moderately permeable since it is highly fractured.

Problems Encountered in Infiltration Drainage

1. During periods of high saturation, the fracture system drainage capacity will generally decrease.

2. When saturated, the bentonitic clays of the marl tend to swell thereby sealing the drainage area and reducing infiltration.

FREE WATER

Moderate.

Qualifications. The Austin Chalk is highly fractured and jointed, and moderately permeable.

NATURE OF OCCURRENCE OF FREE WATER

Only a few wells within the formation produce small quantities of water for domestic use.

Quality. Most of the water produced from the formation is polluted.

PROBLEMS INVOLVING FREE WATER

Since great amounts of septic waste are released throughout the outcrop area of the Austin Chalk, most of the water in the formation is polluted.

SOIL PARAMETERS

SOILS DEVELOPED ON THIS UNIT

Austin series, Eddy series, Houston series, Houston Black series, Stephen series, Sumter series.

RELATION OF THESE SOILS TO SLOPE

Soils of the Austin and Eddy series usually develop on steeper slopes, while soils belonging to the Houston and Houston Black series develop in valleys or on very gentle slopes.

SOIL PARAMETERS BY SOIL NAME

Austin series. Highly calcareous, granular soils developed over chalk and marl. LL=68, PI=38, SL=12, LS=21, SR=1.84, PVR=0.11 to 1.27 inches, Dmc=25%, Dfc=93 lbs./ft^3, Avs=8%.

Eddy series. Highly calcareous, shallow soils. LL=43.2, PI=19.1, SL=15.9, LS=12.3, SR=1.77, PVR=0.03 to 0.07 inches, Dmc=16%, Dfc=108 lbs./ft^3, Avs=2.5%.

Houston Black series. Deep calcareous, "black waxy" soils of the Blackland Prairie. LL=62.3, PI=41.5, SL=28.4, LS=19.3, SR=1.86, PVR=2.92 inches, Dmc=24%, Dfc=92 lbs/ft^3, Avs=6.8 to 10%.

Houston series. Calcareous soils of the Blackland Prairie. For engineering purposes they will be grouped into two depths.

1. 0 to 1 ft.: LL=44, PI=24.5, SL=12.5, LS=15.5, SR=1.87, PVR=2.33 inches, Dmc=18.5%, Dfc=100 lbs./ft^3, Avs=6.5%.

2. 1 to 4 ft.: LL=65.1, PI=42.5, SL=11.3, LS=21.0, SR=1.93, PVR=2.33 inches, Dmc=25%, Dfc=95 lbs./ft^3, Avs=14%.

Sumter series. Calcareous, shallow soils; have almost developed to a Houston soil. LL=77.8, PI=55.9, SL=12, LS=23.9, SR=1.93, PVR=1.73 inches.

SHEARING STRENGTH

Austin series.

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	8.1
at 5 lbs.	21.6
at 10 lbs.	28.2
at 15 lbs.	34.2

Eddie series.

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	43.3
at 5 lbs.	51.9
at 10 lbs.	63.9
at 15 lbs.	69.4

Houston Black series.

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	16.6
at 5 lbs.	18.6
at 10 lbs.	28.7
at 15 lbs.	33.4

Sumter series. No triaxial data available.

Houston series.

1. 0 to 1 ft.

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	18.4
at 5 lbs.	24.1
at 10 lbs.	31.3
at 15 lbs.	36.9

2. 1 to 4 ft.

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	11.9
at 5 lbs.	14.5
at 10 lbs.	19.5
at 15 lbs.	27.8

PROBLEMS WITH SOILS ON THIS UNIT

Austin soils are very plastic. They also exhibit high shrink-swell ratios.

CORRECTIVE MEASURES

Where soil layers are thin, they should be completely removed for foundation construction. In areas where thick soil accumulations are present, foundations should extend down to bedrock either with deep excavations or by the use of piers.

ECONOMIC ASPECTS

VALUE AS MATERIAL

Excellent material for cement production.

Description. Chalk beds with alternating marl beds.

As aquifer. Poor. Some potable water occurs in the formation in small amounts. The great areal extent of the formation, together with the great amount of the water produced from the formation, insures that it will be highly polluted.

As disposal site. Considerable amounts of septic waste can be discharged into the formation. Adequate drainage fields can be installed on a 100-125 feet lot for private residences.

Present use. 1) Raw material for cement; 2) furnishes some low sub-base material for roads and streets.

Potential values. Because of high content of $CaCO_3$ it could be used as fertilizer.

SOUTH BOSQUE SHALE (Ksb)

THICKNESS

160 feet.

LOCALITY WHERE MEASURED

At the J. L. Myers & Sons No. 1 Tiery Well.

DISTRIBUTION (LOCAL)

Topographic expression. The South Bosque Shale is exposed along the Bosque Escarpment. It supports a belt of rolling hills below the Austin Chalk and above an intermediate topographic bench which has developed on the resistant upper flagstone of the Lake Waco Formation.

DESCRIPTION

Dark gray to black, blocky shale. Weathers blue-gray to tan. Bentonite seams are present, but they are less common than in the underlying Lake Waco Formation. The upper 30 to 50 feet of the South Bosque Shale are noncalcareous. Bentonitic shales and low carbonate content comprise the upper portion of the formation. The lower part of the formation is composed of calcareous shales, interbedded with silty limestone flags and bentonite seams.

Lithologic name. Shale—shaley marl.

Color. Fresh: dark gray to black. Weathered: blue-gray to tan.

Bedding. Black, homogenous shale with a few thin, buff to tan limestone flags near the base of the formation.

Megascopic description. Dark gray to black, blocky shale. Fresh: dark gray to black. Surface: blue-gray to tan.

Mineralogic composition. Pyrite, glauconite, $CaCO_3$, phosphatic nodules.

Microscopic character. Foraminifers.

Miscellaneous. Ammonites, fish teeth, vertebrates, foraminifers, pelecypods, shark teeth, phosphatic nodules, etc.

BEARING CAPACITY

DESCRIPTION

Intermediate to low. Varies with depth.

Qualifications. Values of bearing capacity increase with depth. Values range from 3.5 tons/ft^2 at 5 to 12 feet to 18 tons/ft^2 at 30 to 40 feet. Values may be as low as 2 tons/ft^2 near the surface.

BEARING CAPACITY

Two to 18 tons/ft^2 (also see values above).

SHEARING STRENGTH

Low.

POTENTIAL SWELL

High, particularly in the noncalcareous upper part of the formation. When testing for potential swell, one should consider the moisture conditions at the time of testing, additional weight which tends to counterbalance swell, and the depth of potential swelling material.

PROBLEMS RELATED TO BEARING CAPACITY

Failure of slopes and foundations.

CORRECTIVE MEASURES IN FOUNDATION DESIGN

1. Testing should be performed at each individual site.
2. Foundations should extend down into the unweathered shale by means of piers or footings.
3. The bases of piers and footings should be horizontal or slightly inclined away from the hill slope. Foundations of this type transfer loads to more massive sections of the formation.
4. Excavations for foundations and borings should be filled rapidly before allowing surface water to expand the bentonitic clays in the formation.

SLOPE STABILITY

DESCRIPTION

Unstable.

Qualifications. Slope stability of the South Bosque Shale is very low in the upper 40 feet and low in the lower 120 feet. Slope stability depends upon moisture content, height of slope, type of vegetation on slope, and weight added on top of the slope.

MAXIMUM NATURAL STABLE SLOPE ANGLE

Zero to 20 degrees. Normally, slopes remain stable at angles less than 10°. The South Bosque Shale crops out in the immediate Waco area, along the Bosque Escarpment. The slope stability of the shale depends upon many factors, some of which have been described above. The Bosque Escarpment, held and capped by the Austin Chalk, normally exhibits fairly steep slopes. If foundations are dug in the South Bosque Shale, particularly near the Austin Chalk, caution must be exercised, since the slope stability of this formation is considerably lower than that of the Austin Chalk. When wet, the shale will fail readily even on gentle slopes.

SLOPE RETENTION IN EXCAVATIONS

Low. The material fails readily when slopes are oversteepened. Excavation walls should be supported to prevent failure.

Shallow (less than 6 feet). Unsupported walls in excavations readily fail when wet or oversteepened. If excavations are small, the cost of removing slumped material may be less than the cost of wall supports. The South Bosque Shale can support "temporarily" almost vertical slopes in shallow excavations, provided that the builder is ready to control minor slumping. Vertical faces of excavations beside already existing structures must be supported by wall supports. Shoring is necessary to support the previously existing structure. During wet periods slumping is imminent. If the excavation is to remain open for a relatively long time, wall supports or gentle slopes should be kept. Sealing against moisture is advisable to prevent slump failure.

Deep (more than 6 feet). Deep excavations with unsupported walls may be quite hazardous. The methods employed to maintain artificial slopes in deep excavations will depend on the character of the excavation. In some instances, it may be more convenient to maintain gentle slopes (about 3½:1), but in others wall supports may be employed. In either case, it is advisable to seal the material from moisture infiltration to insure more stable slopes.

MAINTENANCE OF ARTIFICIAL SLOPES

Wall supports should be provided. Sealing against moisture is essential for oversteepened slopes which are exposed to climatic conditions.

CAUSES OF SLOPE FAILURE

Oversteepening of slopes, terracing, and high moisture content.

EXCAVATION PROPERTIES

DESCRIPTION

Easy.

Qualifications. Easily excavated with light equipment when dry. When the shale is wet, it becomes sticky due to its high content of clay minerals. Under these conditions the clay is difficult to manage.

NATURE OF EXCAVATED MATERIAL

South Bosque Shale can be classified as friable due to its fissility, although in a more general way it may be better classified as blocky. The unweathered shale is definitely blocky.

EXCAVATION DESIGN PROBLEMS

Slope retention. Natural slopes on the shale range from 0° to 20°. When wet the clay may fail in slopes less than 10°. Normally, slopes remain stable at angles less than 10°.

Drainage. The South Bosque Shale is highly impermeable. Swelling of the clays when wet retards drainage or infiltrataion in this material.

Disposal of material. Inadequate. Extremely large drainage fields are needed for effective septic disposal. When the clays are dry, they crack and fluff and provide temporarily adequate drainage. When wet, infiltration is vastly reduced by clay expansion.

CAUSES OF EXCAVATION PROBLEMS

Wet clays of the South Bosque Formation are sticky and hard to manage. Slope stability is low; slopes less than 10° generally remain stable. Factors controlling slope stability are: 1) moisture content of the clays, 2) height of slope, 3) type of vegetation on the slope, 4) weight added on top of the slope.

NATURE OF MATERIAL WHEN USED AS FILL

DESCRIPTION

Unstable.

Qualifications. The noncalcareous, bentonitic clays of the upper part of the formation are more highly plastic than the clays in the lower part of the formation. The unstable shales in the upper part of the formation should be compacted, stabilized, drained, and gentle slopes should be maintained to prevent slumping.

SLOPE STABILITY OF COMPACTED FILL

Low. When used as fill material, the South Bosque Shale should be stabilized with lime or other agents. Slope angles should be kept to a minimum. In order to obtain best results, compaction and moisture content should be controlled.

PERMEABILITY

Impermeable.

EROSION PROPERTIES

Erodes easily.

PROBLEMS IN USE AS FILL

The South Bosque Shale, when used as fill material, may be unstable due to the following conditions:

1. Improper drainage.
2. Cut and fill modifications.
3. Additional weight due to structures on top soil.
4. Saturation by watering.

DRAINAGE PROPERTIES

INFILTRATION CAPACITY

Low.

Qualifications. When the clays in the South Bosque Formation are dry, they crack and fluff, providing temporarily adequate drainage.

NATURE OF PERMEABILITY

The South Bosque Shale is impermeable. Water that percolates through the overlying Austin Chalk drains out on top of the underlying shale.

PROBLEMS ENCOUNTERED IN INFILTRATION DRAINAGE

1. Extremely large drainage fields are required to provide adequate sewage disposal.

2. Infiltration is greatly reduced by clay expansion during periods of high saturation. During wet periods, septic waste may find its way to the surface and contaminate South Bosque soils.

FREE WATER

None.

Qualifications. Impermeable.

NATURE OF OCCURRENCE OF FREE WATER

Since the material is usually tightly compacted it prevents the percolation of free water.

Quality. No water.

PROBLEMS INVOLVING FREE WATER

Swelling of the South Bosque Shale retards drainage or infiltration through the shale.

SOIL PARAMETERS

SOILS DEVELOPED ON THIS UNIT

Among the soils which develop on this unit are those of the Houston Black series, the Austin series and the Sumter series.

RELATION OF THESE SOILS TO SLOPE

Houston Black soils develop on sloping surfaces where surface drainage is very rapid.

SOIL PARAMETERS BY SOIL NAME

Houston Black series. LL=62.3, PI=41.5, SL=28.4, LS=19.3, SR=1.86, PVR=2.92, Dmc=24%, Dfc=94 lbs./ft^3, Avs=6.8 to 10%.

Austin series. LL=68, PI=38, SL=12, LS=21, SR=1.84, PVR=0.11 to 1.27, Dmc=25%, Dfc=93 lbs./ft^3, Avs=8%.

Sumter series. LL=77.8, PI=55.9, SL=12, LS=23.9, SR=1.93, PVR=1.73.

SHEARING STRENGTH

Low.

Houston Black series.

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	16.6
at 5 lbs.	18.6
at 10 lbs.	28.7
at 15 lbs.	33.4

Austin series.

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	8.1
at 5 lbs.	21.6
at 10 lbs.	28.2
at 15 lbs.	34.2

Sumter series. No triaxial data available.

PROBLEMS WITH SOILS ON THIS UNIT

Soils are highly plastic, have high shrink-swell ratios, and are severely corrosive.

CORRECTIVE MEASURES

In foundation construction, soils on the South Bosque Shale should be removed, and foundations should extend into the unweathered zone of the formation.

ECONOMIC ASPECTS

HORTICULTURAL VALUES

Good. Soils developed on this formation form rich agricultural lands.

VALUE AS MATERIAL

Excellent raw material for cement production and for expanded aggregate.

As aquifer. Poor; no free groundwater.

As disposal site. Poor.

Present use. Raw material for cement and expanded aggregate.

Potential values. May contain some marginal, economic, ceramic clays.

LAKE WACO FORMATION (Klw)

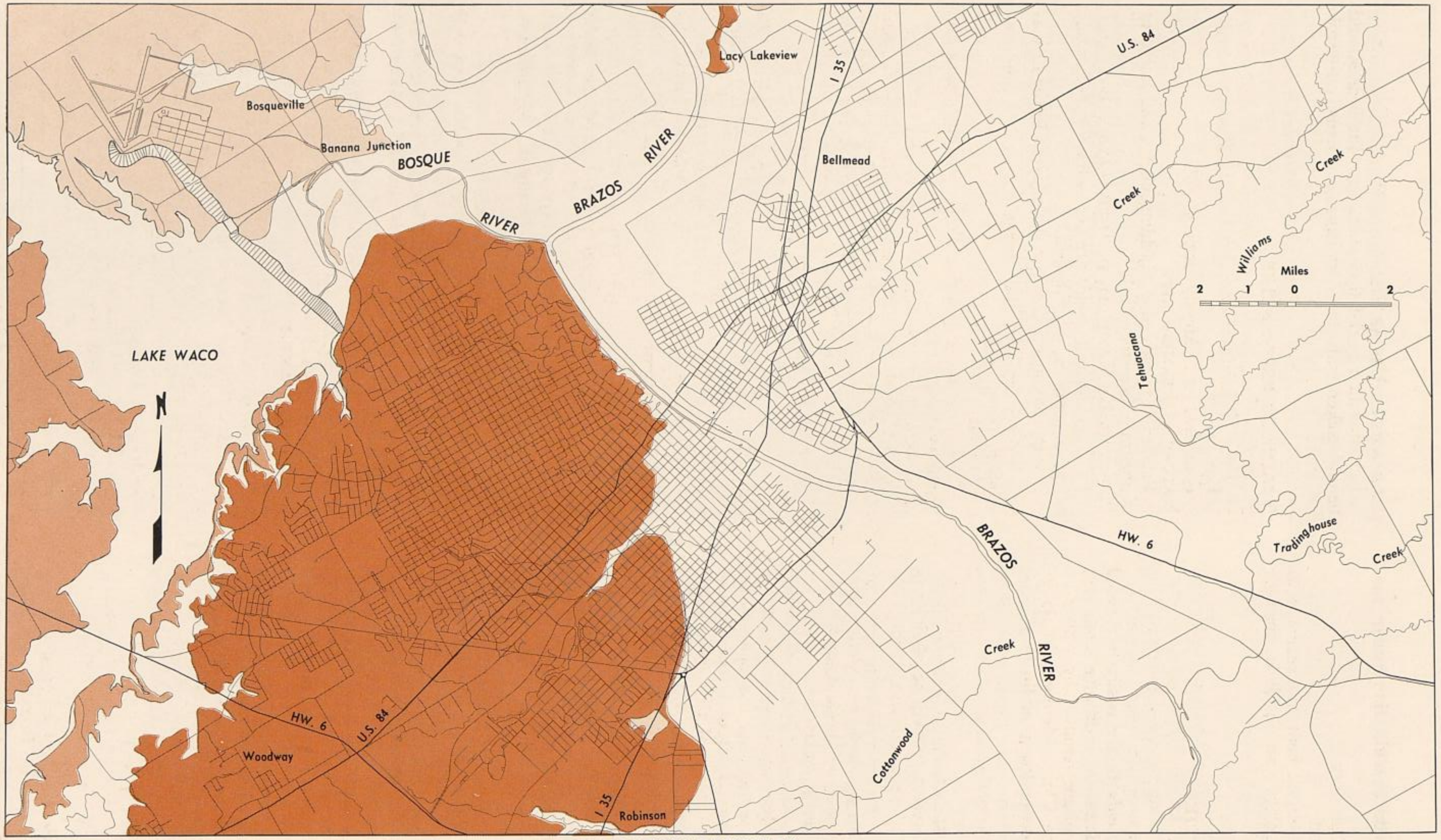
THICKNESS
80 feet.
LOCALITY WHERE MEASURED
Near Moody.
DISTRIBUTION (LOCAL)
Topographic expression. Crops out along the Bosque Escarpment from Lake Waco to Moody and in scattered outcrops northward along the Brazos River. This formation is more resistant to erosion than the overlying South Bosque Shale and, therefore, forms the "lower steps" of the Bosque Escarpment which are supported by thin limestone flags.
DESCRIPTION
This formation has been divided into three members which in descending order are: the Bouldin Member, the Cloice Member and the Bluebonnet Member (see descriptive paragraph below).
Lithographic name. Shale with shaley limestone flags.
Color. Fresh: dark blue-gray. Weathered: tan to buff.
Bedding. Fissile shales interbedded with thin (¼ inch to 1 foot) shaley limestone flags.
Megascopic description. Blocky, fissile shale. Fresh: dark blue-gray. Surface: buff to tan.
Mineralogic composition. The Bouldin and Bluebonnet members contain more than 50 percent $CaCO_3$. The Cloice Member is less calcareous. Other minerals in the formation are: $CaCO_3$, montmorillonite, "bentonites," quartz, and kaolinite.
Microscopic character. Microfauna and megafauna.
Miscellaneous. Beds of the Bouldin and other members are highly faulted.
Description. The Bouldin Member of the Lake Waco Formation is composed of calcareous, bentonitic shales interstratified with thin limestone flags. Bentonite beds are abundant in this member, some bentonite beds measure up to 10 inches in thickness. The contact between the South Bosque Shale and the Bouldin Member of the Lake Waco Formation is arbitrarily placed at the top of the highest bench-forming limestone bed. This member is approximately 14 feet thick in the Waco area. The Bouldin-Cloice contact is gradational and difficult to pin-point. The Cloice Member is highly bentonitic, calcareous, and contains fissile shale. Bentonite seams up to 14 inches in thickness have been reported. Although this member also contains a few limestone beds, they are less common than in the Bouldin and Bluebonnet members. The Cloice Member is approximately 35 feet thick in the Waco area. The Bluebonnet Member is composed mainly of fissile shale. Bentonite beds attain thicknesses of about 10 inches within this member. In the Waco area, the Bluebonnet Member rests unconformably on the highly plastic, noncalcareous Pepper Shale. Within the area, the Bluebonnet ranges from 6 to 12 feet in thickness.

BEARING CAPACITY

DESCRIPTION
Intermediate.
Qualifications. Bearing capacity increases with depth. Limestone beds in the Bouldin and Bluebonnet members have the highest foundation strength. These beds may fail when underlain by thick bentonite seams.
BEARING CAPACITY
Near the surface: 4.5 tons/ft^2. At about 30 feet in depth: 25 tons/ft^2.
SHEARING STRENGTH
Low in bentonitic clays, but high in limestone beds.
POTENTIAL SWELL
High.
PROBLEMS RELATED TO BEARING CAPACITY
Together the bentonitic clays and limestone beds in the formation may be misinterpreted as being suitable for construction. Testing at each particular site is recommended before construction.
CORRECTIVE MEASURES IN FOUNDATION DESIGN
1. Pier support is required for heavy structures.
2. Proper drainage and surface sealing will minimize swelling of the clays.

SLOPE STABILITY

DESCRIPTION
Moderate to low.
Qualifications. Moderate in more calcareous Bouldin and Bluebonnet members; low in the less calcareous Cloice Member.
MAXIMUM NATURAL STABLE SLOPE ANGLE
Forty degrees (40°). Stable slopes are primarily due to the thin, resistant, limestone beds in the formation. The Lake Waco Formation crops out in the immediate Waco area in a narrow band extending along the Bosque Escarpment. This formation forms the "lower steps" of the escarpment and its slope stability is greater than that of the overlying South Bosque Shale and less than that of the Austin Chalk. Slopes having as much as 40° angles appear to be stable in the field. Since the middle member of the formation is less suitable for foundation support than the other two members, testing and analysis of the material should be performed at each site.
SLOPE RETENTION IN EXCAVATIONS
Moderate to low.
Shallow (less than 6 feet). Vertical faces may be maintained for short periods of time during dry seasons. During wet seasons or when the moisture content of the formation is high, failure can occur.
Deep (more than 6 feet). Deep excavations should be sloped well back from the vertical. Heavy retaining structures should be employed to maintain steep faces. Slumping in such excavations may be quite hazardous. The slope stability in deep and shallow excavations in the Lake Waco Formation is somewhat similar to that in the South Bosque Shale, but the presence of numerous limestone flags throughout the formation insures more stable slopes. Depending upon the character of the excavation, sheeting or bracing and/or gentle slopes should be maintained. Excavations should be sealed as quickly as possible and the material should be protected against moisture infiltration. The great abundance of bentonite seams in the Lake Waco Formation insures high potential swelling.
MAINTENANCE OF ARTIFICIAL SLOPES
1. Support of steep faces by heavy retaining structures.



"Easy excavation" applies to those areas where material can be excavated by relatively light machinery, such as back-hoe and shovel, draglines, front-end loaders, etc.

Easy excavation exists mainly in alluvial and Brazos terrace deposits, in the Wolfe City Sand and Lower Taylor Marl, and in the South Bosque and Pepper shales.

Moderate excavation difficulty applies to those areas where resistant beds are interstratified with soft shales and clays, and where cementation of terrace gravels has resulted in the formation of hard, durable conglomerates. Generally, hard beds can be broken and removed by tractor-ripper operations, without the necessity of prior breaking. Blasting or mechanical breaking may be necessary before removing hard beds by back-hoe and shovel operation.

Moderate excavation difficulty exists in Bosque terrace deposits, as well as in the Lake Waco and Del Rio formations. Excavation difficulty should be easier in the middle (Cloice) member of the Lake Waco Formation than in the upper and lower members (Bouldin and Bluebonnet respectively).

Difficult excavation exists primarily in those areas where massive limestone sections are found. Air hammers, ripper or blade, and/or blasting may be necessary to break the material.

Difficult excavation will be encountered along the outcrop areas of the Austin Chalk, Buda Limestone, and Georgetown Limestone.

This map applies only to materials below the weathered and soil zones.

Fig. 4. Excavation difficulty in formations, Waco area.

2. Sealing against moisture with appropriate materials.
3. Maintenance of gentle slopes.

Causes of Slope Failure

During wet periods swelling of bentonite seams, bentonitic clays, and plastic clays can result in massive failure.

EXCAVATION PROPERTIES

Description

Moderately easy.

Qualifications. The shale beds are easily excavated with light machinery. Limestone beds offer some resistance, but fractures facilitate removal by ripper or blade. Excavations in the Cloice Member should be somewhat easier than those in the Bouldin and Bluebonnet members.

Nature of Excavated Material

Blocky.

Excavation Design Problems

Slope retention. Low. Steep faces will be retained in dry weather, but slump failure is common after hard rains.

Drainage. Poor. Infiltration will be retarded by impermeable bentonite seams, bentonitic clays, and dense limestone beds. Large drainage fields are required for sewage disposal. During periods of high saturation sewage disposal will probably always be inadequate.

Disposal of material. The fact that the Lake Waco Formation is exposed along the face of the Bosque Escarpment will insure that much of the septic waste fluid within the formation will reach the surface and find its way into Lake Waco.

Causes of Excavation Problems

1) Dense, hard limestone flags interbedded with the shales will offer some resistance; 2) slump failures.

Recommendations

1. Excavations through the limestone flags may be facilitated by the use of ripper and blade along the fracture lines in the limestone.
2. Since slump failures occur often during wet seasons, or when the moisture content of the formation is high, gentle slopes should be maintained in most excavations (especially deep ones) and heavy retaining structures should be used to maintain steep slopes.

NATURE OF MATERIAL WHEN USED AS FILL

Description

Poor (unstable).

Qualifications. Bentonitic clays should be stabilized by the use of lime, or other suitable type of stabilizing agent. Limestone beds throughout the formation help the clays in overall strength.

Slope Stability of Compacted Fill

Moderate.

Permeability

Generally impermeable. Permeability increases along bedding planes and fractures of limestone beds.

Erosion Properties

Limestone beds are fairly resistant to erosion while shale beds are eroded easily. The Bouldin and Bluebonnet members are affected by erosion to a lesser extent than the Cloice Member.

Problems in Use as Fill

Recompaction of the shale and limestone beds should be undertaken with closed moisture and density control.

DRAINAGE PROPERTIES

Infiltration Capacity

Low.

Qualifications. Mostly impermeable.

Nature of Permeability

Permeability only along bedding planes and fractures of the thin limestone beds.

Problems Encountered in Infiltration Drainage

1. Large drainage fields are necessary for moderately adequate septic sewage disposal.
2. Tight compaction of the shale layers in the formation tends to prevent infiltration.

Free Water

Moderate.

Qualifications. Permeable along bedding planes and fractures.

Nature of Occurrence of Free Water

In the northern and western part of McLennan County the Lake Waco Formation yields some potable water in small amounts. The water is produced by seepage near the thin limestone flags.

Quality. Potable water in "very small" amounts.

Problems Involving Free Water

Water seepage makes the outcrop area dangerous for construction purposes. The clays continuously shrink and swell making stabilization difficult.

SOIL PARAMETERS

Soils Developed on This Unit

Houston series: Developed from marl and calcareous clays.

Relation of These Soils to Slope

Soils of the Houston series usually develop in topographically low places.

Soil Parameters by Soil Name

Houston series. For engineering purposes, soils will be divided into two depths.

1. 0 to 1 ft. deep: LL=44, PI=24.5, LS=15.5, SL =12.5, SR=1.87, PVR=2.33, Dmc=18.5%, Dfc=100 lbs./ft^3, Avs=14%.
2. 1 to 4 ft. deep: LL=65.1, PI=42.5, LS=21.0, SL=11.3, SR=1.93, PVR=2.33, Dmc=25%, Dfc =95 lbs./ft^3, Avs=14%.

Shearing Strength

Moderate.

Houston series.

1. 0 to 1 ft.

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	18.4
at 5 lbs.	24.1
at 10 lbs.	31.3
at 15 lbs.	36.9

2. 1 to 4 ft.

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	11.9
at 5 lbs.	14.5
at 10 lbs.	19.5
at 15 lbs.	27.8

PROBLEMS WITH SOILS ON THIS UNIT

Highly plastic soils with high potential swell.

CORRECTIVE MEASURES

Soils should be completely removed for foundation construction. Piers or deep footings should be used where soils are too deep for removal. These piers or footings should extend into the unweathered zone of the formation and should rest, if possible, on the best sections of the Lake Waco Formation.

ECONOMIC ASPECTS

HORTICULTURAL VALUES

Productive. Well suited as cropland.

VALUE AS MATERIAL

Description. Shales and bentonitic clays with interbedded limestone beds and bentonitic seams.

As aquifer. Poor; permeable only along bedding planes and fractures.

As disposal site. Poor; large drainage fields are required, and during wet seasons septic sewage disposal is inadequate.

Present use. None at present.

Potential values. Bentonites and ceramic clays.

PEPPER SHALE (Kpe)

THICKNESS

60-70 feet.

LOCALITY WHERE MEASURED

Subsurface under the Waco area. At the J. L. Myers & Sons Tiery Well No. 1.

DISTRIBUTION (LOCAL)

Topographic expression. The Pepper Shale crops out at the base of the Bosque Escarpment, east of the South Bosque River, and southwest of Waco. It also crops out in a narrow band north of Waco in the Gholson quadrangle.

DESCRIPTION

Noncalcareous, black, dense, pyrite-rich shale. Crystals of selenite and yellow jarosite are common in the weathered shale.

Lithologic name. Shale.

Color. Fresh: dark black. Weathered: light gray.

Bedding pecularities. None.

Megascopic description. Fresh: black. Weathered: gray.

Mineralogic composition. 20 percent montmorillonite, 20-25 percent illite, 20-25 percent kaolinite, 10-15 percent quartz, and 20-25 percent amorphous material. Also siderite and pyrite.

Microscopic character. Few foraminifers.

Miscellaneous. Foraminifers, ammonites, thick shelled pelecypods. In north-central McLennan County, the Pepper Shale is cut by numerous sandstone dikes. South of Waco it is cut by an igneous dike.

Description. Noncalcareous, dense, black shale that weathers light gray. On weathered surfaces, jarosite and selenite crystals are common.

BEARING CAPACITY

DESCRIPTION

Low.

Qualifications. Varies with depth and moisture content.

BEARING CAPACITY

1.5 tons/ft^2 near the surface; 8 tons/ft^2 at about 25 feet in depth.

SHEARING STRENGTH

Low; fails under its own weight when wet.

POTENTIAL SWELL

High; PVR commonly=10 to 14 inches.

PROBLEMS RELATED TO BEARING CAPACITY

The bearing capacity of the Pepper Shale is so low that it commonly fails under its own weight, especially when wet.

CORRECTIVE MEASURES IN FOUNDATION DESIGN

1. Foundations should extend well into the unweathered surface. If possible, they should go through the Pepper Shale into the more stable Del Rio Clay.
2. Thorough compaction and stabilization with lime or other stabilizing agents will increase the safety factor in construction on this material.
3. Deep piers of flotation support should be employed in foundation construction.
4. Flexible paving should be employed in highway construction. The shale should be compacted and stabilized. Well-drained base material should be provided.

SLOPE STABILITY

DESCRIPTION

Very unstable.

Qualifications. Fails when wet or oversteepened.

MAXIMUM NATURAL STABLE SLOPE ANGLE

Ten percent ($<6°$). The Pepper Shale crops out along the base of the Bosque Escarpment, as well as east of the South Bosque River, southwest of Waco and north of Waco. The geologic nature of the Pepper Shale insures low slope stability, bearing capacity, and shearing strength. Natural stable slopes in the field do not exceed 10°. This material fails readily when wet even at very low angles and when oversteepened. Slopes in this material should never exceed 10°, unless they are adequately supported.

SLOPE RETENTION IN EXCAVATIONS

Requires continuous shoring and/or gentle slopes. Exposed surfaces should be sealed against moisture penetration with impervious material.

Shallow (less than 6 feet). Low. The slope stability of the Pepper Shale in deep and shallow excavations depends primarily on the moisture content of the material and on the steepness of its slopes. Either gentle slopes (usually less than 3¼:1), sheeting, or bracing should be employed to avoid slumping. Shoring is usually necessary in this material. The exposed shale should be sealed against any further moisture penetration.

MAINTENANCE OF ARTIFICIAL SLOPES

1. Maintenance of gentle slopes (less than 10° or 3¼:1).
2. Controlled compaction and stabilization of the shale.

3. Adequate drainage.

Causes of Slope Failure

1. Over steepening.
2. High moisture content.

EXCAVATION PROPERTIES

Description

Easy.

Qualification. Easily excavated in the dry state, but difficult to work when wet.

Nature of Excavated Material

Shaley.

Excavation Design Problems

Slope retention. Gentle slopes are a *must* to insure slope stability.

Drainage. Poor—impermeable material.

Disposal of material. Septic sewage disposal is highly impractical.

Causes of Excavation Problems

1. Steep slopes.
2. High moisture content.
3. Exposure to weathering.

NATURE OF MATERIAL WHEN USED AS FILL

Description

Poor (unstable).

Qualifications. If the shale is properly stabilized with lime or other kind of stabilizing agents, it will support greater loads.

Slope Stability of Compacted Fill

Low.

Permeability

Impermeable.

Erosion Properties

Erodes easily.

Problems in Use as Fill

The small clay particles are layered in such a way that each of them acts as a lubricated sliding surface.

DRAINAGE PROPERTIES

Infiltration Capacity

Low.

Qualifications. Impermeable material.

Nature of Permeability

Impermeable.

Problems Encountered in Infiltration Drainage

Septic tanks are useless in this material.

Free Water

None.

Qualifications. Impermeable material.

Nature of Occurrence of Free Water

None in the Waco area. In northeast McLennan County some water has been reported. The water is probably produced from the Woodbine Sand.

Quality. No water.

Problems Involving Free Water

Impermeability of this material does not permit the accumulation or flow of ground water. The clays in the shale swell greatly when wet from surface runoff. Steep slopes in the Pepper Shale become unstable and dangerous when wet.

SOIL PARAMETERS

Soils Developed on This Unit

Among those soils which develop on this unit are those belonging to the Houston Black and Houston series.

Relation of These Soils to Slope

On flat areas and on gentle slopes.

Soil Parameters by Soil Name

Houston Black series. LL=62.3, PI=41.5, LS=19.3, SL=28.4, SR=1.86, PVR=2.92 (sometimes reaches values of 10 to 15 inches in this material), Dmc=24%, Dfc=92 lbs./ft^3, Avs=6.8 to 10%.

Houston series.

1. 0 to 1 ft. in depth: LL=44, PI=24.5, LS=15.5, SL=12.5, SR=1.87, PVR=2.33, Dmc=18.5%, Dfc =100 lbs./ft^3, Avs=6.5%.
2. 1 to 4 ft. in depth: LL=65.1, PI=42.5, LS=21.0, SL=11.3, SR=1.93, PVR=2.33, Dmc=25%, Dfc =95 lbs./ft^3, Avs=14%.

Shearing Strength

Low T.B.L.P. and U.C.S. lbs/in^2 for both soils.

Problems With Soils on This Unit

Usually too thin to offer problems.

Corrective Measures

Soils should be stabilized with lime or other stabilizing agents.

ECONOMIC ASPECTS

Value as Material

Description. Poor.

As aquifer. No water. Impermeable material.

As disposal site. Very poor.

Present use. None. It has been used as brick material in the Waco area.

Potential value. Ceramic clays.

BUDA LIMESTONE (Kbu)

Thickness

Zero to 20 feet.

Locality Where Measured

In the Waco area north of Bosqueville.

Distribution (local)

Topographic expression. Crops out in a pattern which conforms to the general trend of the Bosque Escarpment. Discontinuous beds of blocky limestone crop out north of Bosqueville and east of the Waco Airport. The Buda Limestone is not recognized north of China Springs.

Description

Lithologic name. Limestone.

Color. Fresh: buff to gray. Weathered: buff to tan.

Bedding. Hard, massive, dense.

Mineralogic composition. 85 percent $CaCO_3$, pebbles and grains of Fe_2O_3, FeS_2 (pyrite), and $FeCO_3$ (siderite).

Description. Buff to gray limestone (hard, massive, dense). Numerous fossil pelecypods. Also see mineralogic composition above.

BEARING CAPACITY

DESCRIPTION
Probably high.
Qualifications. The Buda Limestone is too thin and discontinuous to be of value in supporting heavy structures in Waco and adjacent areas. The Buda Limestone will support heavy foundation loads where present and where thicker than about 2 feet.

BEARING CAPACITY
Thirty to 35 tons/ft^2 in thick sections.

SHEARING STRENGTH
There are no data available. However, due to the physical properties of the formation, shearing strength is probably high.

POTENTIAL SWELL
Low.

PROBLEMS RELATED TO BEARING CAPACITY
Too thin and discontinuous in the Waco area.

CORRECTIVE MEASURES IN FOUNDATION DESIGN
Irrelevant.

SLOPE STABILITY

The Buda Limestone is too thin and discontinuous in the Waco area to affect the stability of slopes.

EXCAVATION PROPERTIES

DESCRIPTION
Difficult; heavy equipment necessary for removal and blasting for fracturing purposes.
Qualifications. The Buda Limestone is too thin and discontinuous in the Waco area.

NATURE OF EXCAVATED MATERIAL
Blocky.

NATURE OF MATERIAL WHEN USED AS FILL

DESCRIPTION
Because it is thin and discontinuous in the Waco area, the Buda Limestone is not suitable for fill.

SLOPE STABILITY OF COMPACTED FILL
Irrelevant.

PERMEABILITY
The Buda Limestone lies between the Pepper Shale and the Del Rio Clay, two impervious materials; therefore, little fluid infiltrates into the Buda. The Buda Limestone is an oil reservoir in northern Falls County.

EROSION PROPERTIES
Resistant to erosion.

PROBLEMS IN USE AS FILL
See qualifications above.

DRAINAGE PROPERTIES

INFILTRATION CAPACITY
Low.
Qualifications. The Buda Limestone is too thin to absorb significant amounts of fluid in the Waco area.

FREE WATER
None.

NATURE OF OCCURRENCE OF FREE WATER
Buda Limestone occurs between two impervious beds that prevent any fluid infiltration into the formation. The Buda Limestone is an oil reservoir in northern Falls County.

SOIL PARAMETERS

SOILS DEVELOPED ON THIS UNIT
Soils developed on the Buda Limestone in the Waco area are insignificant, since the outcrop area of the limestone is too thin and discontinuous. Buda Limestone is generally covered by those soils derived from the overlying Pepper Shale and Eagle Ford Group.

ECONOMIC ASPECTS

VALUE AS MATERIAL
Buda Limestone is an excellent building material, but it is too thin and discontinuous in the Waco area for commercial exploitation.
As aquifer. Problems: 1) very thin (about 2 feet thick), 2) occurs between impervious formations which prevent the infiltration of fluids.

DEL RIO CLAY (Kdr)

THICKNESS
85 feet.

LOCALITY WHERE MEASURED
At the J. L. Myers & Sons No. 1 Tiery Well.

DISTRIBUTION (LOCAL)
Topographic expression. Exposed, generally, west and northwest of Waco and on the higher divides between eastward-flowing tributaries of the Bosque rivers.

DESCRIPTION
Gray-blue, blocky clay containing thin beds of siltstone and limestone. Highly fossiliferous.
Lithologic name. Clay.
Color. Fresh: blue-gray. Weathered: light gray to buff.
Bedding peculiarities. Blocky shale with interbedded siltstones and limestones.
Megascopic description. Fresh: blue-gray. Weathered: light gray to buff.
Mineralogic composition. 10 percent montmorillonite, 20 percent illite, 20 percent kaolinite, 10 percent quartz, 30 percent calcite, and 10 percent amorphous material. Calcite content is considerably lower in the middle of the formation. Pyrite is also present.
Microscopic character. Abundant foraminifers.
Miscellaneous. Very fossiliferous. *Exogyra arietina* and other pelecypods are common.
Description. Gray-blue clay with interbedded siltstones and limestones. Calcite content is lower in the middle of the formation.

BEARING CAPACITY

DESCRIPTION
Intermediate.
Qualifications. Low calcite content in the middle of the formation reduces the foundation support of the clay, as well as its slope stability.

BEARING CAPACITY
Eleven tons/ft^2 near the surface; 6.5 to 7 tons/ft^2 at depths of about 20 feet.

SHEARING STRENGTH
Moderate to low; with additional lime, the shearing strength of the clay increases.

Clay sample in the natural state. At 0 lbs. lateral pressure—3.4 lbs./in^2; at 15 lbs. lateral pressure—21 lbs./in^2.

Clay sample with addition of 6 percent lime. At 0 lbs. lateral pressure—43 lbs./in^2; at 15 lbs. lateral pressure —104 lbs./in^2.

Potential Swell

High; PVR values of 1.5 to 2.5 inches. Sometimes, PVR values in the Del Rio Clay approach the values of the Pepper Shale.

Problems Related to Bearing Capacity

The middle portion of the formation usually fails under the influence of lower loads than those that the upper and lower portions of the formation can withstand. These zones can usually stand loads of about 7 tons/ft^2.

Corrective Measures in Foundation Design

1. Addition of stabilizing agents to increase shearing strength.
2. Pier support is required; deep piers in the non-calcareous part of the formation are required.

SLOPE STABILITY

Description

Unstable to moderate.

Qualifications. (See causes of slope failures).

Maximum Natural Stable Slope Angle

Zero to 15°. The Del Rio Clay crops out west and northwest of Waco and on the higher divides between eastward-flowing tributaries of the Bosque rivers. The outcrop area of the Del Rio Clay is flat to gently sloping. Slope angles as observed in the field range from 0° to 15°. Slopes of 15° are about the maximum stable angle for this formation.

Slope Retention in Excavations

The Del Rio Clay may support nearly vertical slopes in shallow excavations for short periods of time, provided the builder can cope with some minor slumping.

Shallow (less than 6 feet). If excavations are undertaken beside previously existing structures, sheeting or bracing is required to maintain vertical faces. Shoring is required to support the originally existing structure.

Deep (more than 6 feet). In deep excavations, it is advisable to maintain gentle slopes or to employ some kind of wall supports. After soaking rains, the material will usually fail by slumping. Excavations should be closed as quickly as possible and sealed against further moisture penetration. Slumping in deep excavations may be quite hazardous.

Causes of Slope Failure

1. Lack of retaining pressures.
2. High moisture content.
3. Height of slopes.
4. Stream erosion.

EXCAVATION PROPERTIES

Description

Moderate to easy; difficult to work when wet.

Qualifications. Limestone and siltstone beds which occur throughout the formation may require medium to heavy duty equipment. Rippers may be used to cut channels, bar ditches, etc.

Nature of Excavated Material

Friable to blocky.

Excavation Design Problems

Slope retention. Requires gentle slopes (3¼:1).

Drainage. Poor; mostly impermeable.

Disposal of material. Large drainage fields are required.

Causes of Excavation Problems

1. Slumping of the clay when oversteepened or excessively saturated.
2. Difficult to work when wet.
3. Limestone and siltstone beds which occur in the formation may require medium heavy duty equipment.

NATURE OF MATERIAL WHEN USED AS FILL

Description

Poor (unstable).

Qualifications. The upper and lower portions of the formation have a higher $CaCO_3$ content than the middle, and therefore are better than the latter zone when used as fill material.

Slope Stability of Compacted Fill

Moderate.

Permeability

Impermeable material.

Erosion Properties

Clay erodes easily, but limestone and siltstone beds are more resistant.

Problems in Use as Fill

Stabilization with lime or other agents is recommended.

DRAINAGE PROPERTIES

Infiltration Capacity

Low.

Qualifications. Impermeable material.

Nature of Permeability

Impermeable material.

Problems Encountered in Infiltration Drainage

Septic disposal is inadequate in the Del Rio Clay.

Free Water

None.

Nature of Occurrence of Free Water

No water.

Qualification. No potable water.

Problems Involving Free Water

The upper 20 to 25 feet of the formation will swell and seal the material from migration of water.

SOIL PARAMETERS

Soils Developed on This Unit

Houston and Houston Black series, San Saba series (mainly transported from the Georgetown Formation).

Relation of These Soils to Slope

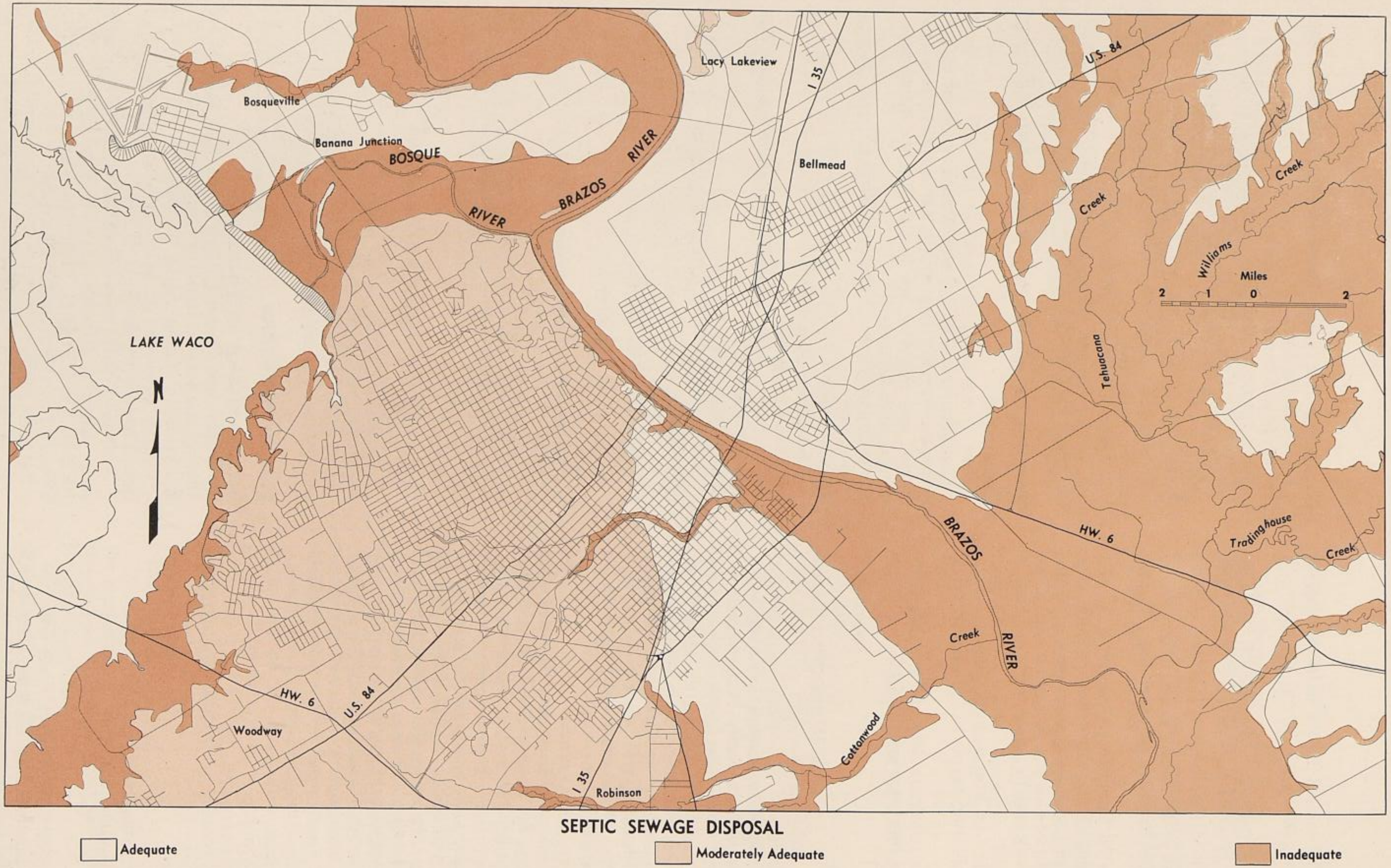
Usually developed on gently sloping surfaces.

Soil Parameters by Soil Name

Average values (undifferentiated soils). Natural state: LL=79, PI=50, LS=23, SL=15, SR=1.86, PVR=1.5 to 2.5 inches. With 6 percent lime: LL=61, PI=28, LS=13, SL=27, SR=1.52.

Houston series.

1. 0 to 1 ft.: LL=44, PI=24.5, SL=12.5, LS=15.5, SR=1.87, PVR=2.33, Dmc=18.5%, Dfc=100 lbs./ft^3, Avs=6.5%.



Inadequate septic sewage disposal is typical in impermeable earth materials, where septic systems are continuously inoperative or become inoperative during each wet period.

Inadequate septic sewage disposal exists in alluvial clays and silts in the Lower Taylor Marl and bentonitic and shaly portions of the Wolfe City Sand; in the South Bosque Shale; in the Lake Waco Formation; in the Pepper Shale; in the Del Rio Clay; and in shale members of the Georgetown Formation.

Moderately adequate septic sewage disposal is encountered in those areas where septic systems are usually operative, except in periods of prolonged saturation. Moderate disposal is typical in moderately permeable earth materials.

Moderately adequate septic sewage disposal exists in some areas of the Wolfe City Sand; in the Austin Chalk; and in the Georgetown Limestone.

Adequate septic sewage disposal is characteristic in highly permeable earth materials, where septic systems are usually operative even in periods of high saturation.

Adequate septic sewage disposal exists mainly in Bosque and Brazos terrace deposits. Where terrace deposits are thin, and rest on impermeable materials, septic sewage disposal may be inadequate.

Fig. 5. Suitability of formations for septic sewage disposal, Waco area.

2. 1 to 4 ft. LL=65.1, PI=42.5, SL=11.3, LS=21.0, SR=1.93, PVR=2.33, Dmc=25%, Dfc=95 lbs./ft^3, Avs=14%.

Houston Black series. LL=62.3, PI=41.5, SL=28.4, LS=19.3, SR=1.86, PVR=2.92, Dmc=24%, Dfc=92 lbs./ft^3, Avs=6.8 to 10%.

SHEARING STRENGTH

Low.

Houston series.

1. 0 to 1 ft.

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	18.4
at 5 lbs.	24.1
at 10 lbs.	31.3
at 15 lbs.	36.9

2. 1 to 4 ft.

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	11.9
at 5 lbs.	14.5
at 10 lbs.	19.5
at 15 lbs.	27.8

Houston Black series.

T.B.L.P.	U.C.S. (lbs./in^2)
at 3 lbs.	16.6
at 5 lbs.	18.6
at 10 lbs.	28.7
at 15 lbs.	33.4

PROBLEMS WITH SOILS ON THIS UNIT

Septic disposal is better in the soils than in the parent material.

CORRECTIVE MEASURES

Foundations should extend down into the unweathered material.

ECONOMIC ASPECTS

HORTICULTURAL VALUES

Good agricultural soils.

VALUE AS MATERIAL

May contain ceramic clays.

Description. Clay with interbedded limestone and siltstone beds.

As aquifer. Impermeable.

As disposal site. Inadequate for septic disposal.

Present use. None.

Potential values. Ceramic clays.

GEORGETOWN FORMATION (Kgt) (MAIN STREET LIMESTONE MEMBER)

THICKNESS

37 feet.

LOCALITY WHERE MEASURED

Along the Bosque River, west of Waco.

DISTRIBUTION (LOCAL)

Topographic expression. Crops out in northeast-southwest trending belt west of Waco, west of the Bosque Escarpment. It is found only in the subsurface in Waco, but crops out along the North Bosque River and along tributaries of the South Bosque River. The Georgetown Limestone is found only in the subsurface in the immediate Waco area.

DESCRIPTION

Lithologic name. Limestone.

Color. Fresh: white. Weathered: buff to tan to gray.

Bedding peculiarities. Limestone beds interbedded with thin marls.

Miscellaneous. Turrilites brazoensis and other fossils.

Descripton. Nodular limestone interbedded with thin marl beds. The Georgetown Formation is divided into seven members. From older to younger these are: Kiamichi Shale, Duck Creek Limestone, Fort Worth Limestone, Denton Shale, Weno Limestone, Pawpaw Shale and Main Street Limestone. These members crop out west and northwest of Waco. The Main Street Member in the greater Waco area is about 35 feet thick.

Other members of the Georgetown Formation cropping out within the mapped area (west of Lake Waco) include the Pawpaw Shale, Weno Limestone, Denton Shale, and Fort Worth Limestone. Their outcrop pattern is usually confined to creek beds and banks where the flowing waters have eroded the overlying materials. The limestone members within the formation have similar engineering properties to those of the Main Street Limestone. Shale members and clayey facies should be avoided, if possible, since they are not well suited for construction purposes. These shales and marls usually exhibit low bearing capacity, slope stability and shearing strength. They are easily excavated, have a high PVR, are impermeable to moisture infiltration and yield no free water. Untreated, they are not suitable to be used as fill material.

BEARING CAPACITY

DESCRIPTION

High.

Qualifications. Excellent foundation material (nodular, interlacing limestone offers excellent foundation support).

BEARING CAPACITY

Values range from 15 to 25 tons/ft^2.

SHEARING STRENGTH

No data available, but estimated as high.

POTENTIAL SWELL

Low in the limestones due to the high content of $CaCO_3$. In the marl beds and shale members the potential swell is usually high.

PROBLEMS RELATED TO BEARING CAPACITY

1. Shale members of the Georgetown Formation are structurally weak and not well suited for foundation support. Foundations should not be placed in these units, if possible.

2. High potential swell of shales within the formation.

CORRECTIVE MEASURES IN FOUNDATION DESIGN

Shale horizons in the Georgetown Formation should be avoided for construction purposes. Foundations will, generally, be much safer if they are placed in the limestone beds.

SLOPE STABILITY

DESCRIPTION

Stable to moderate.

Qualifications. Limestone beds maintain stable slopes while shale beds do not.

MAXIMUM NATURAL STABLE SLOPE ANGLE

Main Street Member (90° slopes). The Main Street Limestone Member of the Georgetown Formation is exposed west of Lake Waco and northwest of the city. This member, composed of nodular limestone with interbedded marl beds, is generally an excellent material for construction purposes. Where exposed (generally along stream cuts), the Main Street Member usually holds nearly vertical slopes. Steep near vertical faces, up to 20 feet and more in height, have been observed on the erosional side of streams cutting through the limestone.

SLOPE RETENTION IN EXCAVATIONS

Good to excellent, in the Main Street.

Shallow (less than 6 feet). Vertical faces can be maintained without the need of any artificial supports in this material, in both shallow and deep excavations.

MAINTENANCE OF ARTIFICIAL SLOPES

There is generally no need of internal supports for excavations in the Main Street.

CAUSES OF SLOPE FAILURE

If shale members fail, they may remove support from more stable units above.

EXCAVATION PROPERTIES

DESCRIPTION

Difficult. Blasting may be necessary to loosen the material. Ripper and blade may be used, especially along the joint planes.

Qualifications. Nodular, interlacing limestone.

NATURE OF EXCAVATED MATERIAL

Blocky.

EXCAVATION DESIGN PROBLEMS

Slope retention. Excellent up to 90°.

Drainage. Although the Main Street Limestone is permeable (it is highly fractured), it occurs between impervious shales which prevent fluid migration.

Disposal of material. (See discussion under economic properties).

CAUSES OF EXCAVATION PROBLEMS

The hard, nodular limestone may require blasting. Ripper and blade may be used, especially along joint planes.

NATURE OF MATERIAL WHEN USED AS FILL

DESCRIPTION

Excellent.

Qualifications. The Main Street Limestone is an excellent fill material. The clayey facies of this unit should be avoided; they are not suitable as fill material.

SLOPE STABILITY OF COMPACTED FILL

Very good.

PERMEABILITY

Permeable; however, it occurs between impermeable shales which prevent any fluid infiltration.

EROSION PROPERTIES

Resistant to erosion.

PROBLEMS IN USE AS FILL

No major problems (extensively used as base material through Central Texas).

DRAINAGE PROPERTIES

INFILTRATION CAPACITY

Low, due to its situation between impermeable clays.

Qualifications. Highly faulted and jointed.

NATURE OF PERMEABILITY

Low, due to its position between impermeable shales.

FREE WATER

None.

NATURE OF OCCURRENCE OF FREE WATER

No potable water is yielded by the Main Street Limestone in the Waco area. During wet seasons, some seepage occurs.

Quality. No potable water.

PROBLEMS INVOLVING FREE WATER

The Main Street Limestone is permeable; however, it occurs between impervious shales which prevent fluid migration.

SOIL PARAMETERS

SOILS DEVELOPED ON THIS UNIT

Denton, San Saba and Tarrant soils.

RELATION OF THESE SOILS TO SLOPE

Tarrant soils: occur on slopes where runoff is rapid. Denton soils: occur on gently sloping areas. San Saba soils: occur on flat areas.

SOIL PARAMETERS BY SOIL NAME

No data available.

SHEARING STRENGTH

Probably high.

ECONOMIC ASPECTS

VALUE AS MATERIAL

Description. Excellent material for foundations.

As aquifer. None.

As disposal site. Probably adequate, except during periods of high saturation. Drainage may be effective during periods of high saturation if drainage fields are located in valleys or scarp faces. Drainage fields extending into thick marl beds will probably encounter problems similar to those encountered in the Taylor Marl.

Present use. Produces some marginal, sub-grade material west of Waco. Excellent base material.

Potential values. Cement (combined with shale).

EDWARDS LIMESTONE (Ked)

DISTRIBUTION (LOCAL)

Topographic expression. Only found in the subsurface in the Waco area. It crops out west of Waco, near Crawford and further west where it caps the flat-topped hills of the Lampasas Cut Plain.

DESCRIPTION

Lithologic name. Limestone.

Color. Fresh: white. Weathered: buff.

Bedding. Massive, dense.

Megascopic description. Fresh surface: buff to white. Weathered surface: gray.

Mineralogic composition. High $CaCO_3$ content; high purity limestone.

Miscellaneous. Fossiliferous. The Edwards Limestone shows subsurface variations, due to reef "build-ups" in the "patch reef" facies. The "inner reef" facies deposits are soft and crumbly and generally have not been recrystallized.

Description. A buff to white, massive, dense limestone (highly fossiliferous).

SLOPE STABILITY

Highly stable; the Edwards Limestone will maintain nearly vertical slopes in excavations of any nature.

EXCAVATION PROPERTIES

Very difficult. The Edwards Limestone cannot be worked with light equipment. Blasting is needed to fracture the material and crushing is the only means to prepare the material for road aggregate.

NATURE OF MATERIAL WHEN USED AS FILL

Excellent. The Edwards Limestone makes excellent fill material, although it should be utilized for better purposes due to the expense of excavation.

DRAINAGE PROPERTIES

Nature of Permeability

Permeable. The Edwards Limestone is permeable and fluids migrate throughout the formation freely. South of Waco, on the Leon River, several oil seeps have been located along fractures in the Georgetown Formation. These seeps are thought to originate in the Edwards reefs.

Free Water

Some. The Edwards Limestone contains ground water west of Waco, but it does not yield potable water within the Greater Waco Area.

SOIL PARAMETERS

Soils Developed on This Unit

Brackett, Crawford, Denton, and San Saba series. Soils of the Edwards Limestone are usually shallow and stony. The Brackett, Denton, and San Saba soils are derived only in limited extent on the formation. The Crawford soils are the most abundant to develop from the hard limestone.

Soil Parameters by Soil Name

No data available. The parameters will vary due to clay pockets in the formation. The plasticity index of the average soils developed on this formation ranges from 8 to 25 depending on the amount of clay present.

ECONOMIC ASPECTS

Description

1. Crushed aggregate for road base material.
2. Riprap material.
3. Excellent building stone.

REFERENCES*

Adkins, W. S. (1923) The geology and mineral resources of McLennan County: Univ. of Texas Bull. 2340.

Agg, F. R. (1924) The construction of roads and pavements: McGraw-Hill, New York.

Ambrose, J. E. (1967) Building structures primer: John Wiley & Sons, New York.

Beall, Arthur O., Jr. (1964) Stratigraphy of the Taylor Formation (Upper Cretaceous), East Central Texas: Baylor Geological Studies Bull. No. 6.

Billings, M. P. (1942) Structural geology: Prentice Hall, New Jersey.

Blanchard, A. H. (1915) Elements of highway engineering: John Wiley & Sons, New York.

Burket, J. M. (1959) Geology of the City of Waco and its environs: Unpublished master's thesis, Baylor University.

———(1965) Geology of Waco *in* Urban Geology of Greater Waco—Part I: Baylor Geological Studies Bull. No. 8.

Chamness, Ralph S. (1963) Stratigraphy of the Eagle Ford Group in McLennan County, Texas: Unpublished master's thesis, Baylor University.

DeSitter, L. V. (1956) Structural geology: McGraw-Hill, New York.

Dixon, J. W. (1955) Population studies of the brachiopod *Kingena wacoensis* occuring in the Lower Cretaceous Georgetown Formation of Central Texas: Unpublished Ph.D. dissertation, University of Wisconsin.

———(1967) Georgetown Limestone, Central Texas; Including discussion of *Kingena wacoensis in* Comanchean (Lower Cretaceous) stratigraphy and paleontology of Texas: The Permian Basin Section, Soc. Econ. Paleo. and Min., Midland, Texas, pp. 241-255.

Elder, W. R. (1965) Soils and urban development *in* Urban Geology of Greater Waco—Part II: Baylor Geological Studies Bull. No. 9.

Fairhurst, C. (1963) Rock mechanics: Macmillan, New York.

Fandrich, J. W. (1968) Studies of bentonites and related rocks in the Eagle Ford Group, Central Texas: Unpublished master's thesis, Baylor University.

Fox, W. J. (1962) The geology of the Crawford and Speegleville quadrangles, McLennan County, Texas: Unpublished master's thesis, Baylor University.

Frost, J. G. (1963) The Edwards Limestone in Central Texas: Unpublished master's thesis, Baylor University.

Hayward, O. T. (1957) The structural significance of the Bosque escarpment, McLennan County, Texas: Unpublished Ph.D. dissertation, University of Wisconsin.

Hill, R. T. (1887) Topography and geology of the Cross Timbers and surrounding regions in northern Texas: Am. Jour. Sci., ser. 3, vol. 133, pp. 291-303.

———(1889) A preliminary annotated check list of the Cretaceous invertebrate fossils of Texas: Texas Geol. Survey Bull. No. 4.

———(1891) The Comanche Series of the Texas-Arkansas region: Geol. Soc. Am. Bull., vol. 2, pp. 503-528.

———(1892) Taylor or *Exogyra ponderosa* marl: Artesian Investigations, final report, pt. 3, p. 73, U.S. 52nd Cong., 1st Sess., S. Ex. Doc. 41.

———(1901) Geography and geology of the Black and Grand prairies, Texas: U. S. Geol. Survey, 21st Ann. Rept. pt. 7.

Hilpman, P. L. and Stewart, G. F. (1968) Environmental geology and urban land-use planning: University of Kansas Publication, Lawrence, Kansas.

Holloway, Harold D. (1961) The Lower Cretaceous Trinity aquifers, McLennan County, Texas: Baylor Geological Studies Bull. No. 1.

Hopkins, O. N. (1961) The geology of the Valley Mills and China Springs quadrangles, McLennan County, Texas: Unpublished master's thesis, Baylor University.

Johnson, Charles (1964) Stratigraphy of the Del Rio Clay, Central Texas *in* Shale enviroments of the Mid-Cretaceous section, Central Texas—A field guide: Baylor Geological Society.

Jumikis, A. R. (1962) Soil mechanics: D. Van Nostrand, New Jersey.

Krynine, D. P. and Judd, W. R. (1957) Principles of engineering geology and geotechnics: McGraw-Hill, New York.

McLean, W. G. and Nelson, E. W. (1962) Engineering mechanics: Schaum, New York.

Nash, W. A. (1957) Strength of materials: Schaum, New York.

O'Rourke, C. E. (1940) General engineering handbook: McGraw-Hill, New York.

Pace, Lula (1921) Geology of McLennan County, Texas: The Baylor Bulletin, vol. 24, no. 1.

Peck, R. B.; Hanson, W. E.; and Thornburn, T. H. (1959) Foundation engineering: John Wiley & Sons, New York.

Peurifoy, R. L. (1956) Construction planning, equipment, and methods: McGraw-Hill, New York.

Ray, Johnny, (1964) The Buda Limestone of Central Texas: Unpublished senior thesis, Baylor University.

Silver, B. A. (1963) The Bluebonnet Member, Lake Waco Formation (Upper Cretaceous), Central Texas—A lagoonal deposit: Baylor Geological Studies Bull. No. 4.

Soil Conservation Service (1958) Soil survey, McLennan County, Texas: U.S. Department of Agriculture, SCS, series 1942, no. 17.

Stephenson, L. W. (1929) Unconformities in the Upper Cretaceous Series of Texas: Am. Assoc. Petrol. Geol. Bull., vol. 13.

Taylor, D. R. (1962) The geology of the Gholson and Aquilla quadrangles of McLennan and Hill Counties, Texas: Unpublished master's thesis, Baylor University.

Taylor, D. W. (1960) Fundamentals of soil mechanics: John Wiley & Sons, New York.

Terzaghi, Karl and Peck, R. B. (1958) Soil mechanics in engineering practice: John Wiley & Sons, New York.

Texas Highway Department (1962) Manual of testing procedures.

———(1964) Foundation, exploration and design manual.

Williamson, E. F. (1967) Urban geology of Temple, Bell County, Texas: Unpublished master's thesis, Baylor University.

Yong, R. N. and Warkentin, Benno P. (1966) Introduction to soil behavior: Macmillan, New York.

*While specific reference is not made to most of these works they were all useful in compiling this study.

GLOSSARY

ATTERBERG LIMITS. Physical properties of soils expressed in terms of water content—ranges of the liquid state, plastic state and solid state—defined by Atterberg in 1911.

AVS. Average volumetric swell or average potential swell.

CONE PENETROMETER. A standard test in which the relative density or consistency and the bearing capacity of any geologic formation is determined. A 3-inch diameter cone is attached to a drill stem and lowered to the bottom of a cored hole. A 170 pound hammer is dropped from a 2-foot distance onto the cone. The number of inches of penetration per 100 blows, or the number of blows per foot of penetration, is recorded.

DFC. DESIRABLE DENSITY FOR COMPACTION of material for better performance in road construction. Usually expressed in pounds per cubic feet.

DMC. DESIRABLE MOISTURE CONTENT. The moisture content recommended for specific soils to obtain better performance in road construction.

FRIABLE. Easily crumbled.

LL. LIQUID LIMIT. Maximum water content of a soil before it passes from the plastic to the liquid state.

PL. PLASTIC LIMIT. Minimum water content necessary for a soil to change from the solid to the plastic state.

PI. PLASTICITY INDEX. Difference between the liquid limit and the plastic limit of a soil sample. It is expressed as a dimensionless number.
LL—PL=PI.

POTENTIAL SWELL. Same as PVR, but usually expressed in terms of volume.

PVR. POTENTIAL VERTICAL RISE. The latent or potential ability of soil material (at a given density, moisture, and loading condition) when exposed to capillary or surface water to swell and thereby increase the elevation of its upper surface together with anything resting upon it. PVR is expressed in inches.

SHEARING STRENGTH. Equivalent to shearing resistance or resistance to shear. Defined by the equation $S=c+e \tan b$, where $c=$ cohesion of the material, $e=$normal pressure acting upon the shear plane, and $b=$angle of internal friction of the material.

SL. SHRINKAGE LIMIT. The lower limit of water content at which the soil sample will no longer decrease in volume due to loss of water.

SLOPE ANGLE. Angle inscribed between a particular slope and a horizontal plane. Usually defined as Ø.
$\frac{\text{vertical}}{\text{horizontal}}=\text{slope angle.}$

SOIL PARAMETERS. Same as Atterberg limits.

SPALL. Breaks off in layers parallel to the surface.

U.C.S. UNCONFINED COMPRESSIVE STRENGTH. Synonimous with shearing strength. This term is used mainly for clays and other "cohesive" soils which can be tested in unconfined compression tests. In an unconfined compressive test a load is applied to a sample until failure occurs. No lateral pressure is applied. For cohesionless materials (e.g. loose, dry sand) a triaxial test, using a lateral or surrounding pressure, is necessary.

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BAYLOR GEOLOGICAL PUBLICATIONS*

Baylor Geological Studies

1. Holloway, Harold D. (1961) The Lower Cretaceous Trinity aquifers, McLennan County, Texas: Baylor Geological Studies Bull. No. 1 (Fall). Out of print.
2. Atlee, William A. (1962) The Lower Cretaceous Paluxy Sand in central Texas: Baylor Geological Studies Bull. No. 2 (Spring). $1.00 per copy.
3. Henningsen, E. Robert (1962) Water diagenesis in Lower Cretaceous Trinity aquifers of central Texas: Baylor Geological Studies Bull. No. 3 (Fall). $1.00 per copy.
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7. Spencer, Jean M. (1964) Geologic factors controlling mutation and evolution—A review: Baylor Geological Studies Bull. No. 7 (Fall). $1.00 per copy.

Urban geology of Greater Waco. A series on urban geology in cooperation with Cooper Foundation of Waco.

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14. Part VI: Conclusions (1968) Urban geology of greater Waco—Summary and recommendations by Editorial Staff: Baylor Geological Studies Bull. No. 14 (Spring). $1.00 per copy.
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101. Type electric log of McLennan County. 1″-100′; 1″-50′-$2.00.
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103. Guide to the mid-Cretaceous geology of central Texas, May, 1958. Out of print.
104. Location map of logged wells in McLennan County, 1959. 1″-1mile. Out of print.
105. Layman's guide to the geology of central Texas, 1959. Out of print.
106. Collector's guide to the geology of central Texas, 1959. Out of print.
107. One hundred million years in McLennan County, 1960. Out of print.
108. Cretaceous stratigraphy of the Grand and Black Prairies, 1960. Out of print.
109. Popular geology of central Texas, west central McLennan County, 1960. Out of print.
110. Popular geology of central Texas, Bosque County, 1961. Out of print.
111. Popular geology of central Texas, northwestern McLennan County, 1961. Out of print.
112. Popular geology of central Texas, southwestern McLennan County and eastern Coryell County, 1962. Out of print.
113. Upper Cretaceous and Lower Tertiary rocks in east central Texas, Fred B. Smith, Leader, 1962. Out of print.
114. Precambrian igneous rocks of the Wichita Mountains, Oklahoma, Walter T. Huang, Leader, 1962. Out of print.
115. Why teach geology? A discussion of the importance and cost of teaching geology in high schools, junior colleges and smaller 4-year institutions. Free upon request. 27 pp. (1961).
116. Popular geology of Central Texas: The hill country—McLennan, Coryell and Bosque counties, 1963. $1.00 per copy.
117. Shale environments of the mid-Cretaceous section, Central Texas—A field guide. Leaders—Beall, A. O.; Johnson, C. F.; and Silver, B. A.; 1964. $2.00 per copy.
118. Geology and the City of Waco—A guide to urban problems, 1964. $2.00 per copy.
119. The Bosque watershed. Geology of the Bosque River basin, 1966. Out of print.
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