A GENERALIZED INVESTIGATION OF SELECTED HIGHWAY DESIGN AND CONSTRUCTION FACTORS BY REGIONAL GEOMORPHIC UNITS WITHIN THE CONTINENTAL UNITED STATES

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Liberal use has been made of data appearing in published literature dealing with geology, geomorphology and physiographic mapping. These sources are referenced in the report. Some of the information dealing with aggregate sources and problems was obtained by means of a questionnaire sent to each state highway agency of the adjacent 48 states.

Special acknowledgement is made to the works of Fenneman, Lobeck, Woods and Lovell. The basic physiographic units studied are those proposed by Woods and Lovell (Reference 390).

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ABSTRACT

This report concerns an investigation of the occurrence and distribution of selected highway factors within regional geomorphic units comprising the adjacent 48 states. The regional classification system used as a basis of examination was that proposed by Woods-Lovell. This system was slightly modified to produce 97 Sections for investigation. The highway factors analyzed by Section were: availability of quality aggregate resources, soil origin and texture, high volume change soils, potentially poor subgrade support conditions (clayey and organic type) and frost susceptible soils. A generalized evaluation of the utility of using Physiographic Sections as information filing units for the highway factors was also conducted.

Several generalized national maps were developed to aid in the analysis of the factors considered. Potential aggregate maps of the United States were compiled and used along with various other sources of information, including a state highway aggregate questionnaire, to obtain a qualitative estimate of the potential aggregate availability

rating for each Section. For factors of design relative to soil texture, a generalized soils map of the United States was developed. Estimates of the frequency of occurrence for soil texture units were made for each Section. Based upon the latter results, frequency of occurrence of organic deposits and the combined severity-frequency rating of plastic (clayey) soils was assessed for each Section. This served as a measure of the poor subgrade support potential. The frequency of occurrence of high volume change soils, within Sections showing a general climatic environment conducive to volume change, was developed via potential high volume change maps. These were obtained by a combined engineering case study, as well as maps of potential high volume change areas derived from a pedologic and geologic analysis. A generalized frost susceptibility map for the northern United States was compiled. Sections generally within the freezing zone were defined and the frequency of occurrence by frost susceptible soil type was qualitatively determined for each Section. A summary table of the salient composite highway factors investigated was compiled for each Section, and represents a brief and concise summary of the major findings.

In order to obtain a generalized evaluation of the utility of physiographic units for uniquely cataloging highway factors, the science of regional geomorphology was examined to ascertain the points of uniqueness used to delineate and separate Sections from their surrounding units. An investigation of the presence of smaller units variant to the modal characteristics of the Sections was also conducted.

It was found that because of the multiplicity of factors used to define and bound Physiographic Sections, it is not possible to make a blanket conclusion regarding the validity of utilizing these Sections as "filing systems" for highway factors. Although generalizations regarding the design factors can and have been made within the physiographic units, the uniqueness of the units appears to be dependent upon the factor in question, the degree to which variant units are present within the Section, and the modal characteristics which define the Section.

The majority of Sections examined showed a significant presence of smaller, variant units within them. Based upon this consideration, plus the overall importance of the parent material - origin characteristics to the highway engineer, a suggested highway engineering - physiographic unit map of the Continental United States is presented. This system is comprised of 242 tentative units.

INTRODUCTION

While engineering design and construction decisions are unique solutions to particular problems, the efficacy of such solutions depends strongly upon the store of highly relevant experiences which can be utilized as background or perspective input. Generalized solutions do exist and are as helpful in art-oriented decisions as are general solutions in rigorous scientific analysis. It is important to recognize that valid and instructive definitions of site and route conditions, and the engineering problems inherent to such conditions, can be deduced from descriptions generalized for areas which are orders of magnitude larger than the job area. Detailed investigations of the job area subsequently validate the predictions, quantify the characterization, and reveal the anomalies where and if present.

The requisite input for highway design and construction decisions is deduced through a process of convergence, for example, moving from a general understanding of a large piece of geography to the specifics of a site or route which is no more than a point or a thin line on any but a very large scale map. Where one starts in the defining process is somewhat dependent upon the geographical scope of his operation ... federal, regional, state, county, municipal.

Just as one might logically study an object first by unmagnified visual inspection and then by successively greater image magnification, the highway engineer might examine bedrock geology on first a national level, followed by successively larger scale maps of region, state, county, topographic quadrangle, and finally, special coverage of the site or route of specific and immediate practical concern. Descriptors attached to each level of the examination would differ in degree of specification but would not contradict (anomalies excepted).

In the search for geographic units within which ground conditions, environment, engineering problems, and presumedly, design and construction practice, demonstrate significant homogeneity, one might first try the jurisdictional or political units (groupings of states, individual states, highway districts, individual counties, and the like). However, since such units bear only coincidental relationship to the factors which produce the surface materials (origin, parent material and environment), they are largely unsuitable. The experienced highway engineer recognizes this to be the case and, for example, does not apply the same technology in areas of residual clay and clayey glacial till even though these lie within the same highway district. Indeed, perhaps the most effective argument for formally developing the concept of generally unique regions lies in the strong framework which it provides for organizing and relating experiences.

One of the most versatile and effective types of areal unit currently known for purposes of examining the concept of regions possessing common highway engineering factors of design, if not for implementing it in optimal form, is that developed by the regional physiographer. Subdivision of geography in this geological - geographical science is accomplished by reference to a number of major descriptive features of the surface and subsurface.

In summary this thesis is built upon the premise that physiographic (geomorphic)units can form an orderly filing system for the many engineering experiences that, when synthesized, constitute engineering judgement. This filing system can be particularly valuable for organizations with large geographical jurisdiction (regional, national) and for engineers youthful in the process of collecting and organizing experiences, i.e., in the process of acquiring engineering judgement.

PURPOSE

The major purpose of this research was to investigate the distribution and occurrence of several salient factors of highway location, design and construction within a selected, pre-existant regional physiographic classification system for the Continental United States. The classification selected was a slightly modified version of the Woods - Lovell Engineering - Physiographic System, presented in 1960 (82)[1]. This version resulted in the establishment of 97 "unique" areas[2] to be investigated within the United States.

The highway factors considered within this report are: the availability of aggregates, soil origin and textural considerations, high volume change soils, potentially poor subgrade support soils (clayey and organic types) and frost susceptible soils.

An allied purpose of comparable importance was an evaluation of the utility of physiographic units for organizing and correlating data and experiences. In so doing, the geologic science of regional geomorphology (physiography) was examined to determine the criteria used to define the uniqueness

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[1] Underlined numbers in parenthesis refer to entries in the Bibliography.

[2] Termed Physiographic Sections.

of a physiographic unit, and to bound or separate it from other units. As a result of such examination, pertinent inclusions could be reached as to the suitability of generalizing any highway factor within any defined physiographic unit.

SELECTED SCIENTIFIC AND ENGINEERING BACKGROUND INFORMATION

General

In order to provide a common base of understanding of frequently used geologic and engineering terminology, certain fundamental information about geomorphology, physiography, aggregates and soil problem follows.

Fundamentals of Geomorphology

Physiography or Geomorphology

Throughout the report the reader will be confronted with the terms "physiographic" or "physiography" and "geomorphic" or "geomorphology". Physiography is defined as (2): "...synonymous with physical geography; a description of existing nature as displayed in the surface arrangement of the globe, its features, atmospheric and oceanic currents, climates, magnetism, life, as well as the changes or variations to which these are subjected". Geomorphology, on the other hand, is defined as: "...the systematic examination of landforms and their interpretation as records of geologic history". The major dissimilarities between the two are: (1) Physiography consists primarily of describing the topographic expression and its geographic extent, while Geomorphology emphasizes interpretation of the origin and development of landforms; and (2) Physiography appears to be more inclusive, since it includes the "environment" of the topography (atmosphere, ocean, climate, etc). Fenneman (18) states: "Geomorphology is definitely limited to the genetic (pertaining to the relationships of a common origin) study of landforms". Lobeck (38) points out that Physiography includes Climatology, Geomorphology and Oceanography.

However, the examination and description of landforms or topographic expressions are basic to both sciences. Fenneman states: "The term Physiography as used in the United States is the approximate equivalent of Geomorphology". Further, if a Geomorphologist studies the areal extent of landforms, he would be acting as a regional Geomorphologist, and his activity would very closely resemble that of the Physiographer.

In the words of another authority: "For many years, in the United States, the study of the origin of landforms has been called Geomorphology, whereas the discussion of the regional distribution and the geomorphic histories of landscapes has been termed Physiography. It seems to me that this inconsistency should be eliminated..." (Thornbury (65)). Accordingly, the author has taken the position that "geomorphic unit" is synonymous with "physiographic unit".

The Physiographic (Geomorphic) Unit

Various physiographers have set forth definitions of a physiographic unit. Bowman (65) suggests it is "... a tract in which the topographic expression is in the main uniform". Hinds (65) states it is, "... characterized by a distinguishing geological record, particularly in the later part of earth history, and by more or less uniform relief features or combinations of features throughout its area". Malott (65) somewhat more comprehensively explains: "A physiographic unit is an area or division of the land in which topographic elements of altitude, relief and type of landforms are characteristic throughout, and, as such, is set apart or contrasted with other areas or units with different sets of characteristic topographic elements".

In most simple terms, physiography is topographic expression; while the implication of a physiographic unit is that it contains a unique set of landforms, i.e., different from its physiographic neighbors. Landforms, or topographic expression, are not readily adapted to exact quantitative evaluation and are generally qualitatively categorized in terms of altitude, relief, form, and interrelationships of the landscape features (65).

Geomorphic Control Factors

A fundamental concept of geomorphic thought, advanced by Davis (64), is that topographic expression of any area depends upon the three control factors of structure, process, and stage.

Structure has a slightly different context than the normal geologic usage. Thornbury (64) defines it (structure) as "... all those ways in which the earth materials out of which landforms are carved differ from one another in their physical and chemical attributes. It includes such phenomena as rock attitudes, the presence or absence of joints, bedding planes, faults and folds, rock massiveness, physical hardness of the minerals, susceptibility of mineral constituents to chemical alternation, permeability (impermeability) of rocks, and various other ways in which rocks of the earth's crust differ from one another. The term structure also has stratigraphic implications...Is the region one of essentially horizontal sedimentary rocks or is it one in which the rocks are steeply dipping or folded or faulted?"

Process describes ways in which the land surface has been modified. Geomorphically, these processes may be thought of as those originating from agencies outside the earth's crust (degradational: tending to level down; or aggradational: tending to level up); or those that originate within the earth's crust (diastrophism: forces that cause the deformation of the earth's crust; or vulcanism: the movement of molten rock or magma onto or toward the earth's surface).

An exact and universally accepted definition of stage has not been formulated, however, in a very broad sense it involves a change with time. Sparks (58) refers to this as the evolutionary phase of landform development.

Based upon the foregoing, Thornbury (65) summarizes the importance of the geomorphic control factors by stating:

"This is equivalent to saying that a certain region possessed an initial geologic framework, as determined by the kind and arrangement of its rocks; this geologic structure has been subjected to gradational processes which have produced a certain assemblage of landforms; and the characteristics of these landforms are to a certain degree related to the length of time that the geomorphic process have been at work".

Categories of Regional Physiographic (Geomorphic) Units

It has been previously stated that a physiographic unit is one of repetitive and/or unique landforms. Obviously, as the size of an area under consideration increases, detail gives way to generality. As a consequence, one should intuitively expect a greater diversity of landforms or topography in the larger major units than in the smaller minor ones. Furthermore, as the definition of areal physiographic units is quite subjective, it is highly probable that, as Fenneman (18) has stated, "...even in the single science of physiography, two men, or the same man at different times may wish to emphasize different elements of the picture, and accordingly, to divide the total area in a different manner".

Since land features may be examined at a variety of scales (different degrees of generalization), several levels or categories of physiographic units are needed. Fenneman

(18, 19) used three categories[1], in order of major to minor: (1) Division, (2) Province and (3) Section.

Table 1 compares the Physiographic Divisions of Fenneman with those of Lobeck(38). The latter authority divides North America into six Divisions; while Fenneman uses eight Divisions in the U. S. alone. The major difference is in the North American Cordillera Division of Lobeck. However, this discrepancy appears to be minor, since Lobeck subdivides this Division into three parts which match the Fenneman Divisions (Table 1).

Differences are compounded at the Province and Section scale; these are discussed later. In addition, others (Freeman et al, as cited by Thornbury (65)) have inserted the intermediate grade of "Subprovince".

A slightly different classification has evolved from the excellent work conducted in England by the Military Engineering Experimental Establishment (MEEE) (43, 44). The descriptors used (in order of major to minor extent) are the: (1) Land Zone, (2) Land Division, (3) Land Province, and (4) Land Region.

Table 2 summarizes the various categorical terminologies. For this study the terminology adopted is the system of: (1) Division, (2) Province, (3) Section, and (4)

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1. Fenneman (19) states on page 55, with respect to the Central Texas Section of the Great Plains Province, "...the Section...embraces a number of clearly distinguished subdivisions which for lack of a technical term may here be called districts". The term has not however gained any consistent usage.

Table 1

Differences Between Physiographers in Physiographic Divisions

	Lobeck[1]	Fenneman[2]
A.	Appalachian Highlands	Appalachian Highlands
B.	Atlantic Plain	Atlantic Plain
C.	Canadian Shield	Laurentian Upland[3]
D.	North American Cordillera[4]	Pacific Mountain System
	---	Intermontaine Plateau System
	---	Rocky Mountain System
E.	Interior Plains[5]	Interior Plains
	---	Interior Highlands
F.	Antillean Mountain System[6]	---

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[1] Mapping of North America.

[2] Mapping of the United States only.

[3] One of three provinces in Lobeck's Canadian Shield Division.

[4] Lobeck recognizes three subdivisions within the North American Cordillera, which are the same as the Fenneman Divisions.

[5] Lobeck's Interior Plains include Fenneman's Interior Highlands. Fenneman's Interior Highland Division contains the Ozark Plateau and Ouachita Provinces.

[6] Not in the U. S.

Table 2

Summary of Regional Physiographic Unit Categories

Scale	Fenneman	Lobeck	Freeman et al.	MEEE	Report Categories
Small	---	---	---	Land Zone[3]	---
	Division	Division[2]	---	Land Division	Division
	Province	Province	Province	Land Province	Province
	Section	Section	Subprovince	Land Region	Section
Large	District	---	Section	---	Subsection[1]

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[1] A category expressly coined for this study.

[2] Sometimes separated into Subdivisions.

[3] A class level reflecting world extents of major climatic types.

Subsection.[1]

Highway Design and Construction Factors

Aggregates

General

One of the more important facets of highway design and construction lies in the availability and selection of good quality mineral aggregates. Within the United States, a wide variety of natural granular deposits, crushed stone and artificial aggregates are presently used for base/subbase, concrete and bituminous pavement mixes. In some areas, however, good quality aggregate sources may be in short supply. The following discussion provides a basic background on the major sources and types of aggregates used in the highway industry, as well the potential problems associated with aggregate uses in different parts of the pavement structure.

Aggregate Types

Aggregate types can be generally grouped by source into three categories, (142). These are: (a) natural sand and gravel, (b) crushed stone and (c) artificial aggregates.

Sand and gravel deposits occur primarily through deposition by water. Hence, origins may be of glacial (glacio - fluvial), alluvial, lacustrine or marine. In 1958, approximately 680,080 short tons of sand and gravel were sold within the United States. Of this total, 407,734 tons, or

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[1] Category description adapted especially for this project.

nearly 60% was utilized by the paving industry (131).

A wide variety of rock is available for use as crushed stone, viz., sedimentaries, igneous and metamorphics. Severinghaus (175) states: "Satisfactory physical and chemical properties can be found in each type so that economic availability becomes the prime determinant for development".

The most widely used crushed stones are those of the carbonate group (limestones and dolomite). Gillson et al, (107) states that, "...no other solid rocks are as important as these in the industrial life of the world, nor are any so widely known". This statement is vertified by Table 3 which shows the quantity by type and principal use for crushed stone in 1958 for the United States. Although the data (in terms of quantity) are over 10 years old, they provide a valuable guide in noting the relative quantities of each type used as well as the principal types of crushed rock used for aggregates.

Artificial aggregates as defined by Woods (142) consist of: (a) blast furnace slag, (b) cinders and (c) other lightweight aggregates. Woods' definition of the latter is confined primarily to "a manufactured aggregate"; while Klinefelter (128) states: "Lightweight aggregates may be natural or manufactured materials or by-products from other commercial operations. Natural materials include pumice and pumicite, tuffs, breccia, scoria, diatomite...Manufactured materials include expanded perlite, vermiculite, slag, clay, shale and slate. By-products include cinders, air cooled slags and coke breeze".

Table 3

Crushed and Broken Stone Sold or Used by Producers in the United States in 1958 by Kinds and Principal Uses (in Thousands of Short Tons)[1]

	Function					
Type of Stone	Concrete and Road Stone	Railroad Ballast	Riprap	Lime and Cement	Others	Total
Limestone	226,693	4,306	4,763	88,484	66,222	390,468
Basalt[2]	39,187	1,421	2,177	---	1,160	43,945
Granite	26,269	1,876	1,023	---	2,124	31,292
Sandstone/ Quartzite	8,862	706	1,657	---	13,259	24,484
Oyster Shell	11,216	---	---	6,258	1,442	18,916
Miscellaneous	9,882	2,257	5,754	1,723	3,828	22,444

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[1] Table abstracted and condensed from ref. (131)

[2] Includes gabbro, diorite and other dark igneous rocks commercially classified as trap rock.

Highway Aggregate Problems

General

Although it is not the intent of this report to present a detailed treatise on the historical backgrounds, pertinent variables, and general test procedures used to ascertain quality requirements for highway aggregates; a brief overview of general aggregate problems is presented. It should be apparent to the reader versed in aggregates and their subsequent problems, that many factors other than those associated with a particular material type are intrinsic to the designation of an aggregate as being suitable or unsuitable for use in highway construction.

Like the highway design engineer, who must base the structural pavement design upon the factors of traffic and environment, and their interrelationship with the foundation soil, for a particular type (rigid or flexible) pavement; the materials engineer must likewise examine the interrelated effects of traffic, environment and pavement type on the materials (aggregate) used.

In bituminous pavement construction, there are a large number of combinations of aggregate - bituminous materials that may comprise any one of several bituminous layers. Rigid pavements generally are "simpler" as only one fundamental mix combination is utilized. Because of the fundamental differences in design concepts between a rigid and flexible pavement, the importance and role of aggregate and aggregate-binder layers within each type differs. A rigid pavement derives its strength primarily through the binding medium in the form of slab action. Ideally, the role of the aggregates within a concrete pavement is to serve as an inert filler. Bituminous pavements are designed to distribute the load to the subgrade soils, and as a result, the aggregate fraction plays an increasingly important role in strength considerations.

Traffic considerations become very important in several aggregate problems, while in others, their effect is small. Such problems as abrasion and skid resistance must be evaluated in light of anticipated traffic conditions. However, this factor is not directly related to the expansion of concrete pavements caused by several cement - aggregate chemical reactions. The role of environment upon aggregate performance is quite complex and is variable in its effect upon aggregate evaluation. It is, however, generally an active consideration in most problems.

Aggregate Problems

It should be realized that it is not generally possible to state that an aggregate is either "good" or "bad" *per se*. However, for a given use (function) and environment (location), an overall evaluation of the aggregate quality requirements can be accomplished.

The most general descriptor of aggregate quality is durability. Several definitions of this general problem appear in the literature. Lewis (132) states that durability "... refers to the ability of the concrete to withstand the attack of natural agents of weathering and deterioration, without consideration of the structural adequancy of the materials to carry the loads to which it is subjected". Woods (142) notes that this term "...refers to the resistance of a paving mixture to disintegration by weathering or the abrasive forces of traffic". Hveem (116) in a general statement declares: "Durability means, in a broad sense, the ability of the aggregate to remain unchanged over a fairly long period of time in spite of adverse natural processes or forces to which it is subjected".

To insure aggregate durability, particularly in concrete pavement, aggregates must possess the characteristic of soundness. Soundness implies a direct resistance to the forces of weathering (142). Neville (152) states that soundness is the "...name given to the ability of an aggregate to resist excessive changes in volume as a result in changes in physical conditions. Lack of soundness is thus distinct from expansion caused by chemical reactions between the aggregate and the alkali in cement". These physical changes are associated with freezing - thawing, heating and cooling, and wetting and drying (152, 164).

Another desirable durability characteristic, relevant only for aggregates utilized in portland cement concrete pavements, is the absence of certain chemical reactions with the cement matrix. In general, each type of harmful chemical reaction manifests itself by destructive expansion of the reactive products, eventually causing loss of pavement serviceability.

The most common type of reaction is the alkali - aggregate or alkali - silica reaction. In essence, the alkalies in cement attack the siliceous minerals of the aggregate, forming an alkali - silica gel around the aggregate which has a tendency to increase in volume. This gel "...is confined, and internal pressures result leading to expansion, cracking and disruption of the cement paste" (152). The reactive forms of silica frequently occur in opaline or chalcedonic cherts, siliceous limestones, rhyolites and rhyolitic tuffs, dacites and dacite tuffs, andesites and andesitic tuffs and phyllites (152).

A more recently discovered and less frequently occurring chemical reaction is the carbonate reaction (alkali-carbonate or dedolomitization reaction). In this case alkalies of the cement and a particular type of argillaceous, dolomitic limestone will react to form an expansive product which may lead to pavement destruction (112, 158). This reaction differs from the well known alkali-silica type in that no visible gel or reaction products are formed (158). The characteristics of potentially reactive carbonate rocks, as postulated by Hadley, are dolomitic limestones in which: the dolomite comprises 40-60% of the total carbonate fraction, there is an approximate 10-20% clay fraction, and a texture of small dolomite crystals is scattered through a matrix of extremely fine-grained calcite and clay (112).

Another cement-aggregate problem, occurring only in the central Great Plains area of the United States, is the "sand-gravel reaction". It is quite similar to the alkali-silica reaction, except that limiting the alkali content of the cement within ordinary limits will not prevent excessive cracking, expansion and general deterioration. Tests and field experience have demonstrated that the deterioration can be controlled if the sand and gravel aggregates are supplemented by 25 to 40%, by weight, of satisfactory coarse aggregates (171).

The final type of chemical problem is the sulphate reaction, which occurs by the formation of gypsum and calcium sulphoaluminate from a reaction of soluble sulphates with the cement pastes. The soluble sulphates may be present in the mineral aggregates (oxidation products of iron sulfides, gypsum, or aluminate-jarosite (142)),or may occur where certain acidic mine waters or soils containing alkali, magnesium or calcium sulphates form an effective groundwater sulphate solution (152).

Aggregate degradation refers to the production of finer aggregates by weathering (both physical and chemical) and/or mechanical breakdown due to the action of mixers, mechanical equipment and/or traffic (94, 97). This mechanical breakdown can occur by compressive failure from concentrated loads at points of contact between aggregates, as well as by the abrasive action of individual aggregates moving with respect to each other (108). Because of the intrinsic differences in rigid and flexible pavements, this factor is of greater relative importance in bituminous layers (142). The resistance to degradation is commonly measured by the Los Angeles Abrasion test. Moavenzadeh (147) found, however, that the aggregate of a bituminous mixture is more important in defining overall degradation properties than the abrasion resistance of the aggregates themselves.

Goetz (108) noted that "...stripping, or the separation of the bituminous film from the aggregate, through the action of water, is probably the greatest single problem in durability of bituminous mixes". This problem occurs primarily with aggregate high in silica (hydrophillic). Rock types which are basic (rather than acidic) generally have a great affinity for bitumen and tend to hold the coating in the presence of water (hydrophophobic).

Aggregates used in surface courses should possess a high skid or polishing resistance. Many factors affect the antiskid properties of any given surface; however, one of the more important factors is the polishing characteristics of the mineral aggregate used. Goodwin (109) has summarized the general features of aggregates that affect skid resistance. Although skidding is a problem on both portland cement and bituminous pavements, it is generally more magnified in the latter because "...it usually requires less traffic to define the polishing characteristics of aggregates in bituminous mixtures since the degree of exposure is greater for the individual pieces of aggregate than with portland cement surfaces" (176). In addition, the skid resistance of portland cement surfaces depends primarily "...on the fine aggregate portion of the mix...a coarse aggregate with high polishing characteristics can be permitted in a mix if the mortar surface has adequate skid resistance" (89).

In general, the polishing resistance of an aggregate is directly related to the hardness of the minerals comprising the aggregate. Pure limestones, i.e., pure calcium carbonate, characteristically exhibit the poorest skid resistance among the major aggregate sources. Limestones contain a wide variety of mineralogic compositions. Gray (110) observes that "...blanket rejections of limestone for skid resistance purposes solely because they belong to this heterogeneous trade name group may result, in many cases, in the refusal to consider perfectly adequate materials."

Soils and Related Factors

Soil Origin and Texture

Many definitions of the term soil exist within the sciences of geology and pedology as well as within Civil Engineering. Each definition intrinsically fits the particular area of interest. An engineer, may define soil as "...everything from rubbish to sand, gravel, silt, clay, shale, partly cemented sandstone, soft or badly shattered rock; everything except solid rock" (211). The slaking test is ordinarily applied to distinguish solid rock, but there will obviously be a number of borderline cases.

An important aspect of soils is their mode of origin, i.e., transported or non-transported. Transporting agencies are ice, water, wind and combinations. Non-transported soils have been residually developed by the combination of their physical and chemical environments. Detailed explanations of each mode of origin can be found in many readily available reports (214, 236, 237, 248, 279, 295).

Soils may be divided into size fractions, and the relative amount of these fractions determines the overall descriptor of texture. Particle size distribution or texture is the basis of certain classification schemes viz., the U. S. Department of Agriculture, and forms a basic portion of the Pedologic Soil Classification system. In general, the major limitations of such systems for engineering purposes lies in their failure to identify or measure the relative plasticity characteristics imparted by the clay size fraction. Stating this in another way, two samples of clay possessing an equivalent distribution of clay sizes may vary considerably in their engineering performance due to differences in the type of clay minerals present.

As a consequence, common engineering soil classifications combine textural and plasticity evaluations, e.g., Unified, AASHO and FAA Soil Classification systems. Excellent reviews on the merits of the various classification systems have been presented by Liu (244) and Wahls and Futrell (293).

Poor Subgrade Support Areas

In general, the finer the soil texture and/or the greater the plasticity characteristics of the soil, the poorer the anticipated performance of this material as a subgrade for a highway or airfield pavement. The effect of soil type upon structural pavement analysis must be evaluated in detail against such design factors as type of pavement, traffic considerations and environmental factors. However, it can be stated that due to the relative differences in stress distributing characteristics between a rigid and flexible pavement system, the effect of subgrade support is more important in a layered flexible pavement than a rigid pavement (213).

As defined in this report, the term organic deposit refers to peat bogs, muck lands, and associated swamps and tidal marshes. Areas of organic terrain called muskeg may also be included although this term is usually reserved for the widespread but relatively thin accumulations common north of the U.S.. Various definitions for each of these categories of organic terrain have been stated in the literature (296). In essence, they are primarily connected with various stages of vegetative decomposition and/or high water levels which either saturate most of the ground or completely cover the area in question.

Organic materials are not used in embankments. Other problem materials are avoided for subgrade use as well. Because of their low topographic position, organic foundations for embankments are potentially numerous. A comprehensive technology exists for the handling of such so-called "soft ground" problems. These range from relocation to avoid them, through compressing them in place, to excavation and displacement, and, in rare instances, bridging with a "peat trestle".

High Volume Change Soils

Throughout many areas of the United States, a very important highway design consideration is the swelling and shrinking of subgrades and foundation soils. The two most important prerequisites for potentially high volume changes are the presence of a relatively active clay structure and a combination of climatic conditions which allow alternate drying and saturation of the soil to occur to appreciable depths.

Swelling pressures vary greatly, but, in general, the relatively light "surcharge" of a highway pavement does not afford enough of a counter pressure to prevent volume change. As a result, highway pavements are subject to severe damage through cyclic heaving (swell) and loss of support (shrinkage).

Frost Action and Frost Susceptible Soils

Another important facet of highway design deals with the problems associated with frost action. This problem generally manifests itself in two effects: those induced during the cold or freezing period (heave), and those associated with the warmer melting period (reduced strength).

Detrimental frost action requires three conditions: (a) freezing temperatures, (b) frost susceptible soils, and (c) a source of water (298). Major heaving due to ice lense formation may be expected if a highly susceptible soil is frozen slowly, with water readily available.

In general design analysis, the air freezing index (FI) is often used to quantify the magnitude and duration of cold effects at the site. Frost susceptible soils are generally defined as those soils having greater than 3 to 10% by weight, finer in size than 0.02 mm (243). For purposes of appraising the relative frost susceptibility among soils, the Corps of Engineers has adopted the Frost Rating Classification system. Ratings range from an F-1, indicative of the least frost susceptible soils (gravelly soils with between 3 to 20% finer than 0.02 mm in size), to an F-4, indicative of the most susceptible soils (silts, lean clays, varved clays, etc.).

The problem of reduced strength is accentuated by deep freezing penetration. As thawing proceeds at shallow depths, drainage may be effectively prevented by the underlying still-frozen zone. Since the water present in this zone may be of greater volume than before freezing, due to ice lense growth, the supporting capacity of the subgrade may be dramatically lowered.

INVESTIGATION PROCEDURES

General

The basic approach to achieve the previously defined objectives was to map either materials or the incidence of a potential highway engineering factor or problem for the U.S. or some part thereof. Whenever feasible, the severity of a problem was also rated. Significant input was derived from the sciences of physiography (geomorphology), geology, pedology and climatology, as well as engineering experience. This input was interpreted, summarized and represented in a form deemed most suitable for the unique needs of the highway engineer.

However, while the concept of generalization is simple, its practical implementation in anything approaching optimal form is a most difficult matter. Of foremost concern is the choice of an appropriate level for the generalization. Broad generalizations have limited predictive capabilities; limited or local geographic generalizations require almost as much effort as specific job-location descriptions, and, are difficult to justify economically as a separate step. The course of action adopted in this study was to accept the regional physiographic <u>Section</u> as the base unit for generalization.

The source information varied widely in quantity (and probably in quality as well) from Section to Section. Since the author was almost wholly dependent upon the expressed opinions of others, as extracted from maps, reports, and questionnaires, the validity of his inferences is variable. Another factor which worked to reduce the overall reliability of the conclusions is the scope of the study. In dealing with over three million square miles of geography, and with a multitude of highway factors, no one area or factor received the attention that a researcher would intrinsically desire. It remains for further studies to reexamine the conclusions with a concentration on certain areas and/or factors.

Regional Geomorphology

Information concerning the physiographic and geologic characteristics of the regional units was based heavily, though not entirely, upon the writings of Fenneman (18, 19), Lobeck (38), Thornbury (65), and Woods-Lovell (82). Much valuable information concerning the particular characteristics of many Sections were obtained from many other individual references such as (31) and (84).

The quantity of physiographic mapping available at a continental or national scale was known to the author, but an uncertainty existed as to the availability of larger scale work. Accordingly, a reasonably comprehensive mapping search was conducted. As a result of this effort the following information was located: 40 state physiographic diagrams for 30 states; one new Province diagram; and 6 Subsection diagrams.[1] In several instances, two or three different physiographic interpretations of a given state were located.

The detailed mapping can be placed in one of two broad groupings, directly physiographic, and indirectly physiographic. In the second category are the Agricultural Land Resource maps, which are delineated utilizing not only physiographic concepts but also the relation of land use and management to the factors of soil, climate and topography. In numerous instances, the "physiographic" boundaries were those shown on a land resource or pedologic map.

In addition to the mapping search, a fairly detailed examination of the physiographic boundaries of the basic report units was undertaken.

Highway Design and Construction Factors

Aggregates

Major Objectives

The overall objectives of this phase of the project were to investigate the type and distribution of aggregates used in the United States, and to obtain information concerning any quality problems or limitations inherent to these aggregates. From this, a qualitative estimate was formed of

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[1] For purposes of brevity, these diagrams are not included, although many have been used for the Recommended Highway Engineering-Physiographic Unit System proposed in the Summary and Conclusions.

the potential availability of quality aggregate resources within each of the report Sections.

Methods of Analysis

General

The analysis was comprised of three phases: identification and mapping of potential aggregate sources; identification and correlation of quality problems with the sources, based upon the literature; and collection of current engineering experience through questionnaires directed to each state highway agency.

Mapping

The major types of aggregates mapped were sand-gravel sources and crushed-stone sources. The latter were subdivided into carbonate rocks, granitic/metamorphic complexes, and other igneous (primarily basaltic type) rocks. Several extant state or regional maps of real or potential sources were located in the literature. References (90, 107, 166, 169, 172) were particularly valuable. Where such information was not located, the author attempted to derive it from sources such as generalized state or regional geologic maps, origin-parent material diagrams, and aggregate production data.

The total output of individual counties[1] producing sand-gravel and/or crushed stone (irrespective of type) was obtained and plotted for 1964 from reference (189). In addition, state productions of sand-gravel and crushed stone were obtained and mapped on the basis of output ratio of sand-gravel

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[1] Or parishes in Louisiana

to crushed stone. This information was obtained from references (175, 189). The factors of population and market demand obviously influence such data, but they did supply perspective and guidance in certain areas where such was otherwise lacking.

Aggregate Problems

Many aggregate problems are identified and described in the literature, particularly reference (144). This information was supplemented by that obtained through the materials questionnaire.

Materials Questionnaire

The questionnaire responses provided a current resume relative to aggregate types, uses, quality and availability. A sample response (from the state of Missouri) is shown in Appendix A.

The questionnaire was written for coded answers that could be applied to the basic Sections with a minimum of effort. It was composed of seven basic questions and three enclosures. The questionnaire was mailed to each state with Column 1 (material type) of Enclosure 1 completed. This initial listing of probable aggregate type was based primarily on an examination of the "non-matallic" mineral industry summary for each state in reference (188). References (169) and (172) provided supplementary information.

Several general problems common to the physical and chemical properties of aggregates used in both concrete and bituminous pavements are listed in Question III. This problem listing is not all inclusive in nature, nor is each problem unique in itself. For example, the chemical reactions for concrete aggregates would also be considered a durability problem. Another code permitted the respondent to rate the relative severity of any reported problem. Question IV dealt with the general functional uses of each aggregate type.

Answers to Questions I thru IV were recorded in specified forms on Enclosure I. Therefore this enclosure provides a summation, with respect to basic report units, of aggregate uses, problems, and problem severities.

Question V asked the respondent to indicate on Enclosure 3 the approximate boundaries of areas lacking in suitable aggregates. Questions VI and VII attempted to identify areas where the availability of aggregates and/or cementing medium played a major role in the selection of pavement type (portland cement or bituminous).

General Limitations of Analysis

Practical Limitations

Input information on aggregates was interpreted for mapping, according to physiographic units. There are several difficulties inherent to such an interpretation.

For example, aggregates can be quarried in one physiographic unit and transported for use (and subsequent performance) in another unit. Although the author attempted to remove this factor from his interpretations, it was not always possible to do so with confidence. Population densities, and the consequent relative demand for aggregates, introduces an additional problem. The natural tendancy is to overestimate the aggregate availability in high density areas and to underestimate the potential where the density is low. Still another factor is the relative size and shape of the physiographic units. A small unit may be inherently impoverished in aggregate sources due to its geology, but the existance of quality sources in an adjacent unit effectively negates the potential shortage. The large unit, on the other hand, may contain enough geologic variability to admit both potential abundance and scarcity, depending on the local area.

Mapping Limitations

The several different methods of mapping aggregate factors have been previously noted. As pointed out, there were several broad geographic areas where the author's definition of potential aggregate areas was very qualitative.

In addition, because of the extreme variability in characteristics and performance of crushed sandstone, combined with the limited information concerning actual production of crushed sandstone, the mapping of sandstone bedrock areas as potential sources was not undertaken on a national scale.

Another very important and limiting factor concerns the distribution of sand-gravel sources. An attempt was made to map <u>major</u> potential river and stream deposits in addition to areas associated with other modes of origin. However, since stream deposits can be quite localized, they will not show on any but a very large scale map. (Since this difficulty is encountered to some degree with all aggregate types, the generalized source mapping must be supplemented with at least as much information as is contained in the unit descriptions of this text.)

Quality Limitations

The criteria of aggregate acceptance or rejection is dependent not only upon the particular specifications of a given jurisdictional unit, e.g., state, but also upon the particular use of the aggregate. As a consequence, a particular aggregate source may be acceptable for a given use in one portion of the country while in another location it could be rejected. Differences in service environments account for a part of the discrepancy while relative scarcity of aggregates, and simple differences in opinion also contribute. As a great deal of information concerning aggregate problems was obtained from state units and then transformed for the basic report units, the factor of differing criteria between jurisdictional units should be kept in mind.

Soils and Related Factors

Soil Origin and Texture

Major Objective

The major objective of this phase of the study was to map a generalized distribution of soil origin and texture for the U. S., and accordingly, to define (to a rather small scale) the distributions within each report unit.

Method of Analysis

For the examination of the factor of soil origin, primary emphasis was placed on the work conducted by Jenkins et. al. (234). Numerous other individual state references, maps, and regional geomorphic descriptions provided supplemental information.

The generalized soil textural map of the United States was developed to a scale of 1:2,500,00 which corresponded to the scale of the national geologic map (269) as well as the pedologic map of the U.S. by the U.S.D.A. (231).

Many references were consulted in the preparation of the map. Principal among these were distribution reports and maps developed for national, regional, or state coverage.

Within the national group were references (232, 236, 250, 279, 295, 296). Regional soil references were available for the western United States (294), north central region (277), southeast region (287) and the northeastern United States (263). Many individual state soil maps were also heavily used for soil data. The references varied widely in content and in data of preparation, e.g., only old coverage was available for some geographic areas (246, 247), while very modern information was located for others (227, 289).

The mapping technique was to retain as much detailed soil information as practicable. This, in part, is the reason for the wide variety of legended soil units contained in the map. In many areas, only a very qualitative assessment of the soil conditions could be made due to the limited information available.

Every attempt was made to distinguish and map the general texture of the parent material. Within residual soil areas, this information was not always possible to obtain, and major emphasis was placed on the general texture in the subsoil (B horizon) as well as the weathered parent materials. Perhaps the most obvious limitation of this mapping technique is the possible obscuring of a highly clayey type of B horizon which may produce special highway problems.

Within each basic report unit, a qualitative assessment was made of the frequency of occurrence of each major soil type. This analysis was based primarily upon the results of the generalized mapping.

Poor Subgrade Support Areas

Major Objective

The major purpose of this phase of the project was to rate for each section the combined severity-frequency of occurrence of highly clayey soils, and the frequency of occurrence of organic deposits.

Method of Analysis

The qualitative assessment of poor subgrade areas within each unit was based primarily upon an examination of the national textural map and supplementary soil descriptions.

High Volume Change Soils

Major Objective

In this phase of the project, the major purpose was to assess qualitatively the relative frequency of occurrence of high volume change soils within the Sections.

Methods of Analysis[1]

Three sources of input were available: (1) reports in the literature of occurrences of high volume change problems within the Continental United States; (2) predictions of swelling soils in pedologic mapping and (3) predictions from geologic mapping. Two distribution maps were drawn; one based upon the pedologic input, and one for the geologic information.

Frequency of occurrence was qualitatively assessed for each method of analysis (pedologic and geologic), within each Section. A final rating of high volume change frequency within each unit was taken as the higher rating given by the two methods of analysis.[2]

Characteristics of the Analysis

The geologic and the pedologic-based mappings reflect the potential of the mapped unit to produce swelling problems, but do not attempt to rate the degree of the potential. The generalized prediction is also significantly influenced by the scale of the mapping. Reported problems of swelling difficulties with engineering structures confirm that the potential has been realized by interaction with the climatic and loading environment.

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[1] The description provided is a combination of the author's effort with that of H. P. Jensen (333).

[2] Several exceptions occurred in areas of surficial transported materials underlain by potential high volume change geologic formations. A detailed discussion of these areas is presented under Results.

Frost Action and Frost Susceptible Soils

Major Objective

The frequency of occurence was determined for frost susceptible soil groupings within the Sections generally lying within the freezing zone. No rating was attached to the severity of subsequent frost problems.

Methods of Analysis

The definition of that portion of the Continental U.S. in which freezing is potentially a significant problem was based upon the work of Sourwine (90). The boundaries suggested by Sourwine were compared with the Section borders, and the Sections were placed wholly, (a) within the frost zone, or (b) outside the frost zone.

In order to ascertain the distribution of frost susceptible soils within the previously defined freezing zone, a composite map was developed, based upon the work of Bloom (90) and Osborne (166). The resultant mapping covered twenty-nine northern states and a portion of Maryland. This map covered most but not all of the area within Sections previously defined as lying within the frost zone. The author rated the frequency of occurrence of frost susceptible soils in each Section by combining the methods of Bloom (90)[1], with an examination of the generalized soil textural map of the United

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[1] Bloom (90), after work by Haas, and using the Corps of Engineers system, considered sands and loamy sands as F-2; silty clay loam, clay loam, silty clay and clay as F-3 and sandy loam, loam, silt loam and silt as F-4.

States.

Characteristics of the Analysis

Several minor difficulties were introduced by the differing generalizations effected by Bloom, Osborne and the author. In many cases, continuity of frost susceptible soil type was not maintained through political borders and the author subsequently modified many of these areas to achieve it. Numerous other small difficulties had to be resolved, e. g., differences in base maps, boundaries, soil units generalized and the like.

RESULTS

Physiography (Geomorphology)

Summary of Basic Report Units

Description and Location

The basic physiographic units were bounded and named in essentially the form suggested by Woods and Lovell (82). Table 4 lists each basic report Province and Section, and provides an alpha-numeric code for identification.[1] Table 5 keys the Sections to the states of the U. S. Individual Province and Section diagrams are contained within Appendix D.

Areas

Approximate areas of each Section and Province were determined by planimetering a national map with a scale of 1:5,000,000. The area of the U.S. (exclusive of Hawaii and Alaska) was taken as 3,022,396 square miles (26). Table 6 summarizes area data keyed to the unit code of Table 4.

Geomorphic Characteristics

Table 7 summarizes the general geomorphic characteristics of each report Section. This table is not meant to

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[1] This alpha-numeric code is frequently used throughout the text. It differs from the references by lacking the underline. For example (18) is a reference, while (18) is a unit identification code.

Table 4

Physiographic Unit Code

1. Western Mountains of the Pacific Coast Range Province
    a. Olympic Mountain Section
    b. Oregon Coast Range Section
    c. Klamath Mountain Section
    d. California Coast Range Section
    e. Los Angeles Range Section

2. Sierra - Cascade Province
    a. Northern Cascade Mountain Section
    b. Southern Cascade Mountain Section
    c. Sierra Nevada Section
    d. Lower California Section

3. Pacific Troughs Province
    a. Puget Sound Section
    b. Willamette Valley Section
    c. California Valley Section

4. Columbia Plateau Province
    a. Walla-Walla Section
    b. Blue Mountain Section
    c. Snake River Plains Section
    d. Payette Section
    e. Harney Section

5. Basin and Range Province
    a. Great (Closed) Basin Section
    b. Sonoran Desert Section
    c. Salton Trough Section
    d. Open Basin (Mexican Highland) Section
    e. Sacramento Highland Section
    f. Great Bend Highland Section

6. Colorado Plateau Province
    a. High Plateaus of Utah Section
    b. Uinta Basin Section
    c. Canyon Lands Section
    d. Navajo Section
    e. Grand Canyon Section
    f. Datil Section

7. Northern Rocky Mountain Province
    a. Montana Section
    b. Bitteroot Section
    c. Salmon River Section

8. Middle Rocky Mountain Province
    a. Yellowstone Section
    b. Bighorn Mountain Section
    c. Wind River Mountain Section
    d. Wasatch Section
    e. Uinta Mountain Section

9. Southern Rocky Mountain Province
    a. Front Range
    b. Western Section
    c. San Juan Mountain Section

10. Great Plains Province
    a. Glaciated Missouri Plateau Section
    b. Unglaciated Missouri Plateau Sectin
    c. Bighorn Basin Section
    d. Wyoming Basin Section
    e. Black Hills Section
    f. High Plains Section
    g. Colorado Piedmont Section
    h. Raton Upland Section
    i. Pecos Valley Section
    j. Plains Border Section
    k. Central Texas Mineral Section
    l. Edwards Plateau Section
    m. Osage Plains Section

11. Central and Eastern Lowlands Province
    a. St. Lawrence Lowland Section
    b. Champlain Lowland Section
    c. Hudson River Valley Section
    d. Mohawk River Valley Section
    e. Eastern Lakes and Lacustrine Section
    f. Central Till Plain Section
    g. Driftless Section
    h. Western Lakes and Lacustrine Section
    i. Dissected Loessial and Till Plain Section

12. Laurentian Upland Province
    a. Superior Upland Section
    b. Adirondack Section

13. Ozark and Ouachita Province
    a. St. Francois Mountain Section
    b. Springfield-Salem Plateau Section
    c. 1. Boston Mountain Section
        2. Arkansas Valley Section
        3. Ouachita Mountain Section

14. Interior Low Plateaus Province
    a. Blue Grass Section
    b. Nashville Basin Section
    c. Shawnee Hills Section
    d. Highland Rim Section

15. Appalachian Plateau Province
    a. Catskill Mountain Section
    b. New York Glaciated Section
    c. Allegheny Mountain Section
    d. Kanahwa Section
    e. Cumberland Section

16. Newer Appalachian (Ridge and Valley) Province
    a. Pennsylvania-Maryland-Virginia Section
    b. Tennessee Section

17. Older Appalachian Province
    a. Blue Ridge Section
    b. Piedmont Section

18. Triassic Lowland Province

19. New England Maritime Province
    a. Seaboard Lowland Section
    b. New England Upland Section
    c. Connecticut Lowland Section
    d. White Mountain Section
    e. Green Mountain Section
    f. Taconic Section
    g. Reading Prong Section

20. Atlantic and Gulf Coastal Plain Province
    a. Embayed Section
    b. Sea Island Section
    c. Florida Section
    d. East Gulf Section
    e. Mississippi Loessial Upland Section
    f. Mississippi Alluvial Plain Section
    g. West Gulf Section

Note: Numbers Represent Physiographic Provinces
Letters Represent Physiographic Sections

Table 5

Occurrence of Physiographic Sections Within States

State	Physiographic Unit Code[1]
Alabama	14d; 15e; 16b; 17b; 20d.
Arizona	5a,b,c,d; 6d,e,f.
Arkansas	13b,c1,c2,c3; 20f,g.
California	1c,d,e; 2b,c,d; 3c; 5a,b,c.
Colorado	6b,c,d; 8e; 9a,b,c; 10d,g,h,f.
Connecticut	19b,c,f.
Delaware	17b; 20a.
Florida	20b,c,d.
Georgia	15e; 16b; 17a,b; 20b,d.
Idaho	4a,b,c,d; 5a; 7a,b,c; 8a,d.
Illinois	11e,f,g,i; 14c; 20d.
Indiana	11e,f; 14a,c,d.
Iowa	11g,h,i.
Kansas	10f,j,m; 11i.
Kentucky	14a,b,c,d; 15d,e; 20d,e,f.
Louisiana	20d,e,f,g.
Maine	19a,b,d.
Maryland	15c; 16a; 17a,b,; 18; 20a.
Massachusetts	19a,b,c,e,f; 20a.
Michigan	11e; 12a.
Minnesota	11g,h,i; 12a.
Mississippi	20d,e,f.
Missouri	10m; 11i; 13a,b; 20f.
Montana	7a,b; 8a,b; 10a,b,c.

Table 5 (cont'd.)

State	Physiographic Unit Code
Nebraska	10b,f,j; 11i.
Nevada	2c; 4c,d; 5a,b.
New Hampshire	19a,b,d.
New Jersey	11c; 18; 19g; 20a.
New Mexico	5d,e; 6d,f; 9a,b,c; 10f,h,i.
New York	11a,b,c,d,e; 12b; 15a,b,d; 18; 19b,f,g.
North Carolina	17a,b; 20a,b.
North Dakota	10a,b; 11h.
Ohio	11e,f; 14a; 15b,d.
Oklahoma	10f,j,m; 13b,c1,c2,c3; 20g.
Oregon	1b,c; 2b; 3b; 4a,b,d,e; 5a.
Pennsylvania	11c,e; 15b,c,d; 16a; 17a,b; 18; 19g; 20a.
Rhode Island	19a,b.
South Carolina	17a,b; 20b.
South Dakota	10a,b,e,f; 11h,i.
Tennessee	14b,d; 15e; 16b; 17a; 20d,e,f.
Texas	5d,e,f; 10f,i,j,k,l,m; 20g.
Utah	5a; 6a,b,c,d,e; 8d,e.
Vermont	11b; 19b,d,e,f.
Virginia	15d,e; 16a,b; 17a,b; 18; 20a.
Washington	1a,b; 2a,b; 3a; 4a,b; 7b.
West Virginia	15c,d; 16a; 17a.
Wisconsin	11e,f,g; 12a.
Wyoming	7a; 8a,b,c,d; 9a,b; 10b,c,d,e,f.

Note: 1. See Table 4 for description of Physiographic Unit Code

Table 6

Area Summary of Basic Report Units

Province	% U.S. Land	Sq. Miles	Section	% of Province	Sq. Miles
1	3.4	102,760			
			a	6.9	7,090
			b	14.9	15,300
			c	19.5	20,040
			d	37.5	38,540
			e	21.2	21,790
					102,760
2	3.0	90,670			
			a	17.8	16,140
			b	39.4	35,720
			c	35.3	32,010
			d	7.5	6,800
					90,670
3	1.4	42,310			
			a	34.3	14,510
			b	11.1	4,700
			c	54.6	23,100
					42,310
4	3.8	114,850			
			a	36.6	42,040
			b	16.6	19,060
			c	15.1	17,340
			d	17.9	20,560
			e	13.8	15,850
					114,850
5	12.0	362,690			
			a	48.4	175,540
			b	15.1	54,770
			c	2.9	10,520
			d	22.6	81,970
			e	6.4	23,210
			f	4.6	16,680
					362,690

Table 6 (cont'd.)

Province	% U.S. Land	Sq. Miles	Section	% of Province	Sq. Miles
6	4.1	123,920			
			a	13.2	16,360
			b	10.2	12,640
			c	21.8	27,010
			d	27.0	33,460
			e	20.3	25,160
			f	7.5	9,290
					123,920
7	3.5	105,780			
			a	41.4	43,800
			b	32.6	34,480
			c	26.0	27,500
					105,780
8	1.5	45,340			
			a	24.8	11,250
			b	20.7	9,380
			c	7.9	3,580
			d	37.8	17,140
			e	8.8	3,990
					45,340
9	2.0	60,450			
			a	41.7	25,210
			b	37.2	22,490
			c	21.1	12,750
					60,450
10	21.6	652,840			
			a	11.2	73,120
			b	18.9	123,390
			c	0.6	3,920
			d	5.4	35,250
			e	1.0	6,530
			f	20.4	133,180
			g	4.0	26,110
			h	2.1	13,710
			i	4.4	28,720
			j	6.1	39,820
			k	3.2	20,890
			l	5.7	37,220
			m	17.0	110,980
					652,840

Table 6 (cont'd.)

Province	% U.S. Land	Sq. Miles	Section	% of Province	Sq. Miles
11	13.0	392,910			
			a	0.5	1,960
			b	0.7	2,750
			c	1.0	3,930
			d	0.6	2,360
			e	22.4	88,010
			f	21.7	85,260
			g	5.2	20,430
			h	25.1	98,630
			i	22.8	89,580
					392,910
12	2.4	72,540			
			a	87.6	63,550
			b	12.4	8,990
13	2.2	66,490			
			a	5.7	3,790
			b	55.4	36,840
			c1	8.4	5,580
			c2	12.8	8,510
			c3	17.7	11,770
					66,490
14	1.7	51,380			
			a	16.3	8,380
			b	5.6	2,880
			c	32.2	16,540
			d	45.9	23,580
					51,380
15	3.4	102,760			
			a	3.2	3,290
			b	21.9	22,500
			c	10.4	10,690
			d	44.7	45,930
			e	19.8	20,350
					102,760
16	1.5	45,340			
			a	57.4	26,020
			b	42.6	19,320
					45,340

Table 6 (cont'd.)

Province	% U.S. Land	Sq. Miles	Section	% of Province	Sq. Miles
17	3.0	90,670			
			a	21.8	19,770
			b	78.2	70,900
					90,670
18	0.2	6,040			
			None	----	----
					6,040
19	2.3	69,520			
			a	17.0	11,820
			b	51.5	35,800
			c	2.7	1,880
			d	16.2	11,260
			e	7.6	5,280
			f	2.5	1,740
			g	2.5	1,740
					69,520
20	14.0	423,140			
			a	8.0	33,850
			b	12.6	53,330
			c	8.2	34,680
			d	21.8	92,240
			e	5.4	22,860
			f	10.8	45,700
			g	33.2	140,480
					423,140
Grand Totals	100.0	3,022,400			3,022,400

Table 7

Geomorphic Summary of Physiographic Sections

	Physiographic Characteristics			Geologic Characteristics		
Section Code	Unit	Elevation	Relief	Material	Structure	Age
1a	Mn	4,8	H	GnM	Cx	8
				IgE*	Vc	6
				S/Ss,Sh*	Ho	5,6
1b	Bg,Val	2-4	S-H	S/Ss,Sh	Ho-Sd,Fo	(3-7)und
				IgE*	Vc	(3-7)und
1c	Mn	3-6,9	H	C	Cx,Fau,Fo	9,(11-17)und
1d	Bg,Val	2-4,7	S-H	S/Ss,Sh	Fo,Fau	(3-10)und
				IgE*	Vc	(3-7)und
				GnM*	Cx	9
1e	Bg,Val	1,4,11	S-H	GnM	Cx,Fau,Fo	9,18
				Wvf		(3-7)und
2a	Mn	6-9	H	GnM	Cx	9
2b	Mn	6-9	S	IgE	Vc-Sd	(3-7)und
				GnM*	Cx	9
2c	Mn	8-13	H	GnM	Cx,Fau	9
2d	Mn	10	H	GnM	Cx,Fau	9
3a	Val	1-2	M	G		2
				IgE	Vc	(3-7)und
				S/Ss,Sh	Ho-Sd	(3-7)und
3b	Val	1	L	Wa		1
				Wvf		(3-7)und
				IgE*	Vc	(3-7)und
3c	Val	1	L	Wvf		(1-2)und
				Wa*		I
4a	Pl,Bg*,Val*	2,6	M-H	(u)IgE	Vc-Ho,Fo	4
				A		2
4b	Mn,Pl*	5-8,9	S	GnM	Cx	9
				S/Ss,Sh,Ls	Ho-Sd	9,10,(11-13)und
				IgE	Vc	(3-7)und
				A*		2
4c	Pn	4-6	S	(u)IgE	Vc-Ho	2
				A		2
4d	Pn,Mn*	6	M	Wl	Ho	4
				IgE	Vc-Ho	(1-7)und
4e	Pl	4	M	IgE	Vc-Ho	(1-7)und
5a	Bg,Bs	5,10	S	Wvf		1,2
				C	Cx,Fau,Fo	Cx
5b	Bs,Bg	2,4	M	Wvf		1,2
				C	Cx,Fau	Cx
5c	Bs	0	L	Wvf-a	Fau	1,2
				IgE*	Vc	(3-7)und
5d	Bs,Bg	5,10	M	Wvf		1,2
				C	Cx,Fau,Fo	Cx
5e	Pl,Bs	5-6,8-10	S	S/Ls,Ss	Ho,Fo,Fau	11
				Wvf		1,2
				IgE*	Vc	(3-7)und
5f	Mn,Pn,Bs	4-5,9	H	IgE	Vc	(3-7)und
				S/Ls	Ho-Sd,Fau	8
				Wvf		1,2
				GnM	Cx	(3-7)und
6a	Pl,Val*	9-11	H	S/Ss,Sh	Ho,Fau	(3-7)und
				IgE	Vc	(3-7)und
				S/Ss,Sh*	Ho,Fau	8,9
6b	Pl	8-10	H	S/Sh,Ss,Ls	Ho-Std	(3-7)und
				IgE*	Vc-Ho	(3-7)und
6c	Pl	4-10	H	S/Ss,Sh	Ho-Std,Fo	8-10
				IgE*	Vc	(3-7)und
6d	Pl	5-8	M	S/Ss,Sh	Ho-Sd	8
				S/Ss,Sh*	Ho-Sd	(3-7)und,9,10
				IgE*	Vc	(3-7)und
6e	Pl,Mn	8-11	M-S	S/Ls,Ss,Sh	Sd,Fau	11
				IgE	Vc	(1-7)und
6f	Pl,Mn	6-9	S	IgE	Vc,Ho	(1-7)und
				S/Ss,Sh,Ls	Ho-Sd	8,9
				GnM*	Cx	18
				S/Ls,Ss,Sh*	Sd-Std	11
7a	Bs,Mn,Bg	10	H	GnM	Cx,Fau,Fo	18
				S/und	Cx,Fau	(11-17)und
				Wl-vf	Fau	(3-7)und
				C	Fau,Fo,Cx	Cx
				G*		2
7b	Mn,Bg	9	H	GnM	Cx	9

See Table legend and notes on last page of Table.

Table 7 (Cont'd)

	Physiographic Characteristics			Geologic Characteristics		
Section Code	Unit	Elevation	Relief	Material	Structure	Age
7c	Mn	9	H	GnM	Cx	9
				IgE*	Vc	(3-7)und
				S/und*	Cx	(11-17)und
				G*		2
8a	Mn,Pl	9	H	IgE	Vc	(3-7)und
				GnM*	Cx	18
8b	Mn,Bg	10	H	GnM	Cx	18
				S/Ss,Sh,Ls*	Std	(8-10)und
8c	Mn,Bg	12	H	GnM	Cx	18
				S/Ss,Sh,Ls*	Std	(8-10)und
8d	Mn,Bs*	12	S	S/Ss,Sh,Ls	Fau,Fo	(8-10)und
				GnM*	Cx	18
				IgE*	Vc	4
				G*		2
				Wvf*	Ho	(3-8)und
8e	Mn	12	H	GnM	Cx	18
				S/Ss,Sh,Ls*	Std	(8-10)und
9a	Mn	14	H	GnM	Cx	18
				S/Ss,Sh,Ls*	Std	(8-10)und
9b	Bs,Val, Mn*,Pl*	12	H	S/und	Ho	(3-7)und
				Wvf	Ho	(3-7)und
				G		2
				GnM*	Cx	18
				IgE*	Vc	(3-7)und
9c	Mn,Pl	12	H	IgE	Vc	(3-7)und
				GnM*	Cx	18
				S/und*	Std	(8-10)und
10a	Pl	2-3	L	G		2
				(u)S/Sh,Ss	Ho	(3-7)und,8
10b	Pl,Mn*,Val*	2-4	L-M	S/Sh,Ss,Ls	Ho	(3-7)und,8
				GnM*	Cx	18
				IgE*	Vc	(3-7)und
10c	Bs	5-6	S	S/Ss,Sh	Ho-Std	(3-7)und
10d	Bs,Mn*	7-9	M-H	S/Ss,Sh	Ho-Std,Fo	(3-7)und
				S/Ss,Sh	Ho-Std	8
				IgE*	Vc	(3-7)und
				GnM*	Cx	18
10e	Mn,Pl*	5-7	S-H	GnM	Cx	18
				S/Ls*	Sd-Std	11
				S/Sh*	Sd-Std	10
				S/Ss*	Ho-Std	8
				IgE*	Vc	(3-7)und
10f	Pn	3-4	I	Wvf	Ho-Sd	(3-7)und
				A*		2
10g	Pl	4-7	M	S/Ss,Sh,Ls	Ho-Std	(3-7)und,8
				IgE*	Vc	(3-7)und
10h	Pl,Mn	6-9,13	S	S/Ss,Sh,Ls	Ho-Std	(3-7)und,8
				IgE*	Vc-Ho	(3-7)und
				GnM*	Cx	
10i	Val	2-5	M-S	S/Sh,Ss,Ls	Ho-Sd	10-11
10j	Pn	1-2	M	S/Ss,Sh	Ho-Sd	11
				S/Ss,Ls,Sh	Ho-Sd	8
				Wvf		(3-7)und
				Wa		1
				A		2
10k	Pl,Mn*	2	M-S	S/Ls	Ho	8
				S/Ss,Sh	Ho	12
				S/Ls,Ss,Sh*	Sd-Std,Fau	16,17
				GnM*	Cx	18
10l	Pl	2	M-S	S/Ls	Ho-Sd	8
10m	Pn,Mn*	1-2	M	S/Ls,Sh,Ss	Ho-Sd	11
				S/Ls,Ss,Sh	Ho-Sd	12
				GnM*	Cx	18
				IgE*	Vc	18
				S/Ls,Ss,Sh*	Sd-Std	16,17
				Wa*		1
11a	Pn	1	I	G		2
				(u)S/Ls,Ss;Sh	Ho-Std	16,17
11b	Pn	1	I	G		2
				(u)S/Ls,Ss,Sh	Ho-Std	16,17
11c	Pn,Val	1-2	M	G		2
				(u)S/Ls,Sh	Fo	16
				(u)S/Ss	Fo	14
				(u)GnM	Fo	17
11d	Pn,Val	1-2	S	G		2
				(u)S/Sh,Ls,Ss	Ho-Std	16
				(u)S/Ss*	Ho-Std	15
11e	Pn	1	M	G		2
				(u)S/und	Ho-Sd	(12-17)
				(u)GnM*	Cx	18
11f	Pn	1	L	G		2
				A*		2
				(u)S/und	Ho-Sd	(12-16)

Table 7 (Con'd)

Section Code	Physiographic Characteristics			Geologic Characteristics		
	Unit	Elevation	Relief	Material	Structure	Age
11g	Pn	2	M	S/Ss,Sh	Ho-Sd	17
				(u)S/und*	Ho-Sd	15,16,18
				A*		2
11h	Pn	2	I	G		2
				(u)S/Ss,Sh	Ho-Sd	8
				(u)S/und*	Ho-Sd	(12-18)
11i	Pn	1	M	G		2
				A		2
				(u)S/und	Ho-Sd	(8,12-14)
				(u)S/und*	Ho-Sd	(11,15-18)*
12a	Pn	2	M	G		2
				(u)GnM	Cx	18
				(u)S/Ss,Sh*	Ho-Sd	17
12b	Pl,Mn	1-4	H	G		2
				(u)GnM	Cx,Fau	18
13a	Mn,Val*	2	S	GnM	Cx	18
				S/Ls,Ss*	Ho-Sd	17
13b	Pl	2	L	S/Ls	Ho-Sd	16
				S/Ls	Ho-Sd	13
13c1	Pl	2-3	S	S/Ss,Sh,Ls	Ho-Sd	12
				S/Sh*	Ho-Sd	14
13c2	Val	1	M	S/Ss,Sh	Fo,Fau	12
				Wa*		1
13c3	Mn,Rg	2-3	S-H	S/Ss,Sn	Fo,Fau	12
14a	Pl	1-2	M	S/Is,Sh	Sd	16
				S/Ls,Sh*	Sd	15
14b	Pl	1-2	M	S/Ls	Sd	16
14c	Pl	1	M	S/Ss,Sh	Sd	12
				S/Ss,Sh,Ls	Sd	13
				Wa*		1
				A*		2
14d	Pl	1-2	M	S/Ls,Sh	Sd	13
				S/Sh,Ss,Is	Sd	14
15a	Pl	4	H	(u)S/Ss,Sh	Ho	14
				G		2
15b	Pl	2	M-S	G		2
				(u)S/Sh,Ss,Is	Ho-Sd	14
				(u)S/Ss*	Ho-Sd	13
				(u)S/Ss,Sh,Is*	Ho-Sd	12
15c	Pl,Rg*	2-4	S	S/Ss,Sh	Ho-Std,Fo	12
				S/Ss	Ho-Std,Fo	12,13
				S/Sh,Is*	Ho-Std,Fo	13
				S/Sh,Ss*	Ho-Std,Fo	14
15d	Pl	3-4	M-S	S/Sh,Ss,Is	Ho	12
				S/Sh,Ls	Ho	11
				S/Ss,Sh,Is	Ho	13
15e	Pl,Mn,Val*	3	M-S	S/Ss,Sh	Ho	12
				S/Ss,Sh*	Fau	12
				S/Ls*	Fo	16
				S/Ls,Ss,Sh	Ho-Sd	13
16a	Rg,Val	1-3	S	S/Ls,Sh,Ss	Fo,Fau	12-17
16b	Val,Rg	1-3	S	S/Ls,Sh,Ss	Fau,Fo	12-17
17a	Mn,Rg	2-6	M-S	GnM	Cx,Fau	17,18
				S/Ls*	Ho	16
17b	Pn,Val*	1-2	L	GnM	Cx	18,(11-17)und
				S/Ss,Sh*	Ho	10
18	Val	1	I	S/Ss,Sh	Ho,Fau	10
				IgE	Vc	10
				S/Ls*	Fo	16
				GnM*	Cx	18
				G*		2
19a	Pn	1	L	G		2
				Wcs		2
				(u)GnM	Cx	18
				(u)S/und	Cx,Ho-Sd	(11-17)und
19b	Pl	1-2,4	M	G		2
				(u)GnM	Cx	18
				(u)S/und	Cx,Ho-Sd	(11-17)und
19c	Val	1	M	G		2
				(u)S/Ss,Sh	Ho,Fau	10
				(u)IgE	Vc	10
19d	Mn	4,6	H	GnM	Cx	18
				G*		2
19e	Mn	2-3,5	H	GnM	Cx,Fo	18
				G*		2
19f	Rg,Pl*,Val*	2,4	S	GnM	Cx	18
				GnM*	Cx-Ho	17
				S/Ls*	Ho-Sd	17
				G*		2

Table 7 (Cont'd)

	Physiographic Characteristics			Geologic Characteristics		
Section Code	Unit	Elevation	Relief	Material	Structure	Age
19g	Rg	2	M	GnM	Cx	18
				G*		2
20a	Pn	1	L	Wcs	Ho-Sd	2,(3-7)und
				Wcs	Ho-Sd	8
20b	Pn	1	L	Wcs	Ho-Sd	(3-7)und,8
				Wcs*	Ho-Sd	2
20c	Pn	1	L	Wcs	Ho	2
				Wcs/Ls	Ho-Sd	6
20d	Pn	1	L	Wcs	Ho-Sd	1-8
20e	Pn	1	L	A		2
20f	Pn	1	L	Wa		1
20g	Pn	1	L	Wcs	Ho-Sd,Fau	1-8

I. Table Legend

A. Physiographic Characteristics

Unit	Elevation	Relief
Mn - Mountain	1 - 0 to 1000 ft.	L - Low (0-100 ft)
Rg - Ridge, Range	2 - 1000 to 2000 ft.	M - Moderate (100-500 ft)
Pl - Plateau	3 - etc...	S - Strong (500-1000 ft)
Pn - Plain		H - High (1000 or more ft)
Val - Valley		
Bs - Basin		

B. Geologic Characteristics

Material

G - Glacial drift
A - Windblown
W - Water
  Wl (Lacustrine)
  Wa (Alluvial)
  Wvf (Valley Fill-outwash)
  Wcs (Coastal Sediments)
GnM - Granitic/Metamorphic Complex
IgE - Igneous Extrusive
S - Sedimentary Rocks
  S/Ls (Limestone/Dolomite)
  S/Sh (Shale)
  S/Ss (Sandstone)
C - Combination of Sedimentary, Igneous and Metamorphic

Structure

Ho - Horizontal
Sd - Slightly dipping
Std - Steeply dipping
Fo - Folded
Fau - Faulted
Vc - Volcanic
Cx - Complex

	Age	
1-Recent	Quaternary (1-2)	Cenozoic (1-7)
2-Pleistocene		
3-Pliocene	Tertiary (3-7)	
4-Miocene		
5-Oligocene		
6-Eocene		
7-Paleocene		
8-Cretaceous		Mesozoic (8-10)
9-Jurassic		
10-Triassic		
11-Permian		Paleozoic (11-17)
12-Pennsylvanian		
13-Mississippian		
14-Devonian		
15-Silurian		
16-Ordovician		
17-Cambrian		
18-PreCambrian		PreCambrian (18)
Cx-Complex Mixture		

II. Explanatory Notes

1. (*) indicates a minor or variant characteristic compared to the major or modal characteristics of the Section.

2. (und) indicates undifferentiated. This may be applied to material or age (eg...(11-17) und implies age is undifferentiated Paleozoic ...(11-17) implies <u>all</u> systems of Paleozoic Era are present in Section).

3. (u) indicates material (generally consolidated) that underlies a transported material.

replace or substitute for the monumental writings of Fenneman and others. Liberal use has been made of information found in these writings. However, the primary exphasis has been accorded to certain physiographic factors deemed most relevant to highway engineers. These factors are : origins of surficial materials, topography, parent material type and geologic age.

Comparison of Units Among Physiographers

While this report basically follows the physiographic subdivision system of Woods-Lovell (82), several minor differences occur. These changes are primarily within: the Basin and Range Province (5), the Sierra-Cascade Province (2), the Northern Rocky Mountain Province (7), and the Older Appalachian Province (17). They are generally in accord with two distinguished physiographers, viz.,Fenneman or Lobeck. Table 8 is a summary of differences between the basic report units and the various "standard" Physiographic categorizations.

The most probable reason for the variations is the qualitative and subjective nature of the classification criteria. Thus, it is not surprising, for example, that Lobeck and Fenneman place the Osage Plains Section in the Central Lowlands Province, while Woods-Lovell consider that the nonglaciated plains do not belong in a predominately glaciated province.

Other differences may stem from chronology or from variations in special knowledge of particular areas. The

Table B

Differences in Physiographic Categorizations Between Physiographers and Basic Report Units

	Basic Report Units	Woods-Lovell	Fenneman	Lobeck
1.	Western Mtns., Pacific Coast Range Prov.	Western Mtns. or Pacific Coast Ranges	Pacific Border Prov.	Pacific Coast Ranges
a.	Olympic Mtn. Sect.	nd[1]	nd	nd
b.	Oregon Coast Rge. Sect.	nd	nd	nd
c.	Klamath Mtn. Sect.	nd	nd	nd
d.	Calif. Coast Rge. Sect.	nd	nd	nd
e.	Los Angeles Rge. Sect.	nd	nd	nd
2.	Sierra-Cascade Prov.	Eastern Mtns. or Sierra-Cascade-Coast Mtns.	Cascade-Sierra Mtns.	Sierra-Cascade-Coast Mtn. Prov.
a.	Nor. Cascade Mtn. Sect.	Cascade and Sierra Nevada Mtns.	Nor., Mid., Sou. Cascade Mtns.	Cascade Section
b.	Sou. Cascade Mtn. Sect.			
c.	Sierra Nevada Sect.		nd	nd
d.	Lower Calif. Sect.	nd	Lower Calif. Prov.	nd
3.	Pacific Troughs Prov.	nd	Part of Pac. Bord. Prov.	nd
a.	Puget Sound Sect.	nd	Puget Trough Sect.	Puget Sound Sect.
b.	Williamette Valley Sect.	nd		
c.	Calif. Valley Sect.	nd	Calif. Trough Sect.	nd
4.	Columbia Plateau Prov.	nd	nd	nd
a.	Walla-Walla Sect.	nd	nd	nd
b.	Blue Mtn. Sect.	nd	nd	nd
c.	Snake R. Plain Sect.	nd	nd	nd
d.	Payette Sect.	nd	nd	nd
e.	Harney Sect.	nd	nd	nd
5.	Basin and Range Prov.	Basin and Range and Mex. Highlands Provinces	nd	Basin and Range and Mex. Highlands Province
a.	Great (Closed) Basin Sect.	nd	nd	nd
b.	Sonoran Desert Sect.	nd	nd	nd
c.	Salton Trough Sect.	nd	nd	nd
d.	Open Basin (Mex. Highland) Sect.	Sections of the Mex. Highlands Province	Part of Mexican Highlands Sect.	nd
e.	Sacramento High. Sect.		nd	nd
f.	Great Bend High. Sect.		Part of Mexican Highlands Sect.	Sect. of Mexican Highlands Province
6.	Colorado Plateau Prov.	nd	nd	nd
a.	High Plats. of Utah Sect.	nd	nd	nd
b.	Uinta Basin Sect.	nd	nd	nd
c.	Canyon Lands Sect.	nd	nd	nd
d.	Navajo Sect.	nd	nd	nd
e.	Grand Canyon Sect.	nd	nd	nd
f.	Datil Sect.	nd	nd	nd
7.	North. Rocky Mtn. Prov.	nd	nd	nd
a.	Montana Sect.	nd	No subdivision	Including parts of Purcel Rge. and Selkirk Mtns.
b.	Bitterroot Sect.	Includes small portions of Purcell, Selkirk and Colum. Range Sect.		
c.	Salmon River Sect.	nd		nd

[1] The designation "nd" denotes essentially no difference in name or boundary from Basic Report Unit.

Table 8 (cont'd.)

Basic Report Units	Woods-Lovell	Fenneman	Lobeck
8. Middle Rocky Mtn. Prov.	nd	nd	Including Wyoming Basin
a. Yellowstone Sect.	nd	No subdivision	nd
b. Bighorn Mtn. Sect.	nd		nd
c. Wind River Mtn. Sect.	nd		Part of Wyoming Basin Sect.
d. Wasatch Sect.	nd		nd
e. Uinta Mtn. Sect.	nd		nd
9. South. Rocky Mtn. Prov.	nd	nd	nd
a. Front Range	nd	No subdivision	nd
b. Western Section	nd		nd
c. San Juan Mtn. Sect.	nd		nd
10. Great Plains Prov.	nd	Parts of 3 Provinces	Parts of 2 Provinces
a. Glac. Missouri Plat. Sect.	nd	nd	nd
b. Ungl. Missouri Plat. Sect.	nd	nd	nd
c. Bighorn Basin Sect.	nd	Part of Middle Rocky Mtns.	Sect. of Middle Rocky Mtns.
d. Wyoming Basin Sect.	nd	Wyoming Basin Prov.	Sect. of Middle Rocky Mtns.
e. Black Hills Sect.	nd	nd	nd
f. High Plains Sect.	nd	nd	nd
g. Colorado Piedmont Sect.	nd	nd	nd
h. Raton Upland Sect.	nd	nd	nd
i. Pecos Valley Sect.	nd	nd	nd
j. Plains Border Sect.	nd	nd	nd
k. Cent. Texas Mineral Sect.	nd	nd	nd
l. Edwards Plateau Sect.	nd	nd	nd
m. Osage Plains Sect.	nd	Sect. of Cent. Low. Prov.	Sect. of Cent. Low. Prov.
11. Central and Eastern Lowland Province	Central and Eastern Lowlands and Plains	Parts of 4 Provinces	Parts of 2 Provinces
a. St. Lawrence Low. Sect.	nd	Nor. Sect., St. Lawrence V.	Sect. of Newer Appalachian Province
b. Champlain Low. Sect.	nd	Champlain Sect. St. Lawrence V.	Sect. of Newer Appalachian Province
c. Hudson R. Valley Sect.	nd	Sect. of Valley and Ridge Prov.	Sect. of Newer Appalachian Province
d. Mohawk R. Valley Sect.	nd	Sect. of Appalach. Plat. Prov.	Part of East. Lake Sect.
e. E. Lakes and Lacustrine Sect.	nd	Eastern Lake Sect.	Includes Mohawk R. Valley
f. Cent. Till Plain Sect.	nd	nd	nd
g. Driftless Sect.	nd	nd	nd
h. W. Lakes and Lacustrine Sect.	nd	Western Lake Sect.	Western Lake Sect.
i. Dissect. Loess and Till Pl. Sect.	nd	Dissect. Till Plains Sect.	Dissect. Till Plains Sect.
12. Laurentian Upland Prov.	nd	Parts of 2 Provinces	nd
a. Superior Upland Sect.	nd	nd	nd
b. Adirondack Sect.	nd	Adirondack Province	nd
13. Ozark and Ouachita Prov.	nd	Ozark Plateaus and Ouachita Provs.	Ozark and Ouachita Provs.
a. St. Francis Mtn. Sect.	nd	Part of Spring-Salem Plat.	nd
b. Springfield-Salem Plat.	nd	Includes St. Francis Mtns.	nd
c1. Boston Mtn. Sect.	Grouped	nd	nd
c2. Arkansas Valley Sect.		nd	nd
c3. Ouachita Mtn. Sect.		nd	nd

Table 8 (cont'd.)

	Basic Report Units	Woods-Lovell	Fenneman	Lobeck
14.	Interior Low Plateaus Province	nd	nd	nd
	a. Blue Grass Sect.	nd	Lexington Plain	nd
	b. Nashville Basin Sect.	nd	nd	nd
	c. Shawnee Hills Sect.	nd	Suggested; not De-limited	Part of Highland Rim Sect.
	d. Highland Rim Sect.	nd	nd	Includes Shawnee Hills
15.	Appalachian Plateau Province	nd	nd	nd
	a. Catskill Mtn. Sect.	nd	nd	nd
	b. N. Y. Glaciated Sect.	nd	Sou. New York Sect.	New York State Sect.
	c. Allegheny Mtn. Sect.	nd	nd	nd
	d. Kanahwa Sect.	nd	nd	nd
	e. Cumberland Sect.	nd	Subdivided into Mtn. and Plateau Sects.	nd
16.	Newer Appalachian (Ridge and Valley) Province	Ridge and Valley Prov.	Valley and Ridge Prov.	Newer or Folded Appalachian Prov.
	a. Penna.-Md.-Va. Sect.	nd	Middle Section	nd
	b. Tennessee Sect.	nd	nd	nd
17.	Older Appalachian Prov.	No Counterpart	No Counterpart	nd
	a. Blue Ridge Section	Blue Ridge Prov.	Blue Ridge Prov.	nd
	b. Piedmont Section	Piedmont Prov.	Piedmont Upland of the Piedmont Prov.	nd
18.	Triassic Lowland Prov.	nd	Piedmont Lowlands of the Piedmont Prov.	nd
19.	New England Maritime Province	nd	New England Prov.	nd
	a. Seaboard Low. Sect.	nd	nd	nd
	b. N. Eng. Upland Sect.	nd	nd	nd
	c. Connecticut Low. Sect.	nd	Part of N.E. Upland Sect.	nd
	d. White Mtn. Sect.		nd	nd
	e. Green Mtn. Sect.	Grouped	nd	nd
	f. Taconic Sect.		nd	nd
	g. Reading Prong Sect.		Part of N.E. Upland Sect.	Part of N.E. Upland Sect.
20.	Atlantic and Gulf Coastal Plain Prov.	nd	Coastal Plain Prov.	nd
	a. Embayed Sect.	nd	nd	nd
	b. Sea Island Sect.	nd	nd	nd
	c. Florida Sect.	nd	nd	nd
	d. East Gulf Sect.	nd	Includes Miss. Loess. Upland	Includes Miss. Loess. Upland
	e. Miss. Loess. Upld. Sect.	nd	Part of East Gulf Coast Plain	Part of East Gulf Sect.
	f. Miss. Alluv. Pln. Sect.	nd	nd	nd
	g. West Gulf Sect.	nd	nd	nd

physiographic subdividing of Fenneman was completed with the publication of his two companion volumes covering the U.S. (19, 18) in 1931 and 1938, respectively. Lobeck's divisioning was published in 1948; while the work of Woods-Lovell, accomplished in 1958, had a definite engineering perspective. Difference in detail of subdividing is pronounced in the Rocky Mountains, where Fenneman stops at the Province level and Lobeck formally divides into Sections.

Physiographic Boundaries

Definition

Fenneman (18) has stated that each defined physiographic unit"...should be as homogeneous as possible; that is, it should admit of the largest number of general statements before details and exceptions become necessary." In fact, any physiographic unit, except the ultimate landform, consists of two parts: (1) a modal topographic expression developed from a unique set (or sets) of geomorphic control factors, and (2) inherent variations from this modal expression. As a consequence, a physiographic boundary ideally delimits different modal topographic expressions, but of practical necessity admits certain variants within any bounded unit.

Description of Basic Unit Boundaries

A great deal of information was obtained concerning the description of the boundaries of the basic units. This information has been summarized and coded to the physiographic diagrams and is contained within Appendix B. Not all of the borders are described in this Appendix. In particular, most of the Rocky Mountain areas, portions of the Basin and Range Province as well as Columbia Plateau Province have not been summarized.

Types

Physiographic boundaries are either relatively definite or indefinite, depending upon the contrast of adjacent topographic expressions. As Thornbury (65) points out: "An escarpment comes as near as any topographic feature to representing a sharp change from one topographic area to another." He emphasizes the indefinite nature of most boundaries with the following statement. "Classifications of any sort are to a considerable degree artificial. They represent man's attempt to pigeonhole natural phenomena into distinct compartments with sharply drawn boundaries between them. In nature, clear-cut (geomorphic) boundaries are the exception rather than the rule."

The difficulties of defining a boundary between two modal expressions are categorized in Figure 1 as: (1) Interfingering, (2) Gradational (Transistional), (3) Overlapping (Inclusive), and (4) Exclusive.

When viewed at a large scale, Type (1) shows an irregular boundary, either definite or indefinite, between the modal areas. However when reduced to a smaller mapping scale, the detail will be lost and the mapped boundary must be classed as indefinite. An example has been noted by

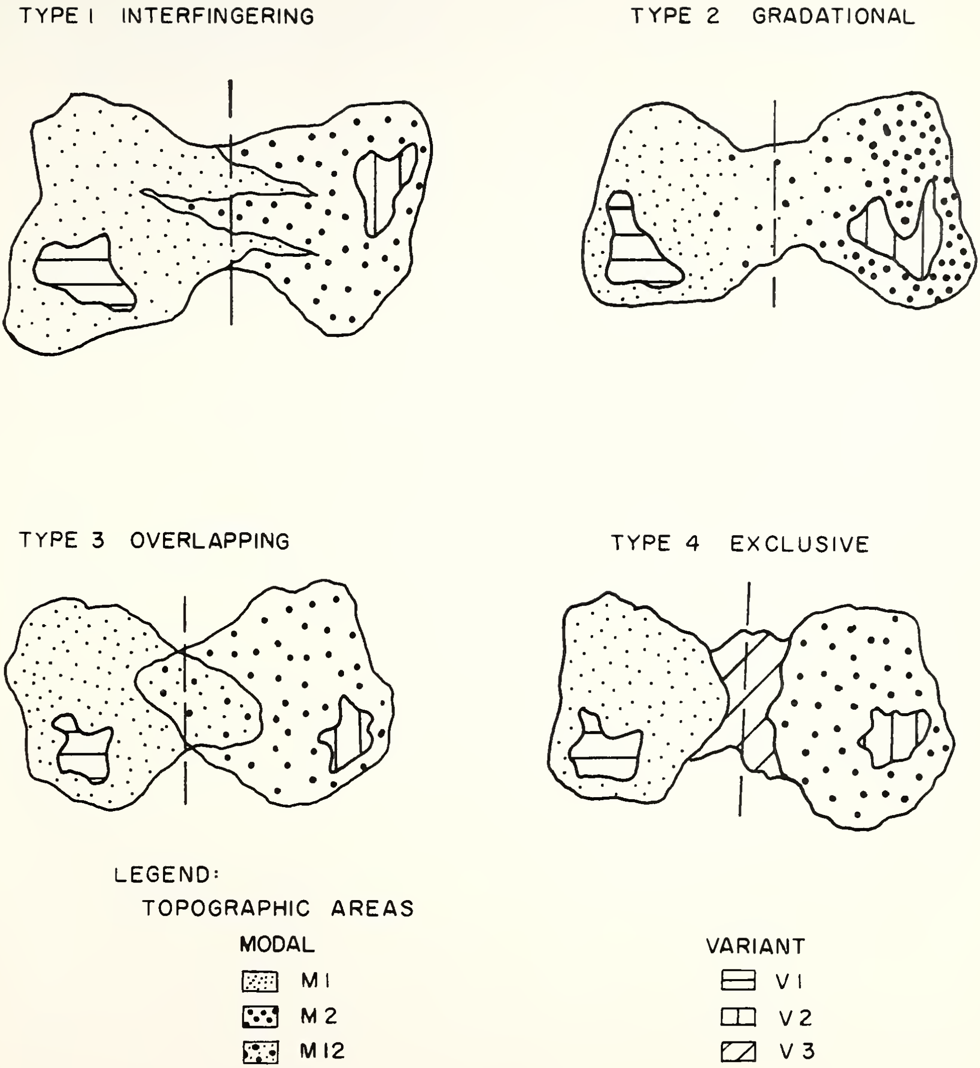


FIG. 1 TYPES OF INDEFINITE BOUNDARIES

Fenneman (18) to exist between the Western Lakes and Lacustrine and the Superior Upland Section. Thornbury (65) states: "The arbitrary straight-line boundary at the west (of the Superior Upland) reflects the difficulty of determining where it should be drawn here."

Type (2) borders are characterized by a gradual merging of modal expressions. An example is the boundary between the Loessial Upland Section and the East Gulf Section. The distinguishing characteristic of the former Section is the surficial cover of the aeolian materials. However, since the thickness of loess gradually decreases from west to east within the Section, the location of the eastern boundary is arbitrary. The Type (2) indefinite boundary can be anticipated where soil origin is used as a discriminating factor, e.g., glacial origin areas bordering residual origin areas.

Type (3) borders occur when a major descriptive characteristic of one modal area extends into an adjacent modal area. An excellent example is the Driftless Section - Superior Upland Section contact. The Driftless Section is characterized by Cambrian sedimentaries and the absence of glacial till. The Superior Upland Section was covered by the ice sheets and is underlain principally by PreCambrian crystalline rocks. However, in the area between the sections, glacial till overlies Cambrian rocks. Hence, within a modal area designated as M_{12} on Figure 1, the glacial origin is common to the Superior Upland Section while the bedrock is that of the Driftless

Section. Another example occurs at the Columbia Plateau-Basin and Range Province border, where the blocky topographic expression of the Basin and Range coexists with the geologic parent material of the Columbia Plateau.

A Type (4) boundary is effected when two modal expressions are separated by a small area of variant expression, i.e., one that is not clearly identified with either modal area. Prime examples occur extensively in the Atlantic and Gulf Coastal Plain Province. In particular, the Embayed Section - Sea Island Section and the Florida Section - Sea Island Section - East Gulf Section borders are of this type.

Other Considerations

From the preceding discussion it is apparent that the guidelines for classifying and bounding physiographic units are qualitative and thus subject to a great deal of individualistic interpretation. Where the topographic expressions lack contrast, recourse to such factors as rock type and age, or even soil type or color, may be required to establish the boundary. One such example occurs where the Triassic Lowland Province adjoins the Atlantic Coastal Plain. Thornbury (65) states, "...there is no marked topographic break; the Fall Line is missing here. However, the two areas are readily recognizable because of the contrast that the red soils of the Triassic Iowland make with the soils of the Coastal Plain".

It is well to focus on the control factors that characterize the modal topographic expressions, rather than on the arbitrary line enclosing them. Or as Fenneman (18) states it: "Some of the boundary lines are almost as sharp in nature as on the map. Some of them represent broad generalizations which are highly important in a rational discussion, even though the lines themselves are hard to locate in the field...No one can be so conscious of the limitations of such a map as the men who labor to produce it. No geological reader will be misled by its seemingly definite committments".

Highway Design and Construction Factors

Aggregates

Questionnaire Response

The overall response to the materials questionnaire was considered good. Thirty-nine of the 48 states answered the entire questionnaire, while four states partially completed it, and five states did not answer any of the questions. As an aid to the development and presentation of the results, the response to the questionnaire is summarized by state in Table 9.

Mapping

Potential Aggregate Areas and Pit and Quarry Locations

Figures 2 to 5 summarize the attempt to delineate regions in the United States where potential regional crushed stone and sand gravel deposits occur. The crushed stone sources are further subdivided into carbonate rocks,

Table 9

Response to Materials Questionnaire by State

State	Response	State	Response
Alabama	Reply-all parts answered	Nebraska	Reply-all parts answered
Arizona	" " " "	Nevada	Reply-no parts answered
Arkansas	" " " "	New Hampshire	Reply-all parts answered
California	Reply-answered questions #5-7	New Jersey	" " " "
Colorado	Reply-all parts answered	New Mexico	Reply-answered question #5
Connecticut	" " " "	New York	Reply-all parts answered
Delaware	" " " "	North Carolina	" " " "
Florida	" " " "	North Dakota	" " " "
Georgia	" " " "	Ohio	" " " "
Idaho	" " " "	Oklahoma	" " " "
Illinois	" " " "	Oregon	" " " "
Indiana	" " " "	Pennsylvania	" " " "
Iowa	" " " "	Rhode Island	No reply
Kansas	" " " "	South Carolina	No reply
Kentucky	Reply-answered questions #4 (partially), #5-7	South Dakota	Reply-all parts answered
		Tennessee	" " " "
Louisiana	Reply-all parts answered	Texas	Reply-answered question #7
Maine	" " " "	Utah	Reply-no parts answered
Maryland	" " " "	Vermont	Reply-all parts answered
Massachusetts	" " " "	Virginia	" " " "
Michigan	" " " "	Washington	" " " "
Minnesota	No reply	West Virginia	" " " "
Mississippi	Reply-all parts answered	Wisconsin	" " " "
Missouri	" " " "	Wyoming	" " " "
Montana	" " " "		

Note: For partial replies, question numbers are referenced to Materials Questionnaire shown in Appendix A.

FIGURE 2
DISTRIBUTION OF GENERALIZED POTENTIAL CRUSHED CARBONATE STONE AREAS

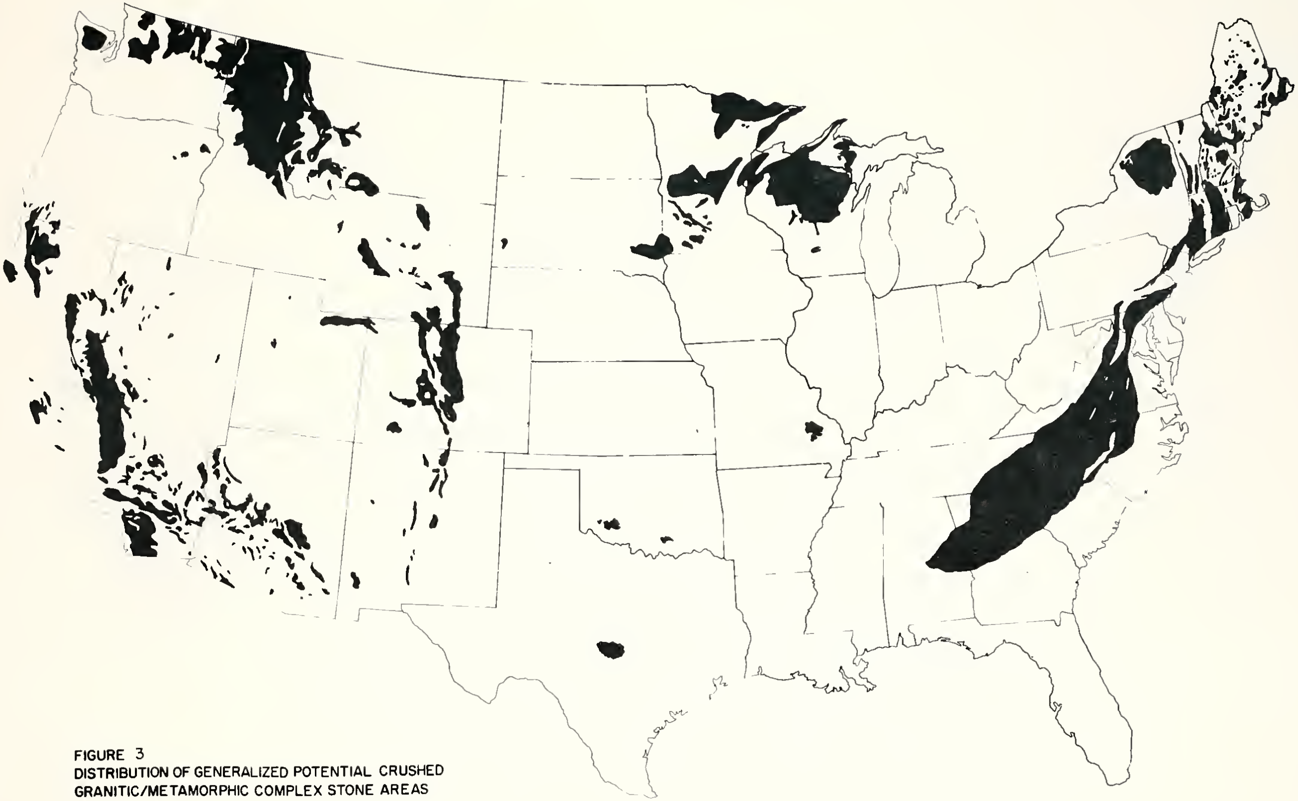


FIGURE 3
DISTRIBUTION OF GENERALIZED POTENTIAL CRUSHED GRANITIC/METAMORPHIC COMPLEX STONE AREAS

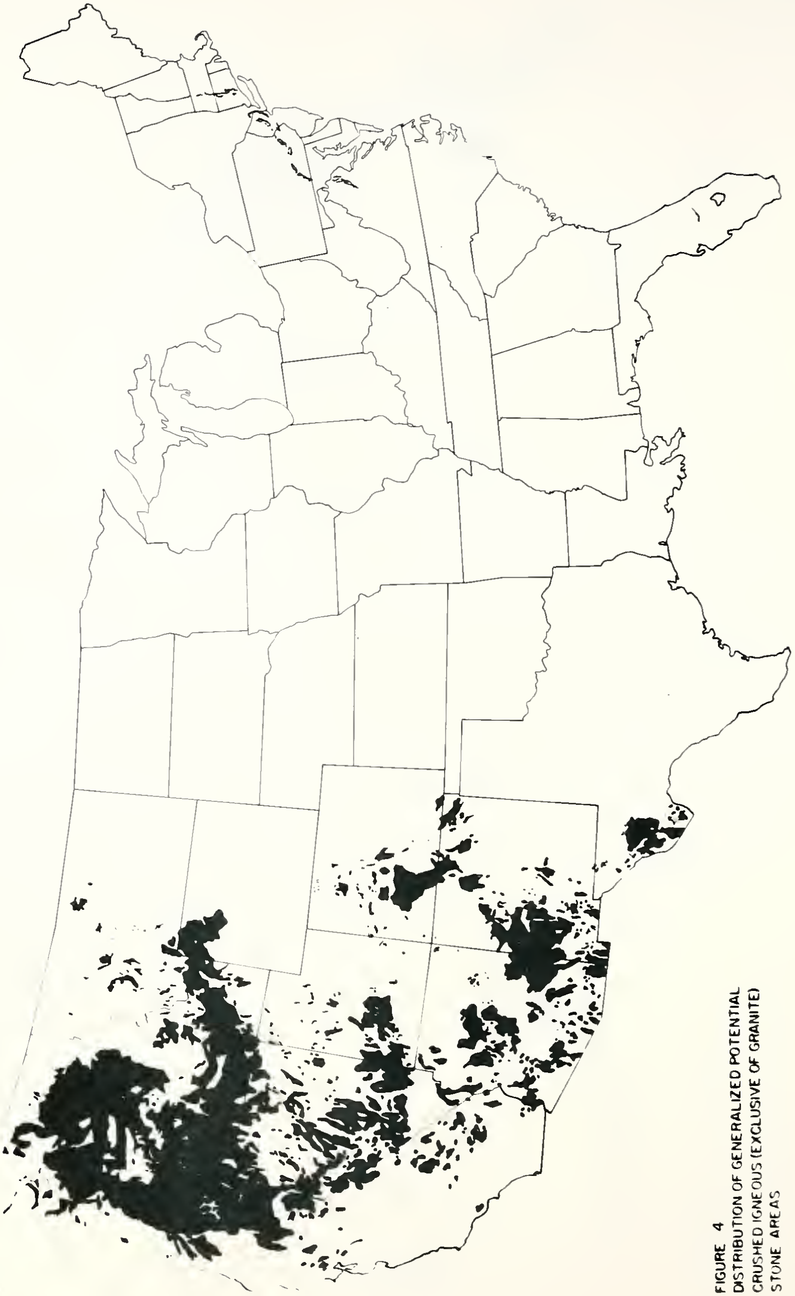


FIGURE 4
DISTRIBUTION OF GENERALIZED POTENTIAL
CRUSHED IGNEOUS (EXCLUSIVE OF GRANITE)
STONE AREAS

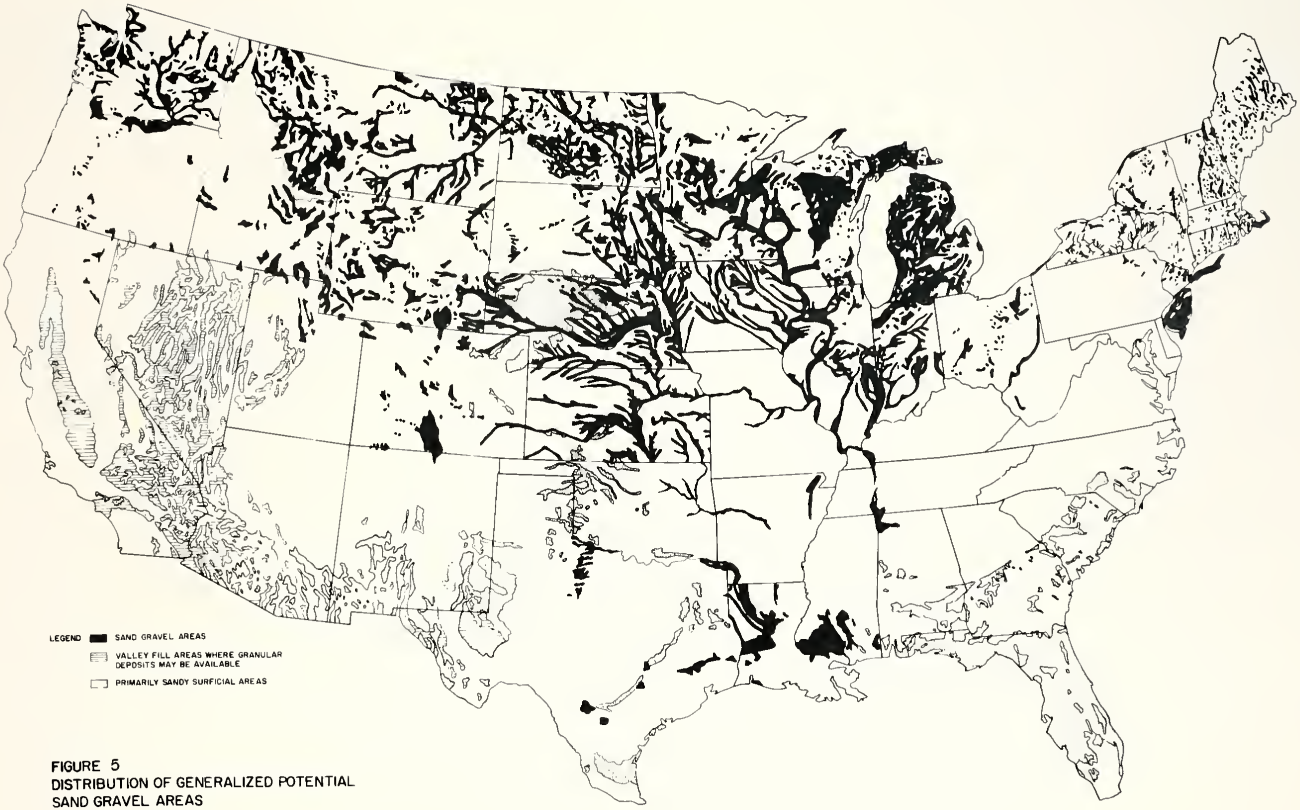


FIGURE 5
DISTRIBUTION OF GENERALIZED POTENTIAL
SAND GRAVEL AREAS

granitic/metamorphic complex type rocks, and other igneous rocks. It is the general opinion of the author that the mapping of the carbonate zones east of the Rocky Mountain - Great Plains border affords a relatively accurate pattern of the distribution of these sources. Not all of the carbonate rock sources have been mapped due to the great difficulty in determining their distribution. Areas where regional carbonate sources may occur but are not mapped are: (a) the northern portion of the New England Upland Section (19b), e.g., in Maine; (b) the Pecos Valley Section (10i); (c) Ranges of the Basin and Range Province (5), composed of carbonate rocks (in part or total); and (d) along the western flank of the Sierra Nevada Section (2c) and other minor areas in California.

The relative accuracy of the granitic/metamorphic complex areas is slightly less than that of the carbonate rocks. For the most part,the former areas were distinguished on the basis of geologic distribution rather than any qualitative estimate of the problems associated with their use as aggregates.

The relative accuracy of definition of the other igneous rock areas is the poorest of the three crushed stone areas. Distribution of these rocks was obtained by a method similar to that for the granitic/metamorphic map.

The relative accuracy of the sand-gravel map is quite variable due to the wide range of references interpreted for assembly of the zones. Further subdivision of types of granular deposits has been made on this map.

Figures 6 to 8 illustrates the distribution of pits and quarries within the United States. Figure 6 shows the available data concerning the distribution of sand and sand-gravel pits.

Figure 7 shows crushed stone quarries irrespective of the major geologic rock type, i. e., metamorphic, igneous, and carbonates. Figure 8 represents the distribution of miscellaneous type sources. Included within this group, but not separately identified, are slag, lightweight aggregate, caliche, clam/oyster shells and coquina.

Table 10 summarizes by state the references from which information concerning potential aggregate areas as well as the pit and quarry distribution was obtained.

Distribution of Counties Not Producing Aggregate Sources

Individual counties within the United States _not_ producing sand-gravel, and crushed stone during 1964 were located from reference (_189_). Figure 9 and 10 show the distribution of those units not producing sand-gravel or crushed stone, respectively. Figure 11 maps counties not producing either, i.e., non-aggregate producing counties. The large size of western counties limited the usefulness of this mapping in generalizing as to potential aggregate areas. Consequently, use of these maps was limited to the eastern part of the United States.

Areas Lacking Quality Aggregates (Materials Questionnaire)

Additional guidance in identifying areas lacking

FIGURE 6
DISTRIBUTION OF SAND AND SAND GRAVEL PITS IN THE U.S.

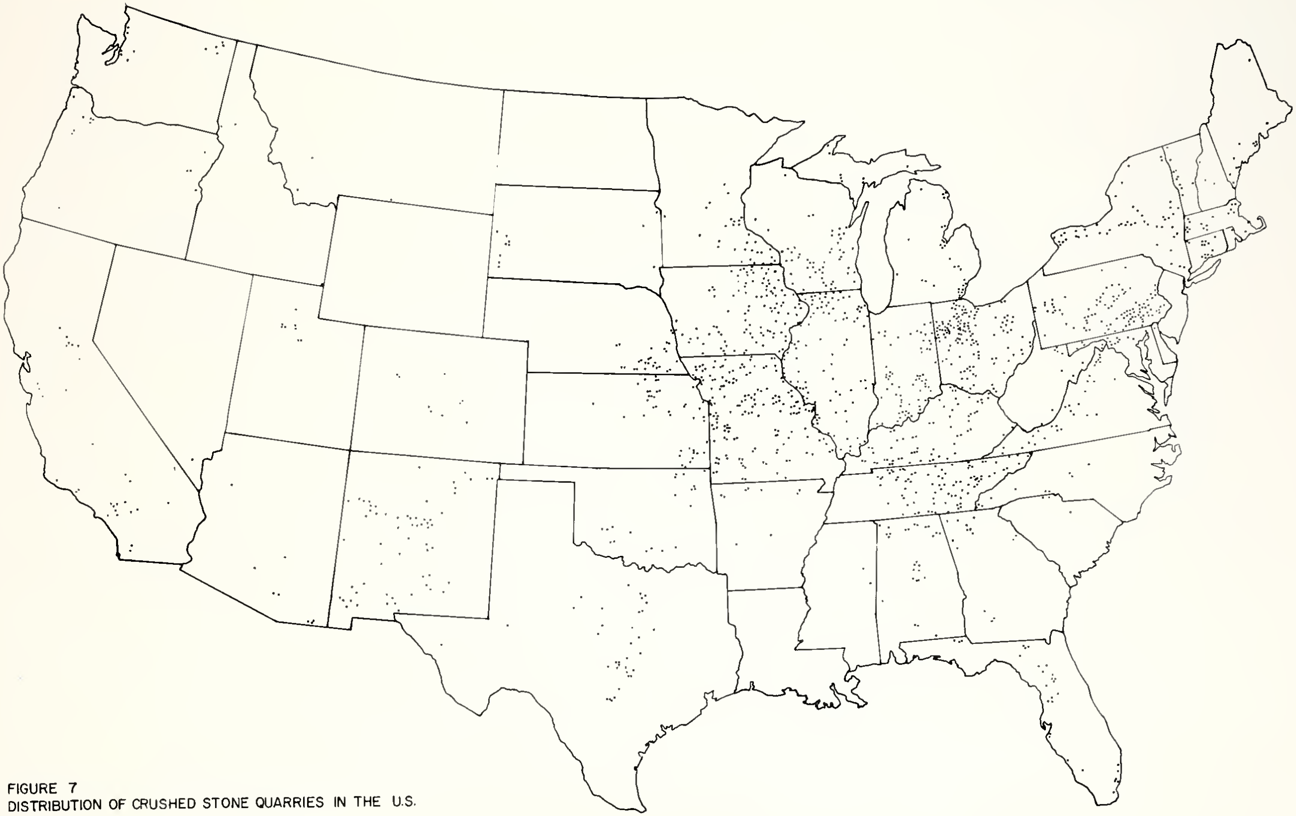


FIGURE 7
DISTRIBUTION OF CRUSHED STONE QUARRIES IN THE U.S.

(INCLUDES SLAG, CALICHE, COQUINA, SHELLS & LIGHTWEIGHT AGGREGATE)

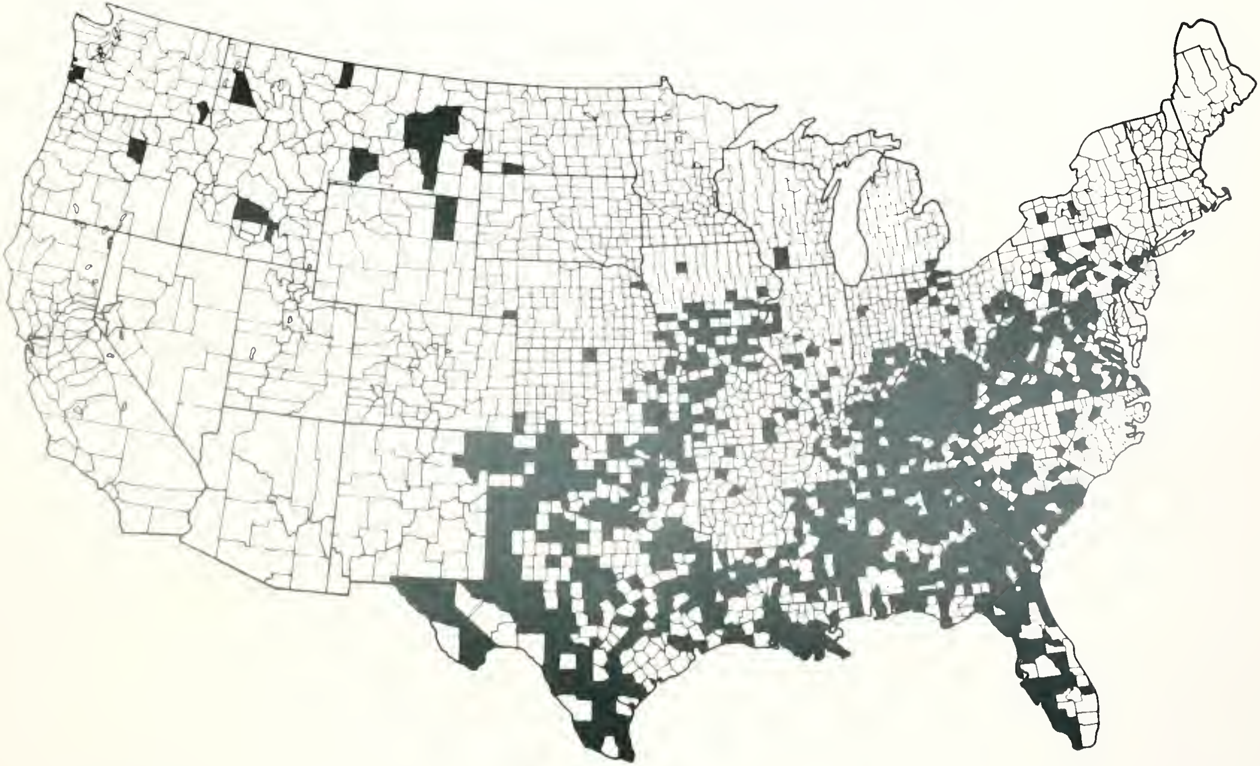
FIGURE 8
DISTRIBUTION OF MISCELLANEOUS AGGREGATE TYPE LOCATIONS IN THE U.S.

Table 10

Reference Summary of State Pit/Quarry-Aggregate Areas

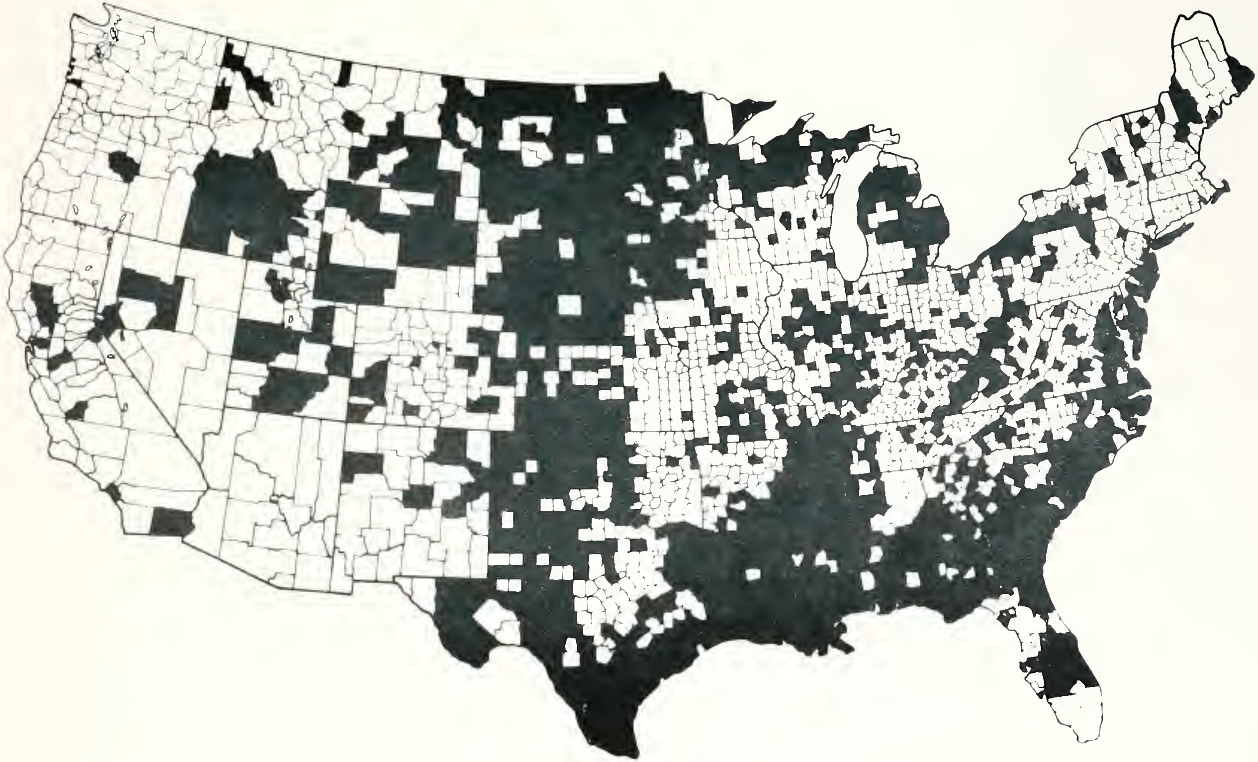
States	Pits/Quarries	Crushed Stone	Sand Gravel
Alabama	(169,172)	(107,137,190)	(123)
Arizona	(169,172)	(190)	(123)
Arkansas	(169,172)	(190)	(123,190)
California	(107,169,172)	(107,190)	(123,204)
Colorado	(166,169,172)	(166,190)	(123,166)
Connecticut	(166,169,172)	(166,190)	(184)
Delaware	(169,172)	(190)	---
Florida	(169,172)	(107)	(123)
Georgia	(169,172)	(123,190)	(123)
Idaho	(166,169,172)	(166,190)	(166,204)
Illinois	(107,169,172)	(90,107,190)	(90)
Indiana	(90,104,169,172)	(90,104,190)	(90)
Iowa	(90,122,169,172)	(90,107,190)	(90,122)
Kansas	(107,169,172)	(90,190)	(90,123)
Kentucky	(169,172)	(107,190)	(123)
Louisiana	(169,172)	---	(123,133)
Maine	(166,169,172)	(166,190)	(184)
Maryland	(169,172)	(190)	---
Massachusetts	(166,169,172)	(166,190)	(184)
Michigan	(169,172)	(107,190)	(90)
Minnesota	(169,172,174)	(90,174,190)	(90,174)
Mississippi	(169,172)	---	(123,204)
Missouri	(169,172)	(90,107,190)	(190)
Montana	(166,169,172)	(166,190)	(166)
Nebraska	(169,172)	(90,190)	(90,123)
Nevada	(169,172)	(190)	(123)
New Hampshire	(166,169,172)	(166,190)	(166,184)
New Jersey	(166,169,172)	(166,190)	(166)
New Mexico	(155,169,172)	(190)	(123)
New York	(107,157,166,169,172)	(107,166)	(137)
North Carolina	(169,172)	(190)	(123)
North Dakota	(90,169,172)	---	(90)
Ohio	(107,169,172)	(90,107,190)	(90)
Oklahoma	(107,169,172)	(107,190)	(123,190)
Oregon	(166,169,172)	(166,190)	(166)
Pennsylvania	(166,169,172)	(107,166,190)	(166)
Rhode Island	(166,169,172)	(190)	(149,184)
South Carolina	(166,169)	(190)	(123)
South Dakota	(90,166,169)	(90,190)	(90)
Tennessee	(107,166,169)	(107,190)	(123)
Texas	(107,166,169)	(107,123,190)	(123)
Utah	(166,169,172)	(190)	(123,166)
Vermont	(166,169,172)	(166,190)	(184)
Virginia	(107,169,172)	(107,137,190)	(190)
Washington	(95,166,169,172)	(190)	(95,166)
West Virginia	(107,166,169)	(107,190)	(166)
Wisconsin	(90,169,172)	(90,190)	(90)
Wyoming	(166,169,172)	(166,190)	(166)

Note: Numbers in parenthesis refer to bibliography number



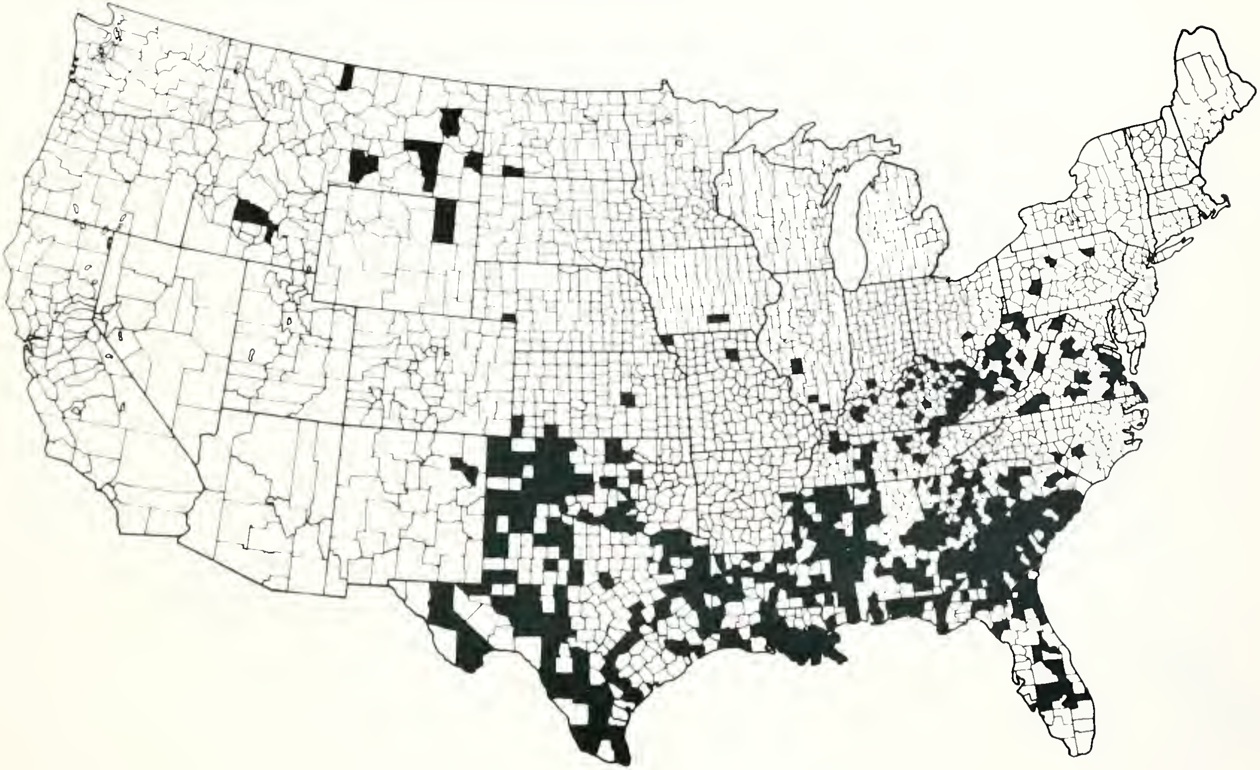
BASED UPON DATA FROM (189)

FIG. 9 DISTRIBUTION OF COUNTIES NOT PRODUCING SAND—GRAVEL IN 1964



BASED UPON DATA FROM (189)

FIG. 10 DISTRIBUTION OF COUNTIES NOT PRODUCING CRUSHED STONE IN 1964



BASED UPON DATA FROM (189)

FIG. 11 DISTRIBUTION OF COUNTIES NOT PRODUCING SAND-GRAVEL NOR CRUSHED STONE IN 1964 quality aggregate resources was obtained from the Materials Questionnaire. Figure 12 shows the aggregate - poor areas reported by the representative state highway officials who completed this portion of the questionnaire. This map was relied upon heavily to provide the estimated potential availability ratings of each basic report unit.

State Aggregate Production Data

Quantitative state production data for sand-gravel and crushed stone sources were obtained from references (175, 189). The sand-gravel data were for 1964, while those for the crushed stone were the reported output for 1958. Differences between states were determined in part by variations in demand caused by size of population and area. In an attempt to "normalize" these production outputs, they were divided by the product of area times population, yielding a "production density".[1] These were arranged in numerical order and divided into three groups or zones.

In addition, a production output ratio of sand-gravel to crushed stone was determined for each state. This ratio was grouped in five zones based upon a visual examination of the numerical ranking. The pertinent data for production tonnage, population and area for each state is presented in the Tables within Appendix C. Figures 13 to 15 portray the zones previously described.

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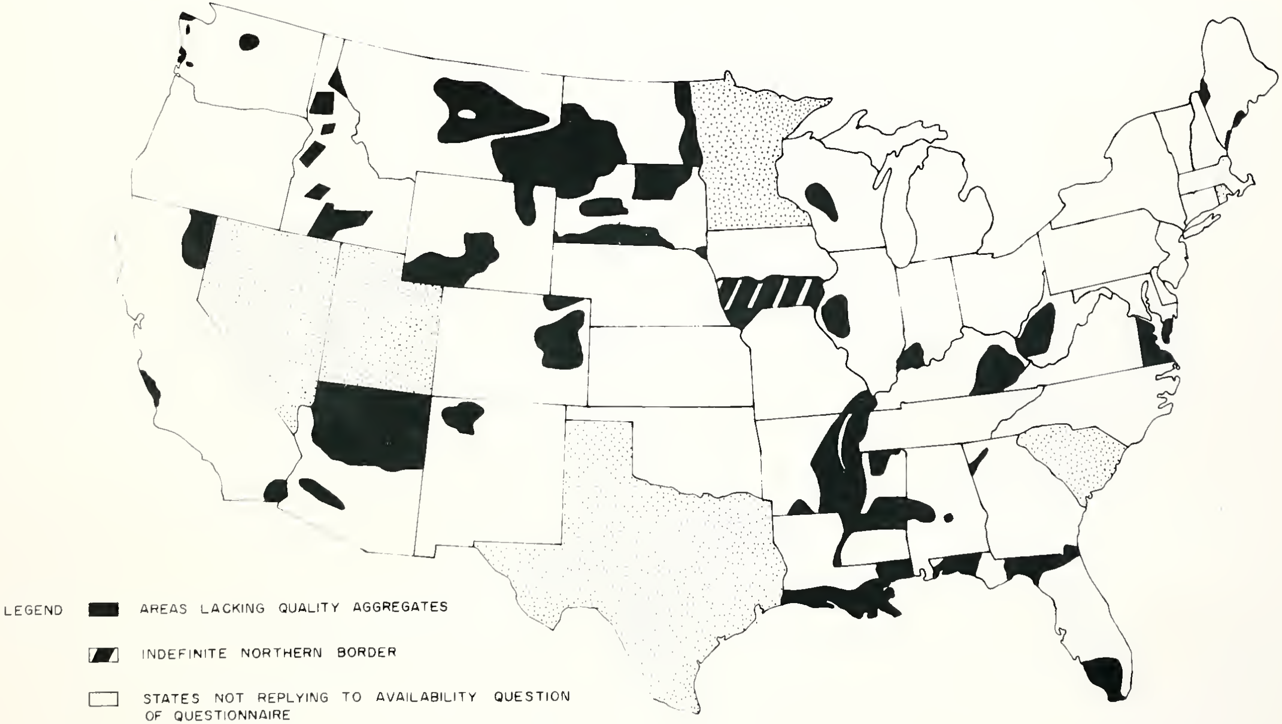
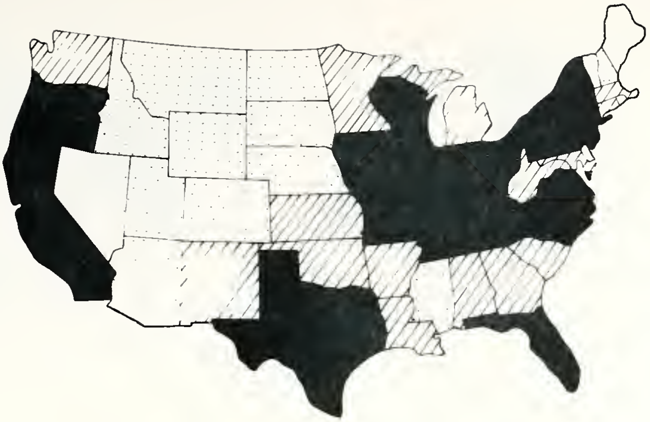
[1] The production density is tons/sq. mi./capita.

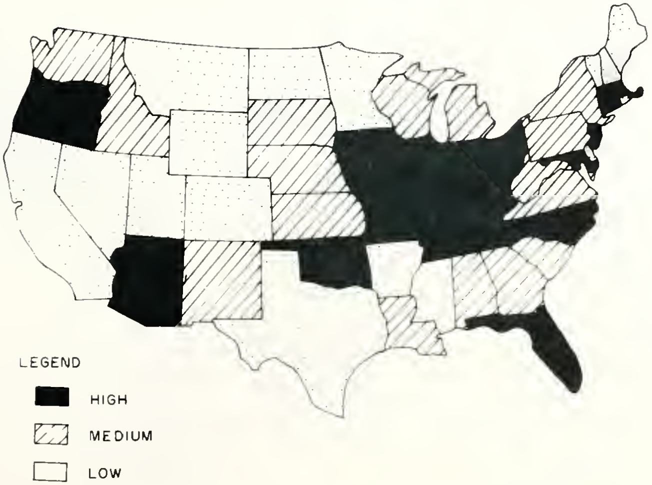


NOTE DATA BASED ON NCHRP MATERIALS QUESTIONNAIRE

FIG. 12 QUESTIONNAIRE SUMMARY OF AREAS LACKING QUALITY AGGREGATES



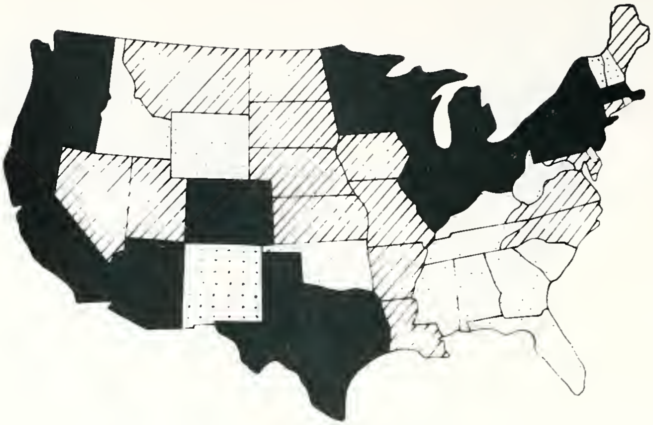
GROUPINGS BASED UPON TOTAL PRODUCTION (TONS)



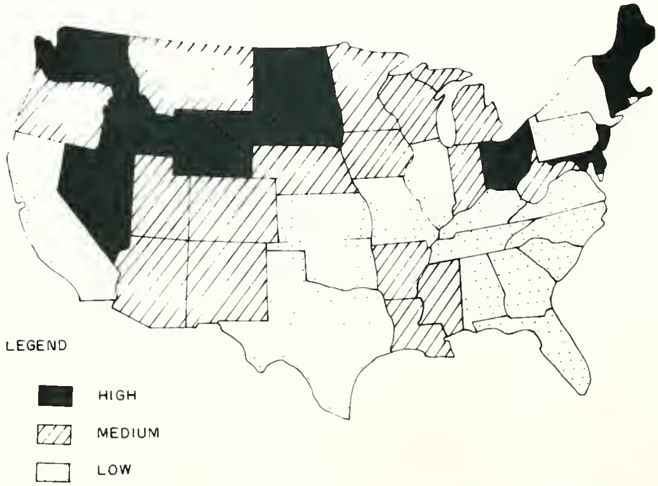
GROUPINGS BASED UPON PRODUCTION DENSITY $= \left(\frac{\text{TONNAGE}}{\text{AREA} \cdot \text{POPULATION}}\right)$

NOTE: DATA BASED UPON 1958 PRODUCTION

FIG. 13 SUMMARY OF STATE CRUSHED STONE PRODUCTION GROUPINGS



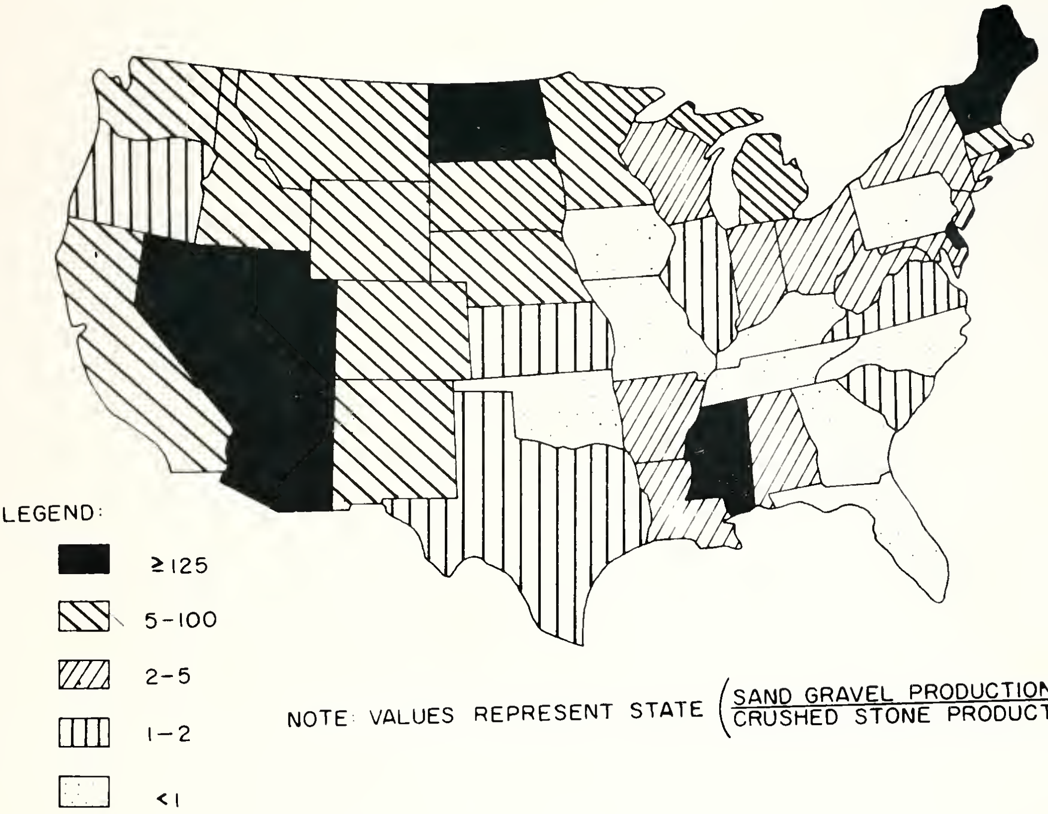
GROUPINGS BASED UPON TOTAL PRODUCTION (TONS)



GROUPINGS BASED UPON PRODUCTION DENSITY $= \left(\frac{\text{TONNAGE}}{\text{AREA} \cdot \text{POPULATION}}\right)$

NOTE: DATA BASED UPON 1964 PRODUCTION

FIG. 14 SUMMARY OF STATE SAND GRAVEL PRODUCTION GROUPINGS



NOTE: VALUES REPRESENT STATE $\left(\frac{\text{SAND GRAVEL PRODUCTION}}{\text{CRUSHED STONE PRODUCTION}}\right)$ RATIO

FIG. 15 STATE SAND GRAVEL/CRUSHED STONE PRODUCTION RATIO GROUPINGS

Aggregate Types

Aggregate Type Code

A wide variety of aggregate sources is used in the highway industry, and a total of thirty-four (34) types are recognized within this report. Table 11 lists these aggregates, keyed to a numerical code. In the table, the aggregates have been grouped as sands and gravels, crushed stone and miscellaneous. The last group consists primarily of artificial aggregates as well as the author's interpretation of several "localized" aggregate sources, e.g., coquina, clam/oyster shell, etc. The crushed stone group has been further subdivided by type of rock. The relation between the coded aggregate number and the general category of aggregate should be apparent (sedimentary crushed stone types have the 10 series, igneous crushed stones are denoted by the 20 series, etc.).

State Usage

A resume of the major aggregate type sources used by each state is given in Table 12. This summary is based primarily upon the responses to the Materials Questionnaire. Where states did not provide such information, input was obtained from references (144, 169, 172, 188), and is accordingly more tentative. Pertinent remarks extracted from the questionnaire responses as well as several by the author, are also shown in the table.

Section Usage

Table 13 is a summary of the aggregate types used

Table 11

Aggregate Type Code

	Key
I. Sands and Gravels	
Sand	1
Gravel	2
Sand Gravel	3
II. Crushed Stone	
A. Sedimentary	
Limestone	10
Dolomite	11
Chert	12
Sandstone	13
Novaculite	14
Argillite	15
B. Igneous	
1. Extrusive	
Basalt	21
Diabase	22
Rhyolite	23
Andesite	24
Greenstone	25
2. Intrusive	
Diorite	26
Gabbro	27
Granite	28
Syenite	29
II. C. Metamorphic	
1. Non-Foliated	
Marble	30
Quartzite	31
Serpentine	32
2. Foliated	
Gneiss	33
Schist	34
Amphibolite	35
III. Miscellaneous	
Limerock	40
Coquina	41
Clam/Oyster Shell	42
Scoria	43
Volcanic Cinders	44
Pumice	45
Expanded Clay	46
Slag	47
Silicified Chalk	48
Caliche	49

Table 12

Summary of General Aggregate Types Used By State

State	Aggregate Type[1]	Remarks
Alabama	2,3,10,11,13,28,30,33,42,47	
Arizona	3,10,13,21,22,23,28,31	
Arkansas	3,10,11,13,14,29,31	
*California[2]	3,10,13,21,28,47	
Colorado	3,10,13,21,28,30,45,47	a) Scoria present in small and scattered areas; not used for any function b) Marble used as Bit. filler only
Connecticut	3,21	a) Granite and Dolomite used only for minor road projects; primarily used for chemical and building material industry
Delaware	1,2,3,33	
Florida	3,10,41,42	a) Sand Gravel generally not suitable for Bit. Base Course
Georgia	3,10,12,28,30,31,33	a) Considerable difference in Limestone of Coastal Region and remainder of state (Ridge and Valley Province)
Idaho	1,2,3,10,11,21,31,47	a) Granite within Rocky Mtn. Section generally not suitable as aggregate source
Illinois	3,10,11,47	

Table 12 (cont'd.)

State	Aggregate Type[1]	Remarks
Indiana	3,10,11,47	
Iowa	3,10,11	
Kansas	3,10,11,12,13,48	
Kentucky	3,10,47	
Louisiana	3,42,46	a) Limestone and Sandstone sources depleted
Maine	3,10,13,28,31	a) Majority of aggregates used are glacial sand/gravel
Maryland	1,2,10,27,28,30,32,33,35,37	
Massachusetts	3,10,21,22,23,26,33	a) Granite not suitable
Michigan	1,2,3,10,11,13,21,23,47	a) Open Hearth Slag not used as Pavement mix aggregate b) Sandstone used for "special" Bit. mix aggregate only c) Limestone and Dolomite used for low traffic Bit. mix d) Gravel used for Bit. mix aggregate is crushed
*Minnesota	3,11,21,28,31	
Mississippi	3,42	a) Note absence of crushed stone group (ie. 10 thru 35)
Missouri	1,2,10,11,13,28	
Montana	3,10,13,15,21,28,31,43,47	a) Uses Sand gravel sources for all of Concrete Pavement Aggregate and most of Bit. Surface mix

Table 12 (cont'd.)

State	Aggregate Type[1]	Remarks
Nebraska	1,2,3,10	
*Nevada	3,10,13,21,28,30,31	
New Hampshire	3,28,31	
New Jersey	1,3,10,11,15,21,22,28,31,33,47	
New Mexico	3,10,21,23,24,26,31,49	a) Aggregate uses not stated in questionnaire
New York	3,10,11,13,22,27,28,30,31,47	a) Gabbro and Granite in Adirondacks obtained from iron mine tailings
North Carolina	2,3,10,26,28,30,33	a) Limestone and Marble limited to 50% of total agg. in Bit. surface mix
North Dakota	3,43	
Ohio	1,2,10,13,47	
Oklahoma	3,10,11,13,28	
Oregon	1,2,3,21	
Pennsylvania	3,10,13,22,28,47	
*Rhode Island	3,10,28	
*South Carolina	3,10,28	
South Dakota	3,10,13,28,31	
Tennessee	3,10,11,13,47	
*Texas	3,10,13,21,28,30,42,47,49	

Table 12 (cont'd.)

State	Aggregate Type[1]	Remarks
*Utah	3,10,13,28,30	a) Aggregate sources are primarily sand gravel deposits
Vermont	3,10,11,25,28,31,32,35	a) Marble not suitable for any use
Virginia	3,10,11,13,21,22,28,30,33,42	
Washington	3,10,13,21,28,31	a) Andesite and Rhyolite not suitable for use
West Virginia	1,3,10,13,47	a) Sandstone used as base/ subbase only
Wisconsin	1,3,11,13,21,28,31	
Wyoming	3,10,11,13,21,28,43	

Notes: [1] See Table 11 for key to aggregate type.

[2] For the states not marked with an asterisk (*) information has been obtained from the materials questionnaire; those marked by an asterisk (*) have been obtained through a literature search as possible aggregate types only.

Table 13

Summary of General Aggregate Types Used by Basic Report Sections

Basic Report Unit	Results of Materials Questionnaire			Results of Literature Review	
Unit Code	Aggregate Type Code[1]	Approx. % of Unit Results Reported For	References[2]	Other Aggregate Types[1]	References[2]
1a	3,13,21	100	(194)	--	--
1b	1,3,13,21	100	(165,194)	--	--
1c	--	0	--	3	(142)
1d	--	0	--	3,10,11,13	(116)
1e	--	0	--	3,10,11,28	(116)
2a	3,13,21,28	100	(194)	--	--
2b	3,10,21	80	(165,194)	--	--
2c	--	0	--	3,10,28	(107,116,142)
2d	--	0	--	3,28	(107,116,142)
3a	3,13,21	100	(194)	--	--
3b	3,21	100	(165)	--	--
3c	--	0	--	3	(142,144,169,172,200)
4a	1,2,3,21	100	(117,165,194)	--	--
4b	1,2,3,21	100	(117,165)	--	--
4c	1,2,3,21,47	(100-)	(117)	--	--
4d	1,2,3,21	(100-)	(117,165)	--	--
4e	2,21	100	(165)	--	--
5a	1,2,3,10,11,21,31	20	(117,151,165,191)	--	--
5b	3,21,23,28	60	(86,151)	--	--
5c	3	25	(86)	--	--
5d	3,10,13,21-24,28,31,44	95	(86,155)	--	--
5e	3,10,31,49	75	(155)	--	--
5f	--	0	--	3,10,21	(190)
6a	3	100	(191)	--	--
6b	3	100	(95,191)	--	--
6c	3,13	100	(95,191)	--	--
6d	3,13,21	100	(86,95,155,191)	--	--
6e	3,21	100	(86)	--	--
6f	3,10,21,44	100	(86,155)	--	--
7a	3,10,13,15,21,28,31,34,47	100	(117,148)	--	--
7b	1,2,3,10,15,21,28,31,34	100	(117,148,194)	--	--
7c	2,3,21	100	(117)	--	--
8a	3,28	100	(117,148,205)	--	--
8b	3,10	100	(148,205)	--	--
8c	3,10,34	100	(205)	--	--
8d	3,10,11,13,34,47	100	(117,191,205)	--	--
8e	3	20	(95)	--	--

Table 13 (cont'd.)

Basic Report Unit	Results of Materials Questionnaire			Results of Literature Review	
Unit Code	Aggregate Type Code[1]	Approx. % of Unit Results Reported For	References[2]	Other Aggregate Types[1]	References[2]
9a	3,10,28	100	(95,155,205)	--	--
9b	3,10,28,30	100	(95,155)	--	--
9c	3,21,31	100	(95,155)	--	--
10a	3	100	(148,160,180)	--	-
10b	1,3,10,13,43	100	(148,150,160,180,205)	--	
10c	3,10,11,13,21	100	(148,205)	--	-
10d	3,10,13,28	100	(95,205)	--	
10e	10,28	100	(180,205)	--	--
10f	1,2,3,10,11,13,28,49	70	(95,125,150,155,162,205)	--	--
10g	3,10,21,47	100	(95)	--	--
10h	3,10,21,26	100	(95,155)	--	--
10i	3,10,49	85	(155)	--	--
10j	1,3,11,13,48	95	(125,150,162)	--	--
10k	--	0	--	3,10	(144,200)
101	--	0	--	3,10	(144,200)
10m	1,2,3,10,11,12,13,28	75	(125,146,162)	--	--
11a	3,10,11	100	(156)	--	--
11b	3,10,11,31	100	(156,192)	--	--
11c	1,3,10,11,13,31,33	100	(154,156,167)	--	--
11d	3,10,11	100	(156)	--	--
11e	1,2,3,10,11,13,47	100	(118,120,143,156,161,167,197)	--	--
11f	1,2,3,10,11,47	100	(118,120,161,197)	--	--
11g	1,3,10,11,13,28,31	95	(118,121,197)	--	--
11h	3,10,11,31	60	(121,160,180,197)	28	(174)
11i	1,2,3,10,11,28,31,47	90	(118,121,125,146,150,180)	--	--
12a	1,2,3,21,23,30	40	(143,197)	31	(90)
12b	3,27,28	100	(156)	--	--
13a	1,2,10,11,28	100	(146)	--	--
13b	1,2,3,10,11,13	100	(87,146,162)	--	--
13c1	3,10,13	100	(87,162)	--	--
13c2	3,10,13,29,31	100	(87,162)	--	--
13c3	3,10,13,14	100	(87,162)	--	--
14a	1,2,3,10,11	100	(120,126,161)	--	--
14b	3,10,47	100	(182)	--	--
14c	3,10	100	(118,120,126)	--	--
14d	3,10,11,13	100	(85,120,126,182)	--	--
15a	3,13	100	(156)	--	--
15b	1,2,3,10,13,47	100	(156,161,167)	--	--
15c	10	100	(138,167,196)	--	--
15d	1,2,3,10,13,47	(95+)	(126,156,161,167,196)	--	--
15e	1,2,3,10,11,12,13,47	(100-)	(85,105,126,182)	--	--

Table 13 (cont'd.)

Basic Report Unit	Results of Materials Questionnaire			Results of Literature Review	
Unit Code	Aggregate Type Code[1]	Approx. % of Unit Results Reported For	References[2]	Other Aggregate Types[1]	References
16a	1,2,3,10,11,13,22,47	100	(138,167,193,196)	--	--
16b	1,2,3,10,11,12,13,30,47	100	(85,105,182,193)	--	--
17a	2,3,10,21,22,28,30,33	(100-)	(105,159,167,193,196)	--	--
17b	1,2,3,11,21,22,26-28,30-35	85	(85,98,105,138,159,167,193)	--	--
18	1,3,10,21,22,28	100	(138,154,156,167,193)	--	--
19a	3,10,13,23,26,28,31,33	(100-)	(136,139,153)	--	--
19b	3,10,11,21,22,25,26,28,31-33,35	(90+)	(96,136,139,153,156,192)	--	--
19c	3,21,22	100	(96,139)	--	--
19d	3,28	100	(136,153,192)	--	--
19e	3,25,28,32,35	100	(139,192)	--	--
19f	3,10,11,31	100	(96,139,156,192)	--	--
19g	1,3,10,11,15,22,28,30,31,33,47	100	(154,156,167)	--	--
20a	1,2,3,28,42,47	100	(98,138,139,154,156,159,193)	--	--
20b	1,2,3,42	70	(101,105,159)	--	--
20c	1,10,41,42,47	100	(101)	--	--
20d	1,2,3,10,11,40,42	100	(85,101,105,118,126,134,145,182)	--	--
20e	3	100	(126,134,145,182)	--	--
20f	1,2,3,42,46	100	(87,118,126,134,145,146,182)	--	--
20g	3,42	25	(87,134,162)	--	--

Notes:

[1] Aggregate Type Code keyed to Table 11

[2] Reference numbers refer to Bibliography number

within the basic report Sections. Results have been compiled primarily from the Materials Questionnaire. In addition, where a review of the literature has indicated an aggregate source not appearing in the questionnaire response, the reference is cited.

Availability of Quality Aggregates by Basic Report Units

General

The primary objective of this phase of the project was to determine a potential availabilty rating of quality aggregate resources for each basic report unit. This rating was based upon an analysis of the various inputs of data previously described. An arbitrary rating scale was devised, consisting of the following: (a) abundant to adequate, (b) adequate to limited, (c) limited to problem and (d) severe problem.

Ratings were assigned to the basic report units by: (a) determining the major type or types of aggregates used; (b) examining their relative distribution within the unit; and (c) assessing the major quality problems of the aggregate sources. Thus it was possible for an area possessing an abundant distribution of a potential aggregate type to receive a "compromised" rating of (adequate to limited) due to the presence of a major (widespread) problem with that particular aggregate type. An example is afforded by the Springfield-Salem Plateau where an abundance of cherty carbonate rocks yields widespread durability problems when used as concrete pavement aggregate. On the other hand, a more limited supply of a good quality aggregate type, which was well distributed within the basic unit, could produce an abundant to adequate rating. The Triassic Lowland unit, with its areally limited but well distributed good quality trap ridges, is an excellent example.

Estimated Potential Availability Rating of Basic Report Units

The following paragraphs give the availabilty ratings for the aggregate resources within the 97 Sections, and briefly describe the aggregate types, uses and problems. The discussions are arranged in order of numerical code identification.

Section: 1a Olympic Mountains
Availability Rating: Adequate to Limited
Remarks: Crushed stone sources are limited. The major portion of the bedrock comprising the area is slates, phylittes and argillites; none of which are currently used as aggregate sources within Washington. Crushed sandstone is used as subbase/base aggregate. Basalt is used as both bituminous and concrete aggregate, however, widespread abrasion and durability problems are frequently encountered. Sand-gravel sources are generally located along the periphery of the Section. Several scattered but regionally defined areas lacking quality aggregates occur.

Section: 1b Oregon Coast Range
Availability Rating: Limited to Problem
Remarks: The widespread soft sandstones and shales afford little, if any, suitable aggregate. Crushed sandstones of suitable quality for base/subbase aggregate may be locally obtained. Crushed basalts, of quality similar to those of the Olympic Mountain Section, are used for all aggregate functions. Sand-gravel sources do not appear to be widely distributed, and frequently give abrasion and durability problems when used locally as concrete pavement aggregate.

Section: 1c Klamath Mountains
Availability Rating: Adequate to Limited
Remarks: This rating is based solely upon an examination of

existant geologic conditions, and should consequently be considered as highly speculative. In this rugged mountainous area, adequate crushed stone sources appear to be available. Sand-gravels may be obtained from rivers, such as the Klamath (200).

Section: 1d California Coast Range
Availability Rating: Limited to Problem
Remarks: This Section is quite similar to the Oregon Coast Ranges. Sandstones are prominent in the area; however, they generally are of low abrasion resistance (116). Crushed limestone sources are found south of the San Francisco area in the Southern California Coast Range (107). Sand-gravel sources from the Salinas River have been noted to be reactive with cement (171).

Section: 1e Los Angeles Ranges
Availability Rating: Limited to Problem
Remarks: Within this Section the availability and general quality of crushed granitic and carbonate sources appears to be good (107, 116). The crushed stone sources are primarily developed in the Traverse Ranges, while sand-gravel deposits appear to be abundantly available within the Province of Southern California Subsection. Alkali-aggregate reactions have occurred with sand-gravel sources from the Santa Clara River (171).

Section: 2a Northern Cascade
Availability Rating: Adequate to Limited
Remarks: The potential for crushed stone sources appears to be quite good within the Section. Crushed granites of good quality, basalts exhibiting localized abrasion and durability problems, and sandstones of quality suitable for base/subbase aggregate are available. Sand-gravels of good quality are generally located along the borders of the Section. A region near the Glacier Peak lacks quality aggregate sources.

Section: 2b Southern Cascade
Availability Rating: Abundant to Adequate
Remarks: Crushed basalt of fairly good quality and sand-gravel are the major sources of aggregate for all functions. Crushed limestone suitable for base/subbase aggregate may be locally available. In general the potential supply of aggregates appears to be quite adequate.

Section: 2c Sierra Nevada
Availability Rating: Abundant to Adequate
Remarks: Crushed granite and natural granular deposits are abundantly available. Localized carbonate areas are present on the western side of the Section. Cement-aggregate reactions may occur with sand-gravel sources.

Section: 2d Lower California
Availability Rating: Abundant to Adequate
Remarks: This Section is similar to the Sierra-Nevada in major types of potential aggregates. Crushed granites of good quality are adequately available.

Section: 3a Puget Sound
Availability Rating: Abundant to Adequate
Remarks: This Section possesses a rather abundant distribution of glacial granular deposits in the form of terraces and outwash plains. Localized deposits of sand-gravel may cause alkali-aggregate reaction. Quality crushed stone sources (primarily basalt) are available. Localized problems of stripping, abrasion and durability occur with this aggregate. Andesite and rhyolite are generally not suitable for use.

Section: 3b Willamette Valley
Availability Rating: Abundant to Adequate
Remarks: This Section is quite similar to the Puget Sound Section in that the major aggregate sources are sand-gravel and crushed basalt. However, the granular material is obtained primarily from either alluvial fans adjacent to the mountainous areas and/or the river and stream system within the Section. Quality aggregates are generally available, however problems with volcanic rock may be somewhat similar to the Puget Sound Section.

Section: 3c Great Valley
Availability Rating: Abundant to Adequate
Remarks: Sand-gravel may be obtained from fans and aprons near mountain ranges surrounding the Section and from alluvial deposits associated with its rivers and streams. Bedrock sources are little exploited due to the relatively deep alluvial cover in the Valley. Quality crushed stone sources must be obtained from nearby mountainous area.

Section: 4a Walla-Walla
Availability Rating: Abundant to Adequate
Remarks: Sand-gravel sources are generally well distributed within the Washington portion of the Section both from glacial outwash and along major rivers

such as the Snake and Columbia. Loess and caliche may be present in the outwash deposits. Quality crushed basalts are generally available.

Section: 4b Blue Mountains
Availability Rating: Abundant to Adequate
Remarks: The major sources of aggregate are sand-gravels and crushed basalt; the general quality of both sources appears to be good. Sedimentary rocks and granite are available, although, at present, they are not used as aggregate sources by Oregon.

Section: 4c Snake River Plain
Availability Rating: Limited to Problem
Remarks: A large portion of the area is veneered by loessial deposits that overlie young basaltic and acidic flows. In general, the crushed basalts of the area, where available, appear to possess poor abrasion, durability, and adhesion characteristics (117). Sand-gravel sources are generally lacking except near the mountainous borders and along some terrace portions of the Snake River. Idaho indicates that suitable concrete gravels are generally lacking. Limited sand-gravels frequently possess a wide spectrum of aggregate problems including the alkali-aggregate reaction.

Section: 4d Payette
Availability Rating: Adequate to Limited
Remarks: The sources of granular deposits are primarily located along the major river terraces. The quality of these sources appears to be highly variable. Widespread abrasion, durability, alkali-aggregate reaction and adhesion problems are noted within the Idaho portion. Crushed basalt sources, where available, appear to be of variable quality. Basalts may frequently be interbedded with fluvial sediments.

Section: 4e Harney
Availability Rating: Limited to Problem
Remarks: The Section does not possess an overall abundance of either natural granular deposits or suitable crushed stone sources. Rivers and streams are scarce in the Section, and a vast portion of the area is surfaced by the disintegrated pumice deposits of the Great Sandy Desert. Limited problems with alkali-aggregate reaction are encountered with gravels of the area, while crushed basalt, where available, produced widespread adhesion problems.

Section: 5a Great Basin
Availability Rating: Abundant to Adequate
Remarks: Natural sand-gravel sources from alluvial fans and aprons near the mountain ranges are rather abundant. Granular lacustrine deposits are utilized as aggregates within old Lakes Lahontan and Bonneville. Many mountain ranges may afford suitable crushed stone resources. Occurrence of alkali-aggregate reactions have been noted within some portions of the Section.

Section: 5b Sonoran Desert
Availability Rating: Abundant to Adequate
Remarks: Natural sand-gravel deposits are found near the mountain ranges (similar to Section 5a). Quality crushed stones (primarily igneous) are located in and developed from ranges in the Section. Alkali-aggregate reactions are associated with the widespread igneous activity. Localized areas lacking quality aggregates occur.

Section: 5c Salton Trough
Availability Rating: Limited to problem
Remarks: Although sand and fine gravel are locally available, aggregate sources are generally lacking in the Southern California portion (Imperial Valley). Alkali-aggregate reactions may be a problem with sources within and east of the Section.

Section: 5d Open Basin
Availability Rating: Abundant to Adequate
Remarks: Natural sand-gravel sources are generally available from the nearby mountain ranges (similar to Sections 5a and 5b). Many different types of quality crushed stone sources can be developed from the mountain ranges.

Section: 5e Sacramento Highlands
Availability Rating: Abundant to Adequate
Remarks: Sand-gravel and crushed limestone sources appear to be well distributed and extensively used. (From the general pit and quarry locations provided by New Mexico (155)). Information concerning the aggregate quality was lacking.

Section: 5f Great Bend Highlands
Availability Rating: Abundant to Adequate
Remarks: Sand-gravel, crushed igneous and limestone sources appear, from geologic maps, to be well distributed. Definite information on aggregate type and quality was lacking.
Notes: In general, the ratings given to the individual

Sections of the Basin and Range Province are based upon potential availability of aggregate resources and are not greatly modified by quality limitations due to insufficient data.

Section: 6a High Plateaus
Availability Rating: Adequate to Limited
Remarks: The quality of sand-gravel sources is quite variable. Alluvial gravels derived from Mesozoic sandstone and shales are of poor quality.

Section: 6b Uinta Basin
Availability Rating: Limited to Problem
Remarks: Generally, the best quality is usually found in the northern portion near the Uinta Mountains. Tertiary sandstones and shales, which comprise the major portion of the Section, are of very poor quality for road aggregates.

Section: 6c Canyon Lands
Availability Rating: Limited to Problem
Remarks: The area is primarily soft sandstone deposits from the Mesozoic and the late Paleozoic, that afford very poor quality (abrasion) aggregates. Riverbed gravels are available in limited quantity and quality.

Section: 6d Navajo
Availability Rating: Limited to Problem
Remarks: A major portion of the Section is underlain by soft sandstones and shales, which are poor aggregate sources. Localized igneous areas exist, and crushed basalt of good quality may be obtained.

Section: 6e Grand Canyon
Availability Rating: Adequate to Limited
Remarks: The rating given to this Section is based on the geologic potential and may be too high because of practical problems of accessibility. Potential crushed limestone sources may be developed in the Kaibab and other limestone formations. Igneous activity is widespread in the central portion of the Section and good quality crushed basalt may be obtained.

Section: 6f Datil
Availability Rating: Abundant to Adequate
Remarks: This rating, like that of the Grand Canyon Section, is questionable, as information concerning quality of aggregate sources is not complete. This Section appears to have a good potential in crushed limestone and basalt. The use of volcanic cinders generally results in durability problems.

Section: 7a Montana
Availability Rating: Abundant to Adequate
Remarks: The Section possesses a wide variety of suitable crushed stone sources as well as regional sand-gravel deposits. The Belt Mountains located in the eastern portion have potential materials of construction that are similar in type and quality to the anticlinal ranges found throughout the Rocky Mountain System. The Tertiary Basins afford variable quality glacial sand-gravel deposits which generally veneer the basin fill. Sedimentary, metamorphic and igneous rocks are crushed as aggregates within Montana; however, sand-gravels are the primary aggregate source within the Section (148). The prominant problem, associated with several aggregate types, is poor adhesion.

Section: 7b Bitterroot
Availability Rating: Adequate to Limited
Remarks: In general, the Washington portion of the Section contains good quality glacial valley gravels, as well as suitable granites, quartzites and limestones (194). The remainder of the Section possesses a wide array of crushed stone sources that may be of rather poor quality. The major problems are adhesion and abrasion.

Section: 7c Salmon River Mountains
Availability Rating: Limited to Problem
Remarks: The major rock of this Section is the massive Idaho batholith (Jurassic age). Idaho (117) notes that this prevalent rock is generally unsuitable for use as a highway aggregate. Crushed basalt is used, but it frequently possesses poor abrasion and adhesion properties. Sand-gravel sources, where available, frequently contain substances deleterious to concrete. Idaho (117) notes that quality concrete aggregates are generally not available.

Section: 8a Yellowstone
Availability Rating: Adequate to Limited
Remarks: The use and quality of volcanic areas as crushed stone sources was not noted in the Questionnaire responses. However, quality sand-gravels as well as crushed limestone(steeply dipping flanking strata around the Pre-Cambrian core) are major sources of aggregates.

Section: 8c Wind River Mountains
Availability Rating: Abundant to Adequate
Remarks: (Remarks identical to Section 8b)

Section: 8d Wasatch
Availability Rating: Adequate to Limited
Remarks: The rating is based primarily upon the quality information concerning aggregate problems within the Idaho portion of the Section. The potential sources of crushed stone are extremely variable by type and geologic age. Idaho indicates that the sand-gravels and crushed carbonate (limestone and dolomite) sources may have extremely poor abrasion and durability characteristics. Alkali-aggregate reactions may occur with sand-gravels and limestones as well. The Jackson Hole area of Wyoming has adequate glacial outwash sands and gravels.

Section: 9a Front Range
Availability Rating: Abundant to Adequate
Remarks: In general, the potential availability of good quality crushed stone obtained from the Pre-Cambrian crystalline ranges is undoubtedly quite high. The primary sources of crushed aggregates are granites and flanking limestones.

Section: 9b Western
Availability Rating: Abundant to Adequate
Remarks: Due to the presence of numerous ranges identical to those of the Front Range Section, the Western Section has a similar crushed stone potential. Regional sand-gravel sources derived predominantly from glacial outwash are found within the North and Middle Parks, as well as the San Luis Valley portions of the Section.

Section: 9c San Juan
Availability Rating: Abundant to Adequate
Remarks: Sand-gravels and crushed basalts of good quality are available.

Section: 10a Missouri Plateau (Glaciated)
Availability Rating: Limited to Problem
Remarks: Suitable crushed stone sources are non-existent within a large majority of the Section and, as a result, sand-gravel sources are exclusively used as highway aggregate (148, 160, 180). These aggregates are located primarily along portions of the Missouri River, from limited stratified glacial deposits, and from isolated gravel-capped benches in Montana, viz., Flaxville gravels (142). In general, the overall quality of the sand-gravel sources is rather poor. The widespread presence of deleterious material in the gravels, due to the underlying soft sandstone and shale bedrock, renders them unsuitable for use in concrete, particularly in North and South Dakota.

Section: 10b Missouri Plateau (Unglaciated)
Availability Rating: Severe Problem
Remarks: Within this unit, sand-gravels, crushed limestones, some sandstones and scoria are used as highway aggregates. The major source of sand-gravels are the terraces associated with the Yellowstone River in Montana (142, 148), and the Cheyenne and White Rivers in South Dakota (180). A potential source of sand-gravel also appears along the eastern portion of the Black Hills - Unglaciated Plateau border in South Dakota. Availability of crushed stone sources is extremely limited in the Section due to the widespread presence of soft sandstones and shales. The quality of sand-gravel sources in the Section appears to be poor, with the most noted problems being abrasion and deleterious constituents. Almost the entire Section has been categorized by the respective state highway departments as lacking quality aggregate supplies.

Section: 10c Bighorn Basin
Availability Rating: Abundant to Adequate
Remarks: Sand-gravels, crushed carbonates, sandstones, and basalts are used. Of these, the sand-gravels are the most important source, and appear to be widely distributed throughout the unit. The quality of these aggregates appears to be good, as no problems were reported. Crushed stone sources are available only near the surrounding mountain ranges. The regional bedrock of the unit (Tertiary sediments) is generally unsuitable for crushing.

Section: 10d Wyoming Basin
Availability Rating: Limited to Problem
Remarks: A large area within the central portion of the unit has been reported to lack quality aggregate (205). The major source of aggregate is sand-gravel, but limited supplies of crushed limestones, sandstones and granites are available. For the most part, these aggregates are primarily available between the mountain extensions of the bordering Middle Rocky Mountain Province. In particular, basin areas such as the Wind River, northern part of the Green River Basin, and the Waskakie Basin appear to possess a good regional supply of aggregates (166, 200). Problems within the unit are associated with durability (205), alkali-aggregate reaction (144) and adhesion (95). These problems are generally of a localized nature, and are predominantly associated with the sand-gravels.

Section: 10e Black Hills
Availability Rating: Abundant to Adequate
Remarks: In general, good quality crushed limestones, granites, felsites and felsite porphyries are abundantly available within the unit (90, 180, 205).

Section: 10f High Plains
Availability Rating: Limited to Problem
Remarks: The unit possesses an almost complete absence of bedrock suitable for crushing due to the modal parent material of Tertiary outwash. The major aggregates are sand-gravels from major rivers (and their tributaries) originating in the Rockies and flowing directly east to the Missouri and Mississippi Rivers. These occur in the northern portion of the Section and include the Niobrara, Platte, Republican, Arkansas, and Canadian Rivers. In general, these sand-gravels are deficient in the coarse sizes and frequently cause the unique "sand-gravel" reaction in concrete. Localized, but noteworthy, adhesion problems are also associated with the sand-gravels in the north (200). In the southern portion, sand-gravels are not abundant and caliche is frequently used as aggregate.

Section: 10g Colorado Piedmont
Availability Rating: Limited to Problem
Remarks: This unit bears many marked similarities in general aggregate characteristics to the Unglaciated Missouri Plateau (10b). Aggregate types are sand-gravels, restricted to areas adjacent to the Rocky Mountains and along the South Platte and Arkansas Rivers (95, 144), and limited sources of limestones, basalts and slag. A large area has been cited by Colorado (95) as lacking quality aggregates. This area is underlain primarily by relatively soft sandstone, shale and clay shales. Problems of adhesion are the most common problem associated with the sand-gravels.

Section: 10h Raton Upland
Availability Rating: Adequate to Limited
Remarks: Sand-gravels, crushed limestone, basalts and diorites are commonly used as highway aggregate within the unit with the igneous rocks appearing to be the most abundant source. Localized adhesion problems, identical to those of the Colorado Piedmont, are encountered with sand-gravels. No areas were identified by Colorado and New Mexico as lacking in aggregate sources.

Section: 10i Pecos Valley
Availability Rating: Limited to Problem
Remarks: The major sources of aggregates utilized within the unit are sand-gravel, caliche and very limited crushed limestone. An examination of the pit and quarry locations shows that caliche pits are widely distributed. Limestone quarries are not extensive within the Permian and early Mesozoic deposits which are characteristically gypsum, sandstone and shale bedrock.

Section: 10j Plains Border
Availability Rating: Limited to Problem
Remarks: Sand-gravels, crushed dolomites, sandstones and silicified chalk are used as highway aggregates (125, 150). The sources of sand-gravel are primarily limited to the major rivers and tributaries. The Republican and Arkansas Rivers provide aggregates similar in quality to the High Plains Section to the west. Potential crushed stone areas are generally confined to the Blue Hills Subsection of Kansas. Widespread carbonate reactions have been noted by Kansas (125). The quality of crushed sandstone appears reasonably good, although widespread adhesion and limited durability problems are associated with its use. The unit rating tends toward the "limited" than the "problem" category.

Section: 10k Central Texas Mineral
Availability Rating: Abundant to Adequate
Remarks: This rating is based on fairly limited information. The major sources of potential aggregates are sand-gravels, limestones and granites. Crushed limestones of Upper Cretaceous (Edwards and Commanche) are similar to those of the Edwards Plateau. Carbonates of Cambrian to Ordovician age are located around the flanks of the Llano uplift granitic core. The quality of aggregates is unknown to the author, and the rating is based priarily upon the abundant distribution of potential sources.

Section: 10l Edwards Plateau
Availability Rating: Abundant to Adequate
Remarks: Cretaceous limestone of quality acceptable for most engineering purposes is very widespread throughout the area and forms an important part of the crushed stone industry of Texas (107, 200). In addition, numerous river valleys provide gravels of both carbonaceous and siliceous character (144).

Section: 10m Osage Plains
Availability Rating: Adequate to Limited
Remarks: The major types of aggregates utilized for highway construction are sand-gravels and crushed carbonate rocks. In addition, minor uses of sandstones, granites, and chat occur (107, 125, 144, 146, 162). There is an extremely wide range of aggregate availability.Gravels occur in substantial quantities in Texas and Oklahoma (142, 144). Four major carbonate zones of variable quality are present. The cherty limestones of the Flint Hills offer little suitable aggregate for concrete, but can be used as base/subbase aggregates (144). The Pennsylvanian limestones found in the Scarped Plains (northeast portion of Section) also possess undesirable durability characteristics for concrete aggregate (125, 146). Limestones of Ordovician age, found adjacent to the Wichita and Arbuckle uplifts, have provided one third to one half of Oklahoma's annual limestone production (107). The carbonates found in the southwestern portion are very similar in characteristics to carbonates found in the Central Texas Mineral and Edwards Plateau Sections of Texas (107).

Crushed granites of good quality are located in the uplift cores of the Wichita and Arbuckle areas of Oklahoma. Locally, sandstones of quality suitable for base/subbase use can be obtained.

The remaining bedrock of the area is composed of sandstone and shale, and generally affords little if any suitable aggregate.

Section: 11a St. Lawrence Lowlands
Availability Rating: Abundant to Adequate
Remarks: Major aggregate sources are good quality glacial sand-gravels and crushed carbonates (Ordovician). The carbonates are adequately distributed throughout the entire Section.

Section: 11b Champlain Lowland
Availability Rating: Abundant to Adequate
Remarks: The major sources of aggregates used are glacial sand-gravels and crushed carbonates (Cambrian-Ordovician). Crushed quartzite is used within the Section but the source is outside its boundaries. Crushed marble is not suitable as normal highway aggregate due to its poor abrasion characteristics. The quality of the remaining aggregates appears to be quite good.

Section: 11c Hudson River Valley
Availability Rating: Abundant to Adequate
Remarks: Major sources of aggregate are glacial sand-gravels

and crushed carbonates. The Ordovician limestones are located primarily near the contacts with the adjacent uplands. New Jersey reports that the sand-gravel sources contain much deleterious matter. The crushed carbonates may exhibit poor skid resistance. Crushed sandstone is used for all aggregate functions. Crushed quartzites and gneisses are used in the Section, but their origin is from the older crystalline areas to the east (New England Maritime Province).

Section: 11d Mohawk Valley
Availability Rating: Abundant to Adequate
Remarks: Good quality sand-gravels and crushed carbonates are located within the Section. The carbonates are found primarily near the border contacts with the Adirondacks to the north and the Appalachian Plateau to the south. Low skid resistance is locally a problem with these carbonates.

Section: 11e Eastern Lakes and Lacustrine Plains
Availability Rating: Adequate to Limited
Remarks: The availability as well as type and distribution of aggregates used in the Section is highly variable. Much stratified granular material is present within the Cary and younger Wisconsin drift in Michigan. The quality of these deposits, however, is generally compromised by the presence of chert particles, as well as high abrasion loss. Crushed carbonate sources are generally found along the outer periphery of the Michigan Basin in eastern Wisconsin, in the upper peninsula of Michigan, and in southeastern Michigan. A major problem with many of these carbonate rocks is their poor skid resistance. Slag is also used extensively.

Section: 11f Central Till Plains
Availability Rating: Adequate to Limited
Remarks: This Section appears to possess the most variable aggregate availability rating in the Province. Major aggregate sources are crushed carbonates (predominantly dolomites) and glacial sand-gravel. The major sand-gravel deposits occur in the numerous glacial sluiceways. Stratified glacial landforms are not present in any great quantity. The availability of crushed carbonates in the Section ranges from abundant in the Indiana - Ohio area due to the Cincinnati Arch (predominantly Silurian dolomites) to almost a complete absence in the Illinoian Coal Basin (western portion of the Section). Regional areas lacking aggregate within the Section are located within this Structural Basin area.

Section: 11g Driftless Section
Availability Rating: Limited to Problem
Remarks: The major sources are limited sand-gravels, crushed carbonates (predominantly dolomites), sandstones, granites and quartzites. The supply is variable, with a large area in the central portion of Wisconsin (Central Sand Plain) generally lacking in coarse aggregates. The availability of aggregates generally increases to the southwest. Ordovician dolomites afford crushed stone of variable quality. They generally possess poor abrasion resistance and durability. The crushed sandstone (Cambrian) is likewise rather weak and is used primarily for subbases. Good quality crushed quartzites are located in the Baraboo area. Sand-gravel sources are confined to limited glacial outwash in and along the Mississippi River and its tributaries in Minnesota.

Section: 11h Western Lakes and Lacustrine Plains
Availability Rating: Limited to Problem
Remarks: The major type of aggregate is sand-gravel of glacial origin. Crushed stone sources are limited to: the good quality, but rather small, Sioux Uplift area in South Dakota; scattered granitic areas in Minnesota; and localized Devonian and Mississippian limestones in Iowa. There are large areas completely void of aggregates, viz., large old glacial lakebeds (Dakota and Agassiz). Sand-gravels, where available, are frequently contaminated by sandstone and shale particles from the dominant regional bedrock.

Section: 11i Dissected Loessial and Till Plains
Availability Rating: Adequate to Limited
Remarks: As with the Central Till Plain Section, the availability of aggregates is quite variable within the Section. Alluvial, glacial and interglacial gravels are used as aggregates. Crushed stone sources are primarily limestones, with the Sioux Uplift area providing good quality crushed quartzites and granites in South Dakota and Minnesota. Quality aggregates are also found in the northeast, where Silurian and Devonian carbonates are extensively quarried for road aggregate. Crushed stone sources are limited to non-existent in the western portion, while quality natural granular deposits are limited in the south. This subsequently leaves large regional areas in southwest Iowa and northwest Missouri void of quality aggregate supplies. Localized alkali-carbonate reactions have occurred in the Iowa portion of the Section. Alkali-silica reactions of a more frequent nature are found with the sand-gravels found in Nebraska and Kansas.

Section: 12a Superior Upland
Availability Rating: Abundant to Adequate
Remarks: In general, the availability of good quality, crushed stone sources and glacial sand deposits is quite adequate within the Section. Major crushed stone sources are primarily PreCambrian igneous-metamorphic complexes. Regional sand-gravel sources may be lacking within the northeast portion of Minnesota where bedrock is generally near the surface.

Section: 12b Adirondack Mountains
Availability Rating: Abundant to Adequate
Remarks: This Section is quite similar in aggregate characteristics to the Superior Upland. Quality potential crushed stone sources (PreCambrian igneous-metamorphic complex) are presently utilized as a source of aggregate. Sand-gravel deposits of glacial origin are present and utilized as aggregates within the Section.

Section: 13a St. Francis
Availability Rating: Abundant to Adequate
Remarks: Limestone and granite generally are the best sources of crushed stone. The Cambrian limestone generally lacks chert impurities and contrasts strongly with the carbonates in the surrounding Springfield-Salem Plateau. Dolomite is generally of poor quality, frequently cherty and similar in performance characteristics to Section 13b. Gravel deposits produce widespread durability problems when used in concrete. Sandstone is generally unsuitable for use.

Section: 13b Springfield-Salem Plateau
Availability Rating: Adequate to Limited
Remarks: Although carbonate rocks predominate in the entire Section, their use in concrete mixes is limited by chert impurities. Carbonate rocks produce poor skid resistance when used in bituminous pavements. Similar to Section 13a, river gravels are suspect for concrete pavement. Sandstone is generally low in abrasion resistance and consequently cannot be considered as a major source. Aggregate availability may act as a major factor in the selection of pavement type.

Section: 13c1 Boston Mountains
Availability Rating: Limited to Problem
Remarks: Potential sources may be extremely limited due to the widespread distribution of sandstone and shale. Limestone, where available, is frequently cherty and performs similarly to Section 13b. Sandstone

generally has poor abrasion resistance. Availability of aggregate sources may act as a significant factor in determining pavement type.

Section: 13c2 Arkansas Valley
Availability Rating: Limited to Problem
Remarks: The type and quality aspects of aggregate resources are quite similar to Section 13c1. Sandstone is generally of low abrasion resistance, but may be of slightly better quality than that of the Boston Mountain Section. Alluvial sand-gravel deposits, where available, are generally good sources. Availability of aggregates is less of a problem than in the Boston Mountain Section.

Section: 13c3 Ouachita Mountains
Availability Rating: Adequate to Limited
Remarks: As a large portion of this Section is underlain by sandstone and shales, similar to Sections 13c1 and 13c2, it does not possess an abundance of quality sources. However, the Novaculite Uplift Subsection generally provides a good potential crushed stone source. Sandstone may be of questionable quality. Alluvial sand-gravel sources are generally of good quality.

Section: 14a Blue Grass
Availability Rating: Abundant to Adequate
Remarks: Good quality crushed carbonate sources (lower Ordovician) are available in the Inner Blue Grass Subsection and in scattered inliers of the Outer Blue Grass Subsection. The majority of the upper Ordovician limestone in the Outer Blue Grass Subsection is argillaceous and unsuitable for use in construction. Skid resistance may be problem with the carbonates. Sand-gravels (Ohio River) generally are of good quality.

Section: 14b Nashville Basin
Availability Rating: Abundant to Adequate
Remarks: Good quality crushed limestone (lower Ordovician) is available throughout the entire Section. Low skid resistance may be a problem with the carbonate sources. The gravels may be cherty and generally of poor durability in concrete. Poor adhesion with bituminous materials may be a problem with the gravels of the Section.

Section: 14c Shawnee
Availability Rating: Limited to Problem
Remarks: A major source of quality crushed carbonates is the Mississippian age rocks. The remaining rocks are

of Pennsylvanian age and generally are of little value for highway aggregates. Sand-gravels deposits are badly contaminated with chert and shale of low specific gravity and demonstrate poor durability in concrete.

Section: 14d Highland Rim
Availability Rating: Abundant to Adequate
Remarks: The availability of good quality sources is commonly adequate but highly variable. Quality crushed carbonate sources are generally widespread in the Western Pennyroyal Limestone Plain Subsection. Chert particles may be abundant in the sand-gravels.

Section: 15a Catskill Mountains
Availability Rating: Adequate to Limited
Remarks: The major sources are sand-gravels and crushed sandstones. Overall, good quality aggregates can be obtained; however, there is much relatively soft sandstone and associated glacial sand-gravels.

Section: 15b New York Glaciated
Availabilty Rating: Adequate to Limited
Remarks: Suitable crushed carbonate aggregate is located adjacent to the outfacing escarpment in New York. Some hard, quality sandstones are crushed in southeast New York and northern Pennsylvania. Slag is available near the Youngstown, Ohio area and near other steel centers outside the Section in the Central Lowlands Province. Glacial outwash sands and gravels are quite well distributed along the river valleys. Sandstone, of variable hardness, may form the largest percentage of gravel particles.

Section: 15c Allegheny Mountains
Availability Rating: Adequate to Limited
Remarks: This Section is quite difficult to categorize for potential aggregate availability. The only highway aggregate type used is crushed limestone. The occurrence of this rock type is quite restricted. Hard limestones, conglometerates and local quartzites do exist and <u>may</u> provide quality supplies. The same may be said of river sands and gravels(<u>144</u>).

Section: 15d Kanawha
Availability Rating: Limited to Problem
Remarks: In general, there is a shortage of quality aggregate resources within the entire Section. Limited crushed stone sources are primarily limestones and sandstones. The <u>overall</u> quality of these sources is considered poor due to durability

problems, although localized sources of suitable quality may exist. Major streams provide an important source of sand-gravel aggregates in much of the Section. The coarseness and amount of gravel decrease to the south and west.

Section: 15e Cumberland Plateau
Availability Rating: Adequate to Limited
Remarks: The availability of aggregates is highly variable. Crushed aggregate sources (primarily limestones) are generally abundant to adequately available in the southern portions of the Section due to the presence of variant Ordovician limestone valleys and limestone found along the outfacing escarpments. In and around the Kentucky and northern Tennessee portions, the availability of quality aggregate supplies is considered to be of a "limited to problem" nature.

Section: 16a Pennsylvania-Maryland-Virginia
Availability Rating: Abundant to Adequate
Remarks: Valleys in Cambrian and Ordovician carbonate rocks generally provide a good source of crushed stone; however, widespread skid problems may occur. Cherty layers or pockets may be present in the carbonate formations, but their presence is less widespread than in the Tennessee Section (16b).

Section: 16b Tennessee
Availability Rating: Abundant to Adequate
Remarks: Aggregate sources and skid problems are similar to Section 16a. The regional distribution of chert may be more widespread in this Section due to the Mississippian Fort Payne formation (99, 137, 184).

Section: 17a Blue Ridge
Availability Rating: Abundant to Adequate
Remarks: Construction materials have characteristics similar to the Piedmont Section (17b).

Section: 17b Piedmont
Availability Rating: Abundant to Adequate
Remarks: The section possesses complex and numerous types of potential crushed stone sources. Granitic and gneissic sources are generally of good quality. Triassic basins within the Section possess traprock (basalts, diabase, etc.) of good to excellent quality. Sand-gravels are primarily river deposits and may yield several localized problems.

Section: 18 Triassic Lowland (no sections)
Availability Rating: Abundant to Adequate
Remarks: Crushed stone of good quality is generally obtained

from traprock sources within the Triassic Sediments. Crushed limestone is available from the Ordovician limestone valleys which are variant to the Province. Crushed granite can be obtained from local Piedmont areas within and surrounding the Province. Glacial sand-gravel deposits are available in the northern portion. These deposits may contain deleterious materials for concrete. Triassic sandstone is generally soft, and its use as an aggregate source is not cited.

Section: 19a Seaboard Lowland
Availability Rating: Adequate to Limited
Remarks: The distribution of the Precumscot Fm (fine grained marine deposits) overlying much of the area may possibly increase localized areas where aggregate sources are lacking. Crushed stone sources are generally similar in characteristics (types and problems) to Section 19b.

Section: 19b New England Upland
Availability Rating: Abundant to Adequate
Remarks: Good quality glacial fluvial sand-gravels are generally abundantly distributed. Crushed stone sources of granite and limestone may be of poor quality due to abrasion resistance and durability.

Section: 19c Connecticut Lowland
Availability Rating: Abundant to Adequate
Remarks: Glacial and terrace sand-gravels are generally abundant and of good quality. Occasionally, soft sandstone particles may be encountered in the gravels. The traprock found in the Triassic sediments is generally an excellent crushed stone source.

Section: 19d White Mountains
Availability Rating: Adequate to Limited
Remarks: The region is sparsely inhabited, and no known or existent pits or quarries were cited for the Section. Granite, may have poor abrasive characteristics. A region within Maine was stated to lack quality aggregate resources from the questionnaire.

Section: 19e Green Mountains
Availability Rating: Abundant to Adequate
Remarks: This rating is based upon rather limited information. The crushed stone potential in the old Pre-Cambrian crystalline rocks of the Section is considered good. Questionnaire results indicated no widespread problems with aggregates in the area.

Section: 19f Taconic Mountains
Availability Rating: Abundant to Adequate
Remarks: The major bedrock type of the Taconic Ranges is schist. However, its use was not reported in the Materials Questionnaire. Sand-gravels, crushed carbonates, and quartzite sources occur and are of good quality. Vermont marble is not a suitable highway aggregate.

Section: 19g Reading Prong
Availability Rating: Abundant to Adequate
Remarks: New Jersey reports that marble found in the Section is unsuitable. A wide variety of good quality crushed stone types are available within and surrounding the Section.

Section: 20a Northern Embayed
Availability Rating: Adequate to Limited
Remarks: The availability of aggregate sources is quite variable. Long Island and Cape Cod generally have abundant quantities of glacial sand-gravel. Within the remainder of the Section, sand-gravels are generally found in the higher terraces. The coastal portion of Virginia possesses very restricted supplies of aggregates. The major aggregate source is sand-gravel, with minor utilization of slag and clam/oyster shells for highway aggregate.

Section: 20b Sea Island
Availability Rating: Adequate to Limited
Remarks: Sand-gravel from river and stream terraces, as well as along the Fall-Line Hills, generally afford the major aggregate supply in the entire Section.

Section: 20c Florida
Availability Rating: Limited to Problem
Remarks: Crushed limestone sources are available in the Lime-Sink Area (northwest portion of the peninsula) and in the extreme southern tip. Coquina is used, particularly along the east coast of Florida. The remainder of the area is veneered with sand, resulting in large areas in the southern and central portion being void of coarse aggregate. Florida (101) states that concrete aggregate is lacking everywhere except along the southern tip. The availability of aggregates is considered by Florida as a major factor in the selection of a pavement type.

Section: 20d East Gulf Coast
Availability Rating: Adequate to Limited
Remarks: The availability of aggregates appears to be quite variable. The occurrence of quality aggregates

decreases as one proceeds toward the coast except in the Southern Pine Hills of Mississippi. Local limestones, limerock and clam/oyster shells are used, but sand-gravel sources are the most important. These deposits are nowhere widespread except in the southern portions of Mississippi and Louisiana. Skid resistance, adhesion and the presence of deleterious materials in the sand-gravels are the most salient problems. The limestones of the Coastal Plain appear to be significantly different in quality from limestones found in the adjacent Provinces.

Section: 20e Mississippi Loessial Upland
Availability Rating: Limited to Problem
Remarks: In general, aggregate supplies are lacking. The only source of aggregates are sand-gravel deposits from terraces along some major rivers and from the "Lafayette gravels" in the southern portion of the Section. Skidding problems, associated with sand-gravel sources may be a major problem. Mississippi reports that aggregate availability is a major factor in determining pavement type (<u>145</u>).

Section: 20f Mississippi Alluvial Plain
Availability Rating: Severe Problem
Remarks: The only sources of aggregates are local terrace and point bar sand-gravels. An exception to the areal deficiency are the good quality sand-gravel deposits of Crowley's Ridge in Arkansas. Aggregates play an important role in determining pavement type in Mississippi and Missouri (<u>145</u>, <u>146</u>). Much of the needed aggregate must be imported from bedrock regions in Arkansas, Missouri and Tennessee, or from coastal plain sediments in these states (<u>144</u>).

Section: 20g West Gulf Coast
Availability Rating: Adequate to Limited
Remarks: The characteristics of aggregates in this Section are quite similar to those of the East Gulf Coast. No information concerning aggregate problems was available.

Soils and Related Factors

Soil Origin

The basic Provinces have been divided into three major categories and six minor or subcategories of soil origin. The major categories are: (a) non-transported, (b) transported, and (c) mixtures.

The non-transported class has been further subdivided into areas: in which bedrock predominates (non-soil), thin residual soils predominate, and significant residual soils are developed. Transported soil Provinces have been divided into those in which water is the dominant mode of transport, and areas characterized by glacial surficial deposits. Wind deposited soils do not form the predominating soil origin of any Province, although they do characterize several Sections. Table 14 groups the Sections according to their origin classes.

Soil Texture

General

A wide variety of information was utilized to map the general distribution of soils within the United States. By far the greatest amount of detailed information was in terms of soil texture. However, the data varied from classification by engineering systems to such generalities as "fine textured" or "moderately coarse". Table 15, developed from references (216) and (219), was helpful in the requisite correlations and interpretations of descriptions.

The soil texture map of the United States is shown in six map sheets (Figures 16 to 21). Every effort has been

Table 14

Summary of Surficial Soil Origin by Sections

1. Provinces Characterized by Non Transported Soils

A. Bedrock Predominating

Province 1	Major Origin	Minor Origin
1a	NT-B	NT-R,T-W(vf)
1b	NT-B	NT-R,T-W(vf)(cs)
1c	NT-B	NT-R,T-W(vf)
1d	NT-R	NT-B,T-W(vf)
1e	NT-B,T-W(vf)	NT-R

Province 2	Major Origin	Minor Origin
2a	NT-B,T-G	
2b	NT-B	NT-R
2c	NT-B	NT-R
2d	NT-B	T-W(vf)

Province 7	Major Origin	Minor Origin
7a	NT-B,T-W(vf)	
7b	NT-B,T-G	T-W(vf)
7c	NT-B	T-W(vf)

Province 8	Major Origin	Minor Origin
8a	NT-B,R	
8b	NT-B	
8c	NT-B	T-W(vf)
8d	NT-B	NT-R,T-W(vf)
8e	NT-B	

Province 9	Major Origin	Minor Origin
9a	NT-B	NT-R
9b	NT-B	NT-R,T-W(vf)
9c	NT-B	NT-R

B. Thin Residual Soil Development

Province 4	Major Origin	Minor Origin
4a	T-L	NT-B
4b	NT-B,R	
4c	T-L	NT-B
4d	T-W(1),NT-R	
4e	NT-R	

Province 6	Major Origin	Minor Origin
6a	NT-B	T-W(vf)
6b	NT-R,B	
6c	NT-R,B	
6d	NT-R	
6e	NT-R	
6f	NT-R	

C. Significant Soil Development

Province 13	Major Origin	Minor Origin
13a	NT-R	
13b	NT-R	
13c1	NT-R	
13c2	NT-R	T-W(A1)
13c3	NT-R	NT-B

Province 14	Major Origin	Minor Origin
14a	NT-R	
14b	NT-R	NT-B
14c	NT-R	
14d	NT-R	T-W(A1)

Province 15	Major Origin	Minor Origin
15a	T-G	
15b	T-G	
15c	NT-R	NT-B
15d	NT-R	
15e	NT-R	NT-B

Province 16	Major Origin	Minor Origin
16a	NT-R,B	
16b	NT-R	NT-B

Province 17	Major Origin	Minor Origin
17a	NT-B	
	NT-R	

Province 18	Major Origin	Minor Origin
	NT-R	T-G

Note: See second page of Table for legend

Table 14 (cont'd.)

II. Provinces Characterized by Transported Soils

A. Water Deposited Soils

Province 3	Major Origin	Minor Origin
3a	T-G,NT-R	
3b	T-W(Al),NT-R	
3c	T-W(vf)	NT-R

Province 5	Major Origin	Minor Origin
5a	T-W(vf),NT-B	T-L
5b	T-W(vf),NT-B	
5c	T-W(1)(vf)	NT-B
5d	T-W(vf),NT-B	
5e	T-W(vf),NT-B,R	
5f	T-W(vf),NT-B,R	

Province 20	Major Origin	Minor Origin
20a	T-W(cs)	T-G
20b	T-W(cs)	
20c	T-W(cs)	NT-R
20d	T-W(cs)	
20e	T-L	
20f	T-W(Al)	
20g	T-W(cs)	

B. Glacial Deposited Soils

Province 11	Major Origin	Minor Origin
11a	T-W(m),G	NT-B
11b	T-W(m),G	
11c	T-G,W(m)	
11d	T-G	
11e	T-G,W(1)	
11f	T-G	T-L
11g	NT-R,T-L	
11h	T-G,W(1)	
11i	T-G,L	

Province 12	Major Origin	Minor Origin
12a	T-G	NT-B
12b	T-G	

Province 19	Major Origin	Minor Origin
19a	T-G,W(m)	
19b	T-G	NT-B
19c	T-G	
19d	T-G,NT-B	
19e	T-G,NT-B	
19f	T-G	NT-B
19g	T-G,NT-B	

III. Provinces Characterized by Mixed Origin

Province 10	Major Origin	Minor Origin
10a	T-G	
10b	NT-R	
10c	NT-R	
10d	NT-R	T-W(ow)
10e	NT-R,B	
10f	T-W(ow)	T-L,NT-R
10g	NT-R	T-W(ow)
10h	NT-R,B	
10i	NT-R	T-W(vf)
10j	NT-R,T-L,T-W(Al)(ow)	
10k	NT-R,B	
10l	NT-R,B	
10m	NT-R	

Legend: NT - Non-Transported Soils
B - Bedrock
R - Residual Soil

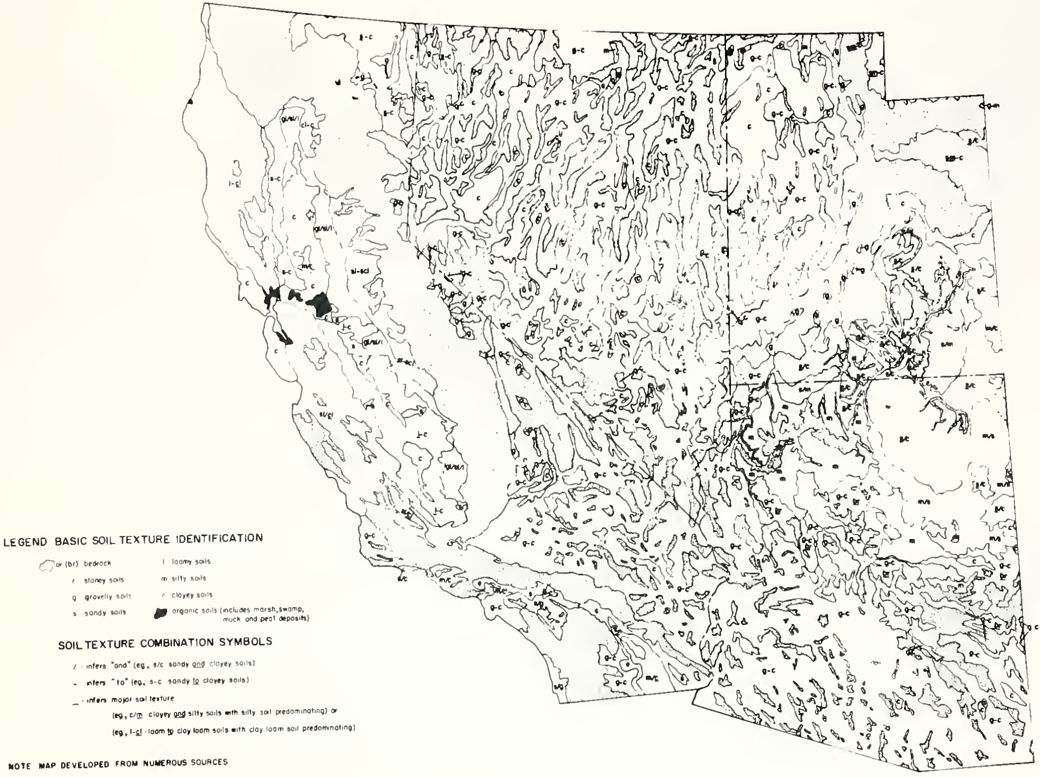
T Transported Soils
G - Glacial
L - Wind
W - Water
(ow) - outwash
(vf) - valley fill
(1) - lacustrine
(Al) - Alluvium
(m) - marine
(cs) - coastal sediments

Table 15

General Soil Classification Correlation

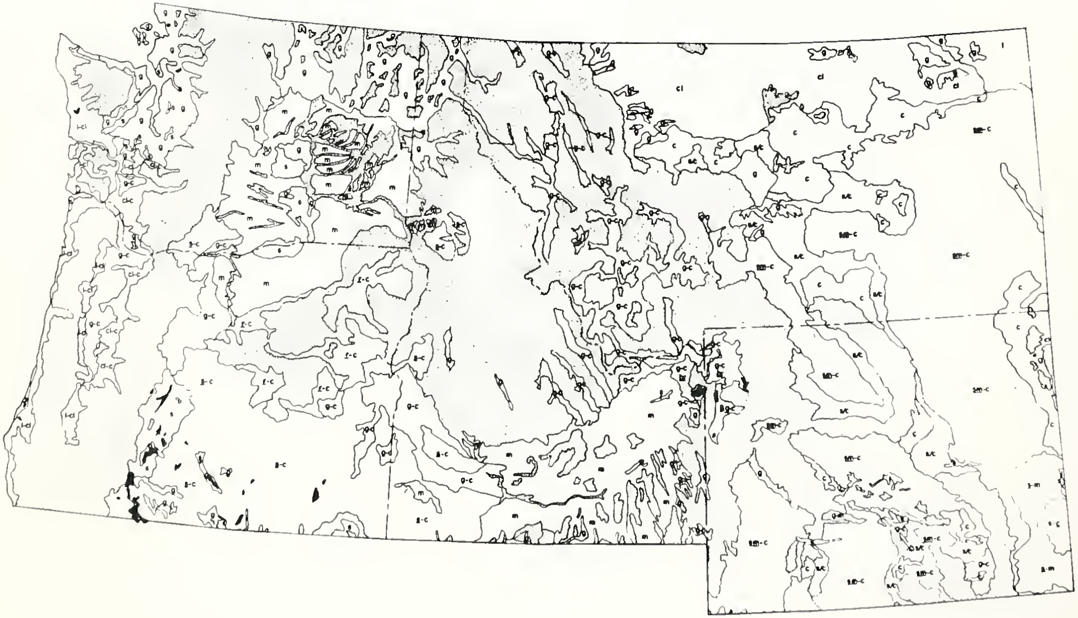
General Texture	Texture Type	U.S.C.S. Most Probable	U.S.C.S. Other
Coarse	Gravel	GP;GW	GM,GC
	Sand	SM;SP-SM	SM-SC
	Loamy Sand	SM	SC
Moderately Coarse	Sandy Loam	SM	ML;SC
	Fine Sandy Loam	SM;ML	SC;SM
Medium	Very Fine Sandy Loam	SM;ML	
	Loam	CL	ML;ML-CL
	Silt Loam	CL	ML;ML-CL
Moderately Fine	Sandy Clay Loam	CL	SC
	Silt	ML	CL
	Silty Clay Loam	CL	CH
	Clay Loam	CL	CH
Fine	Sandy Clay	SC;CL	
	Silty Clay	CH	CL
	Clay	CH	CL,MH

Note: Developed from references (216, 219).



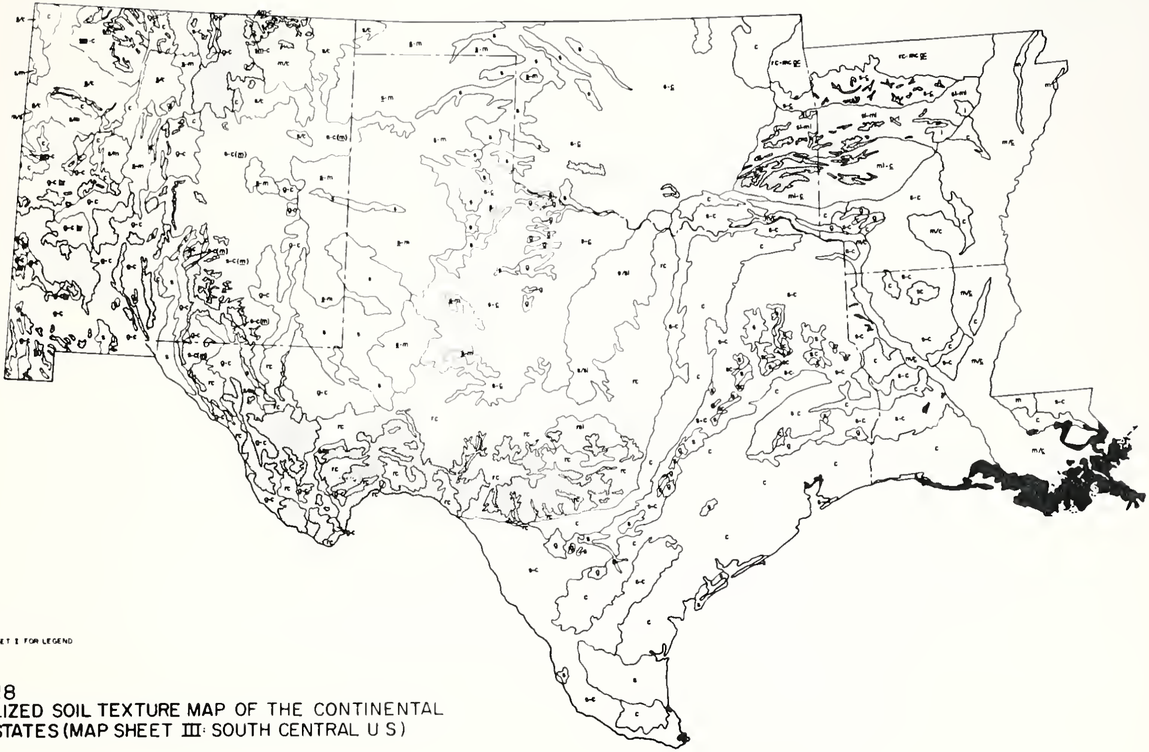
NOTE MAP DEVELOPED FROM NUMEROUS SOURCES

FIGURE 16
GENERALIZED SOIL TEXTURE MAP OF THE CONTINENTAL UNITED STATES (MAP SHEET I: SOUTHWEST U.S.)



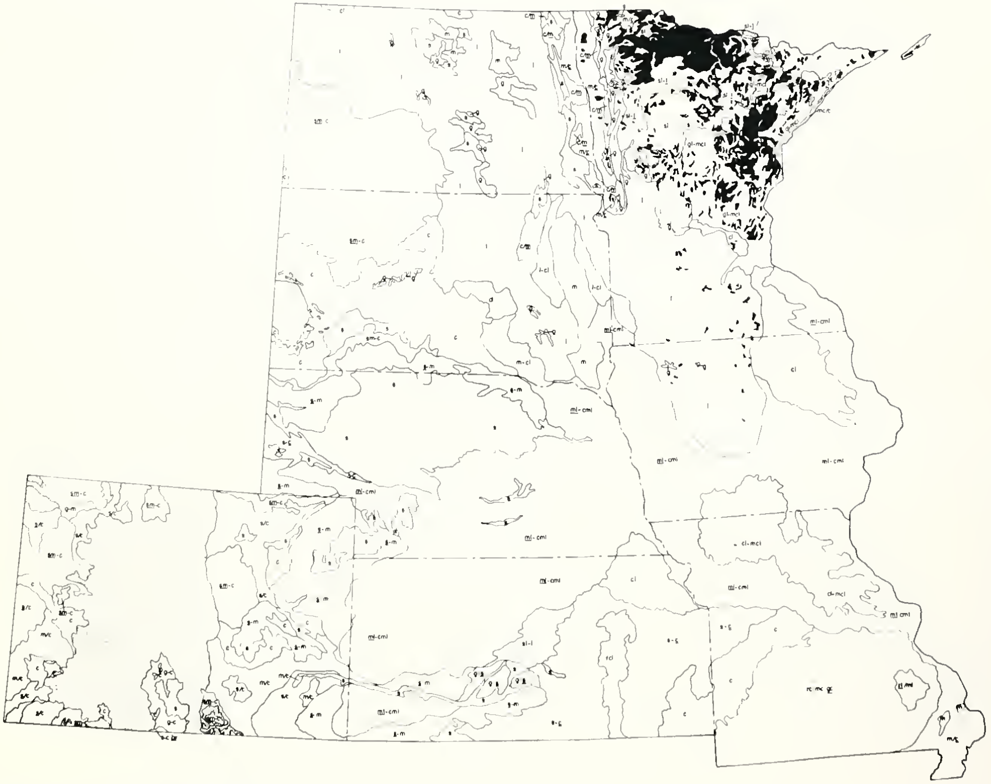
NOTE: SEE MAP SHEET I FOR LEGEND

FIGURE 17
GENERALIZED SOIL TEXTURE MAP OF THE CONTINENTAL UNITED STATES (MAP SHEET II NORTHWEST U.S.)



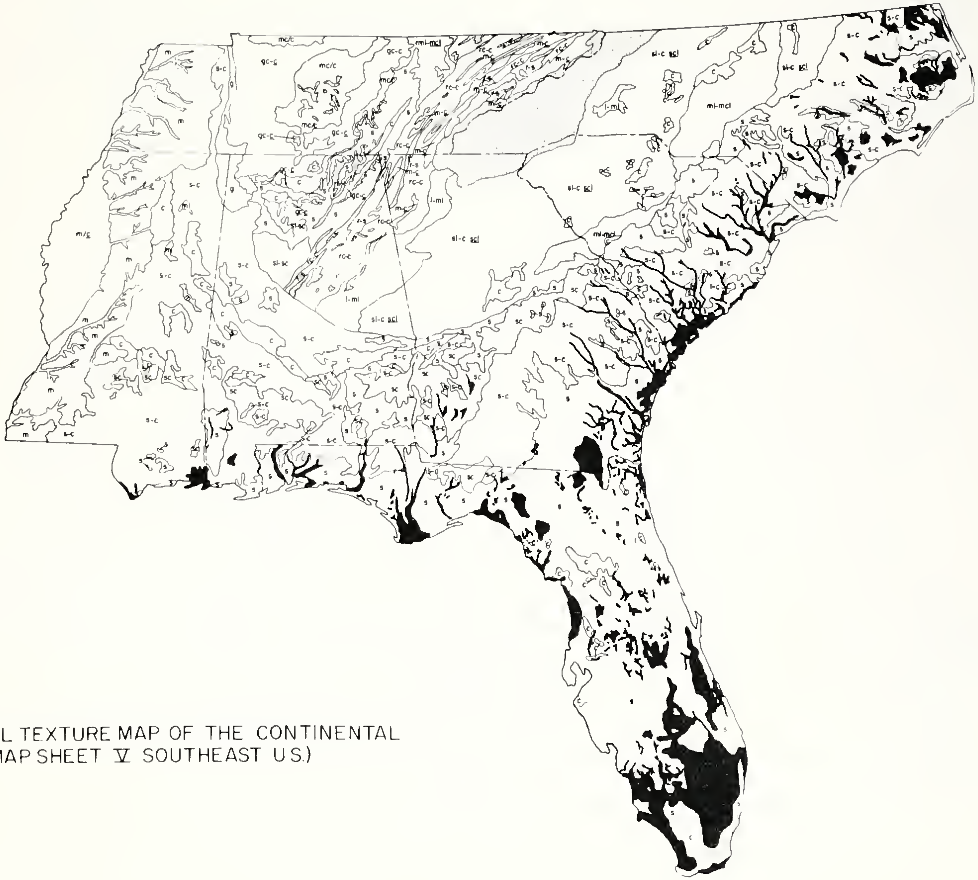
NOTE SEE MAP SHEET I FOR LEGEND

FIGURE 18
GENERALIZED SOIL TEXTURE MAP OF THE CONTINENTAL UNITED STATES (MAP SHEET III: SOUTH CENTRAL U S)



NOTE SEE MAP SHEET 2 FOR LEGEND

FIGURE 19
GENERALIZED SOIL TEXTURE MAP OF THE CONTINENTAL UNITED STATES (MAP SHEET IV: NORTH CENTRAL U.S.)



NOTE SEE MAP SHEET I FOR LEGEND

FIGURE 20
GENERALIZED SOIL TEXTURE MAP OF THE CONTINENTAL UNITED STATES (MAP SHEET V SOUTHEAST U.S.)

NOTE SEE MAP SHEET 2 FOR LEGEND

FIGURE 21
GENERALIZED SOIL TEXTURE MAP OF THE CONTINENTAL UNITED STATES (MAP SHEET VI NORTHEAST U.S.)

made to keep the level of map unit descriptions as detailed as the information from which it was obtained. This factor resulted in a rather wide range of map unit combinations. In general, three broad categories of units are mapped. They are (a) single textured units, (b) multiple textured units and (c) gradationally textured units. When soil types occur in combination, and one is known to dominate, it is underlined in the designation. The legend for the soil types is shown on Figure 16 and is considered to be self-explanatory.

Section Distribution

General. The major soil types within each Section are discribed in the following paragraphs. In some cases, several map units have been combined for brevity. The descriptions are presented in the Province sequence of Table 14. The codes used to describe the frequency of occurrence of soils within the Sections are as follows: (VW) very widespread, (M-W) medium to widespread, (L-M) limited to medium, (N-L) non-existent to limited.

Distribution of Soils by Basic Report Units

Province 1

Section 1a

1. Non soil area (VW).
2. Loamy to clay loam soils (L-M): thin residual soils developed from sandstones and shales.
3. Gravelly soils (N-L): surround the north and east flanks of the mountanious portion.
4. Organic soils (N-L).

Section 1b

1. Non soil area (VW): sandstone and shale bedrock.
2. Loamy to clay loam soils (N-L): residually developed from sandstones and shales.
3. Sandy soils (N-L): appears in small coastal plain areas.
4. Organic soils (N-L): associated with coastal plain portion.

Section 1c

1. Non soil area (VW).
2. Loamy to clay loam (N-L): residual sandstones and shales within small areas near coast.

Section 1d

1. Non soil area (L-M).
2. Loamy to clay loam (clay loam predominating) (L-M): residual sandstones and shales found primarily in the northern coastal range area.
3. Sandy loam to clay loam (clay loam predominating) (L-M): residual sandstones and shales found primarily in the southern coastal range area.
4. Clayey soils (N-L): generally associated with shale hills near San Francisco.
5. Organic soils (N-L): muck deposits near San Francisco Bay.

Section 1e

1. Non soil area (M-W): generally associated with Transverse Ranges.
2. Gravelly to clayey soils (L-M): primarily found in Los Angeles Basin; appears that coarse textured soils predominate.

Province 2

Section 2a

1. Non soil area (VW): generally granitic type mountains.
2. Gravelly soils (N-L): associated with valley outwash and glacial drift.

Section 2b

1. Non soil area (VW): generally igneous rocks.

2. Clay loam to clay (L-M): residual soils on western flank developed from basic igneous rocks. In many cases, this unit gradually merges into the troughs as foothills.

3. Sandy to clayey soils (sandy predominating) (L-M): residual soils developed primarily from basic and acidic igneous rocks on the eastern flanks of the mountain range.

Section 2c

1. Non soil area (VW): generally granitic rocks.
2. Sandy loam to sandy clay loam (L-M): residual soils from granitic rocks occurring along the western portion of the unit.

Section 2d

1. Non soil area (VW): generally granitic rocks.
2. Gravelly to clayey soils (gravelly soils predominating) (N-L): associated with valley fill material.

Province 7

Section 7a

1. Non soil area (M-W): rugged mountainous areas.
2. Gravelly to clayey soils (L-M): these soils are associated with the basin areas characteristic to the unit; texture is frequently coarse but clayey soils are within many basins.

Section 7b

1. Non soil area (M-W).
2. Gravelly soils (L-M): this unit occurs as coarse textured glacial drift in the Washington portion and valley fill in the remaining areas.

Section 7c

1. Non soil area (VW): primarily associated with granitic batholith.

Province 8

Section 8a

1. Non soil area (VW): rugged igneous/metamorphic rocks.

2. Gravelly to clayey soils (bedrock predominating) (L-M): generally associated with thin residual soils from volcanic rocks.

Section 8b

1. Non soil area (VW).

Section 8c

1. Non soil area (VW).

Section 8d

1. Non soil area (M-W).
2. Gravelly to clayey soils (gravelly predominating) (N-L): associated with coarse textured glacial outwash in Jackson Hole.
3. Sandy silt to clay (sandy silts predominating) (N-L): thin residual soils developed from sandstones and shales.
4. Organic (N-L): associated with glacial outwash in Jackson Hole.

Section 8e

1. Non soil area (VW).

Province 9

Section 9a

1. Non soil area (VW).

Section 9b

1. Non soil area (VW).
2. Gravelly and sandy soils (N-L): this unit is generally associated with the glacial and alluvial outwash found in the San Luis Valley.

Section 9c

1. Non soil area (VW).
2. Sandy to clayey (bedrock predominating) (N-I): this unit is associated with thin (generally) residual soils developed from basalts within the San Luis Hills portion.

Province 4

Section 4a

1. Silty soils (VW): aeolian (Loessial deposits).
2. Sandy and gravelly soils (L-M): generally coarse textured deposits from alluvial deposition.
3. Non soil areas (L-M): generally basaltic rock.

Section 4b

1. Non soil area (VW).
2. Stoney to clayey (stoney predominating) (L-M): generally residual soils developed from basic igneous rocks.

Section 4c

1. Silty soils (VW): aeolian deposits overlying acidic flows.
2. Non soil area (N-L): bare acidic lava areas.

Section 4d

1. Sandy to clayey soils (sandy predominating) (L-M): generally thin residual soils from extrusive flows.
2. Gravelly to clayey (L-M): associated with lacustrine areas which characterize the unit: textures vary considerably.
3. Silty (N-L): small aeolian area which is variant to the unit.

Section 4e

1. Sandy to clayey soils (sandy predominating) (M-W): thin residual soils developed from flows present in the unit.
2. Sandy (L-M): associated with pumice deposits in Great Sandy Desert area.
3. Organic (N-L): appear in isolated areas within the western portion of the unit.

Province 6

Section 6a

1. Non soil areas (VW).
2. Sandy and clayey soils (sandy predominating) (N-L): thin residual soils developed from sandstone and shale.
3. Gravelly soils (N-L):associated with valley deposits.

Section 6b

1. Sandy silt to clay (sandy silt predominating) (M-W): thin residual soils developed primarily from Tertiary sandstones and shales.
2. Non soil area (L-M): sandstones and shales.
3. Gravelly soils (N-I): associated with outwash from Uinta Mountains: occur within northernmost portion of unit.

Section 6c

1. Sandy, silty and clayey soils (sandy predominating) (M-W): generally thin residual soils from sandstones and shales.
2. Clayey soils (N-L): associated with clay shales.
3. Non soil area (N-L): associated with canyon lands.

Section 6d

1. Sands, silts and clays (sandy predominating) (M-W): associated with residual development from sandstones and shales.
2. Non soil area (N-I).
3. Clayey soils (N-L): associated with clay shales.

Section 6e

1. Silty soils (M-W): thin residual soils from limestone.
2. Silty and sandy soils (I-M): thin residual soils from sandstones and shales.
3. Gravelly to clayey soils (bedrock predominating) (I-M): thin residual soils from flows.
4. Non soil area (N-L).

Section 6f

1. Clayey soils (L-M): associated with clay shales.
2. Sands, silts and clays (sandy predominating) (I-M): thin residual soils associated with sandstones and shales.
3. Gravelly to clayey (bedrock predominating) (L-M): thin residual soils from flows.
4. Non soil areas (N-I).

Province 13

Section 13a

1. Stoney loams (VW): residual soils developed

from granitic type rocks.
2. Silty loams (L-M): residual soils developed from sedimentary rocks within isolated valley areas.

Section 13b

1. Stoney clays to silty clays (gravelly clay predominating) (VW): soil unit is associated with residual development from cherty limestones (primarily).

Section 13c1

1. Sandy to clayey soils (clayey predominating) (M-W): residual soils developed primarily from sandstones and shales: stoney soils may locally occur.
2. Non soil areas (N-L): associated with rugged sandstone outcrops.

Section 13c2

1. Sandy loam to silty loam (M-W): residual soils developed from folded sandstones and shales.
2. Loamy soils (N-L): associated primarily with alluvial deposits from Arkansas River.
3. Non soil areas: rugged sandstone (primarily).

Section 13c3

1. Silty loam to clayey soils (clayey predominating) (M-W): residual soils developed from sandstones, shales and minor areas of slates and quartzites.
2. Non soil area (L-M): associated with rugged sandstones, and novaculite of unit: appears to be more widespread in northern and eastern (Cklahoma) portion.

Province 14

Section 14a

1. Silty clay loam to clayey soils (clayey predominating) (M-W): residual soils developed within the Cuter Blue Grass and Eden Shale Belt units: parent materials are argillaceous limestones (Outer Blue Grass) and shale with minor siltstone (Eden Shale Belt).
2. Silty clays and clays (L-M): residual soils developed within Inner Blue Grass from pure limestones.

Section 14b

1. Silty clays and clays (VW): residual soils from limestones.
2. Non soil area (N-L): associated with bare limestones outcrops known as "glades".

Section 14c

1. Sandy loams to sandy clay loams (L-M): residual soils developed from sandstones, shales and minor amounts of limestone.
2. Sandy clay loam to silty clay loam (L-M): residual soils similar to #1.
3. Silts and clays (N-L): associated with alluvial areas within unit.
4. Silty loam to clayey silt loam (silty loam predominating) (N-L): aeolian deposits generally found in the western portion of the unit and irregularly along portions of the Ohio.

Section 14d

1. Gravelly clay to clayey (clayey predominating) (M-W): residual soils generally associated with cherty limestones.
2. Silty clay and clayey soils (L-M): residual soils from relatively pure limestones.

Province 15

Section 15a

1. Non soil area (M-W): bare, hard sandstone to higher area.
2. Stoney soils (M-W): associated with sandstone-derived drift.
3. Sandy loams to silty loams (silty loams predominating) (L-M): glacial drift generally in valley portions.

Section 15b

1. Sandy loam to silt loam (silt loam predominating) (M-W): glacial drift found primarily in New York and Pennsylvania generally derived from hard sandstones with some shale.
2. Clay loam and loamy soils (L-M): glacial drift found primarily in the western portion (Ohio and northwest Pennsylvania): drift is generally more plastic (i.e., less silty) than drift noted in #1.

3. Gravelly and sandy soils (N-L): generally associated with valley (glacial) outwash; found primarily in New York State.
4. Organic soils (N-L): small scattered areas.

Section 15c

1. Stoney silt loam to silty clay loam (silty clay loam predominating) (M-W): associated with residual soil developed primarily from sandstones and shales; appears similar to soil found in adjacent Kanawha unit.
2. Non soil areas (L-M): associated with rugged sandstone areas in the southern portion.

Section 15d

1. Stoney silt loam to silty clay loam (silty clay loam predominating) (M-W): residual soils developed primarily from Mississippian rocks and the Pottsville and Allegheny formations of Pennsylvanian age.
2. Sandy clay loam to clayey (clayey predominating) (M-W): residual soils developed from parent material higher in soft shale and limestone outcrops than #1; geologically, this unit conforms to the Conemaugh and Monongahela formations of Pennsylvanian age and the Dunkard formation of Permian age. Residuum developed from these rocks is generally more plastic than the other soil unit of the Section.
3. Non soil area (N-L): isolated areas in southern portion of unit.

Section 15e

1. Sandy soils (M-W): generally associated with residual soils from sandstone.
2. Sandy loam to sandy clay (N-L): residual soils similar to soil unit #1.
3. Non soil areas (N-L): rugged sandstone areas.
4. Gravelly clay to clay (clay predominating) (N-L): residual soil developed from cherty limestones in the Sequatchie and Wills Creek Valleys.
5. Clayey (N-L): residual soils developed from pure limestone and found in association with the variant limestone valleys noted in soil unit #4.

Province 16

Section 16a

1. Stoney to sandy soils (M-W): generally associated with thin residual cover from sandstones occupying ridges of the unit.
2. Non soil areas (L-M): sandstone ridges.
3. Silty to clayey (clayey predominating) (L-M): residuals soils developed from limestones and shales within the valley portion; texture of these soils varies greatly but fine textured soil residuum is generally common in many portions of the valley areas.

Section 16b

1. Stoney clays to clays (M-W): residual soils from carbonate rocks that are frequently cherty in nature; chert residue may yield a stoney or gravelly to clayey matrix.
2. Silty to clayey (clayey predominating) (L-M): residual soils from chert free carbonates.
3. Non soil area (N-L): sandstone ridges.
4. Stoney to sandy soils (N-L): thin residual development from sandstone ridges.

Province 17

Section 17a

1. Non soil area (V-W): although the entire Section has been noted to be of a non soil area type, thin to moderately thick residual soils are present. Generally, the type of soil depends upon the parent rock and possesses a counterpart soil within the Piedmont Plateau Section to the southeast.

Section 17b

1. Sandy loam to clay (sandy clay loam predominating) (VW): residual soils developed primarily from granitic and gneissic rocks.
2. Silty loam to silty clay loam (L-M): associated with residual soils of the Slate Belt areas of the Carolinas.
3. Loamy to silty loam (I-M): residual soils generally developed from schists.
4. Clayey soils (N-L): residual soils primarily associated with basic igneous rocks.

Special remarks: This unit is characterized by a relatively deep development of residual soil. Generally, almost all soils possess very heavy (clayey) B horizons. In addition, much mica is present in the soil and frequently yields A-7-5 or MH Engineering soil classification.

Province 18

1. Sandy to clayey (clayey predominating) (VW): residual soils from Triassic sandstones and shales.
2. Clayey (N-L): residual soils from limestones in valleys.
3. Stoney to clayey (N-L): residual soils associated with trap ridges; portions may be non soil area.
4. Sandy loam to clay (sandy clay loam predominating) (N-L): residual soils from granitic and gneissic rocks.
5. Sandy and gravelly (N-L): glacial drift in northern portion of the unit.
6. Organic soils (N-L): associated with glaciated portion.

Province 3

Section 3a

1. Gravelly and sandy soils (M-W): associated with glacial deposits.
2. Clay loam to clay (L-M): residual soils developed from basalts found within the Trough.
3. Organic (N-L): found in glaciated portion.

Section 3b

1. Gravelly to clayey (VW): this unit is associated with the alluvium of the flood plains or non-marine terraces occupying much of the unit; soil texture is extremely variable.
2. Loamy to clayey loam (N-L): residual soils from sandstones and shales along the west flank of the Valley.
3. Clayey loam to clay (N-L): residual soils from basic igneous rocks on the eastern side of the valley.

Section 3c

1. Loamy to clayey (loam predominating) (L-M): associated with flatter trough areas.

2. Clayey (L-M): generally associated with mixed alluvium and valley terraces within the Trough.
3. Gravelly loams, sandy loams and loams (L-M): generally associated with alluvial fans along Sierra Nevada.
4. Sandy (N-L): wind modified areas found predominating in the southern portion of the Valley.
5. Organic (N-L): occurs in Sacramento - San Joaquin delta.

Province 5

Section 5a

1. Gravelly to clayey (M-W): valley fill areas that characterize the basin portion; soil texture is generally highly variable but varies gradationally in size as one proceeds towards the central portion of the basins.
2. Non soil area (M-W): mountain ranges of the unit.
3. Clayey (L-M): associated with old lacustrine beds (playas) common to the central basin area.
4. Silty soils (N-L): aeolian deposits occurring in the northeast portion.
5. Sandy to clayey (sandy predominating) (N-L): residual soils, generally thin, developed from extrusive rocks in the northwest portion.

Section 5b

1. Gravelly to clayey (M-W): associated with valley fill; general characteristics similar to those found in the Section 5a.
2. Non soil area (L-M): ranges.
3. Clayey (N-L): associated with playas similar to Section 5a; frequency of occurrence is not as great as Section 5a.

Section 5c

1. Silts and clays (clayey predominating) (M-W): associated with fine textured lacustrine and alluvial soils of the unit.
2. Sandy soils (N-L): wind modified dune areas.
3. Gravelly to clayey (N-L): valley fill.
4. Non soil area (N-L): mountain range to the east.

Section 5d

1. Gravelly to clayey (M-W): valley fill.
2. Non soil area (L-M): ranges and mountains.
3. Gravelly to clayey (bedrock predominating) (N-L): thin residual soils from extrusive rocks; found in the northern portion.
4. Clayey (N-L): found in central basin areas.

Section 5e

1. Non soil areas (L-M).
2. Sandy to clayey (silty predominating) (L-M): residual soils derived primarily from sandstones and shales.
3. Gravelly to clayey (L-M): associated with water deposited soils (predominatly valley fill).
4. Stoney clays (N-L): residual soil from limestone.

Section 5f

1. Non soil area (M-W).
2. Stoney clays (L-M): residual soils from limestones comparable to those found in the Edwards Plateau.
3. Gravelly to clayey (L-M): valley fill.

Province 20

Section 20a

1. Sandy (M-W): associated with coastal terraces.
2. Mixed sands and clays (M-W): coastal deposits.
3. Organic (l-M): associated with tidal marshes which occupy areas of the outer coastal plain but which may follow estuaries up to the inner zone.
4. Clayey (N-L): associated with Cretaceous deposits in Raritan Lowland; often associated with greensand belt.
5. Sandy and gravelly soils (N-L): glacial deposits on Cape Cod and Long Island.

Section 20b

1. Mixed sandy and clayey (M-W): coastal deposits.
2. Sandy (L-M): coastal deposits.
3. Organic (L-M): similar to Section 20a.
4. Sand clay (N-L): coastal deposits.

Section 20c

1. Sandy (VW): coastal deposits.

2. Organic (M-W): area contains many large swamps.
3. Clayey (L-M): generally associated with residual soils from water deposited marls and chalky limestones; major concentration occurs around the Ocalla uplift and in southern Florida.
4. Non soil area (N-L): minor area of limerock south of Everglades.

Section 20d

1. Mixed sands and clays (M-W): coastal deposits.
2. Sandy clay (L-M): coastal deposits.
3. Sands (L-M): coastal deposits.
4. Clayey soils (L-M): primarily associated with residual development upon Cretaceous and younger limestones and chalks in the Belted Coastal Plain area.
5. Organic (N-L): small outer coastal areas possess isolated deposits.

Section 20e

1. Silty (VW): loessial deposits.
2. Silts and clays (clays predominating) (N-L): associated with floodplains of rivers dissecting the area.

Section 20f

1. Silts and clays (clays predominating) (VW): alluvium from Mississippi and Red Rivers.
2. Silty (N-L): loessial area variant to alluvial plain called Crowley's Ridge.
3. Organic (N-L): associated with deltaic deposits of the Mississippi River.

Section 20g

1. Clayey (M-W): generally associated with three distinct areas and types; residually developed from limestones and chalks (Cretaceous); marine clays found along the coast; and isolated alluvial clays similar to those which characterize the Mississippi Alluvial Plain Section.
2. Mixed sands and clays (L-M): coastal deposits.
3. Sands and gravels (N-L): coastal deposits.
4. Organic (N-L): minor areas along coast.

Province 11

Section 11a

1. Clays and silts (clays predominating) (M-W): associated with marine deposits; frequently interspersed with silty type till.
2. Organic deposits (L-M).
3. Non soil areas (N-L).
4. Sandy soils (N-L).

Section 11b

1. Clayey soils (VW): associated with marine deposits.
2. Organic (N-L).

Section 11c

1. Clayey soils (M-W): marine clays restricted to northern portion.
2. Loamy (M-W): glacial drift derived from slates, limestones and sandstones in southern portions.
3. Organic (N-L): occurs in southern portion.

Section 11d

1. Loamy to silty clay loams (M-W): glacial till predominatly from dark shale; low in lime.
2. Stoney soils (L-M): occurs in Tug Hill Cuesta.
3. Gravelly soils (N-L): occurs near Tug Hill Cuesta.
4. Organic (N-L).

Section 11e

1. Organic (M-W).
2. Soils associated with glacial lacustrine areas (reworked till in part) (L-M):
   a. Silty clays, clays, silty clay loam, clay loam.
3. Soils associated with glacial drift (primarily late Wisconsin age) (M-W):
   a. Gravelly loam, sandy loams and loams (M-W): occur extensively in Michigan and Wisconsin.
   b. Loam to silty clay loam (L-M): occurs in New York and portions of Illinois and Wisconsin.
   c. Sandy loam to loam (N-L): occurs in Indiana.

- d. Loam to silty loam (N-L): occurs in parts of Wisconsin, Michigan and Indiana.
- e. Clay loam (N-L): occurs primarily in tri-state area of Michigan, Ohio and Indiana.

Section 11f

1. Organic (N-L).
2. Silty loam to clayey silt loam (L-M): loessial deposits in western Illinois and southwestern Indiana.
3. Gravelly soils (N-L): alluvial (sluiceway) terraces.
4. Soils associated with glacial drift (M-W).
   - a. Illinoian till (L-M):
     - i. Loam to clay (clay loam predominating).
     - ii. Clay loam: occurs primarily in Illinois.
   - b. Wisconsin (early) till (L-M):
     - i. Silty clay loam (L-M): occurs in Illinois, Indiana and Ohio.
     - ii. Loam (L-M): generally occurs in a belt south of soil unit (bi).
     - iii. Loam to silty clay loam (L-M): Illinois.
     - iv. Loam to silty loam (N-L): Illinois.

Section 11g

1. Sandy soils (M-W): associated with old glacial lacustrine area and residual soils from Cambrian sandstones and shales; forms the greatest portion of the Central Sand Plain of Wisconsin.
2. Silty loam to clayey silt loam (silty loam predominating) (M-W): aeolian deposits that mantle Cambrian sandstones and shales and younger Paleozoic carbonates.
3. Organic (N-L): occur principally within northeast portion.

Section 11h

1. Soils associated with glacial till (VW).
   - a. Loamy (M-W): occurs in all states within Section.
   - b. Gravelly loam, sandy loam and sandy clay loam (L-M): occurs primarily in northern Minnesota.

2. Soils associated with glacial lacustrine areas (L-M):
   a. Clays and silts: fine texture lacustrine deposits.
   b. Sandy and gravelly soils: water-sorted (beach) deposits.
3. Organic (L-M): occur primarily in northeast.

Special Remarks: The clayey textured soils appear to be more prominant in the Lake Agassiz area with silty soils flanking the finer clays on all sides. Sandy beach deposits predominate on the western side (North Dakota) while gravelly material is found in Minnesota. Lake Souris appears to have an equitable distribution of both silt and clay size deposits, while Lake Dakota appears more silty in texture. Both of the latter lacustrine areas have associated granular beach deposits.

Section 11i

1. Silty loam to clayey silt loam (silty loam predominating) (M-W): aeolian deposits overlying glacial drift.
2. Clay loam to silty clay loam (clay loam predominating) (M-W): glacial drift; primarily Kansan, in part, Iowan.

Province 12

Section 12a

1. Soils associated with glacial drift (M-W): mainly gravelly loams, sandy loams, sandy clayey loams, and silty clay loams.
2. Non soil areas (L-M).
3. Organic (L-M).
4. Silty clays and clays (N-L): lacustrine deposits.

Province 19

Section 19a

1. Clayey soils (M-W): marine clays generally present in northern portion.
2. Stoney sandy and gravelly soils (M-W): glacial drift, generally thin and similar to that found in the adjacent upland unit to the north.
3. Organic (L-M): includes muck and peat bogs associated with glaciation as well as marshy deposits in estuarine deltas near mouths of

rivers and streams.
4. Non soil area (N-L).

Section 19b

1. Stoney sandy and gravelly soils (M-W): generally thin glacial drift of Wisconsin age derived from two major rock groups: (a) granites, gneisses and schists and (b) shales and limestones; sedimentary rock derived till found primarily in the northern portion.
2. Non soil areas (L-M).
3. Clayey gravelly soils (N-L): glacial till generally derived from limestones and shales in northeast Maine.
4. Organic (N-L).
5. Clayey soils (N-L): small scattered areas of marine clays which are modal to the adjacent Seaboard Lowland unit; existence of this soil unit may be due to the relatively indefinite border which separates the New England Upland from the Seaboard Lowland.

Section 19c

1. Sandy and gravelly soils (VW): coarse glacial drift occurring within till, outwash plains and terraces.
2. Organic (N-L): small area noted in southern portion.
3. Non soil area (N-L): associated with trap ridges.

Section 19d

1. Non soil area (VW).
2. Stoney gravelly and clayey gravelly soils (N-L): isolated patches of glacial drift similar to that found in New England Upland Section.
3. Organic (N-L).

Section 19e

1. Non soil area (M-W).
2. Stoney gravelly soils (M-W): generally thin cover of coarse glacial drift.

Section 19f

1. Loamy (VW): glacial till derived from schists, slates, shales and limestones; minor areas

may be stoney.
2. Non soil areas (N-L).

Section 19g

1. Non soil area (M-W): occurs with glaciated portion.
2. Stoney loam (M-W): thin residual soils developed from primarily gneissic rocks; occurs in nonglaciated portion.

Province 10

Section 10a

1. Loamy soils (M-W): forms bulk of glacial till of North Dakota and South Dakota portions of Section.
2. Clay loam (M-W): glacial till found primarily in Montana and smaller isolated areas of the Dakotas.
3. Non soil areas (N-L): several Rocky Mountain outliers.
4. Gravelly soils (N-L): found near Montana border with Rocky Mountains and in the north central portion of Montana.

Section 10b

1. Sandy silt to clayey (sandy silt predominating) (M-W): residual soils derived from sandstones and shales.
2. Clayey (M-W): associated with clay shales of the unit; Pierre Hills area is a primary example.
3. Gravelly soils (N-L): small isolated areas associated with outwash.
4. Non soil areas (N-L).

Section 10c

1. Sandy silts to clayey (sandy silt predominating) (M-W).
2. Clayey (N-L): associated with scattered areas of clay shales.
3. Gravelly to clayey (N-L): coarse textures generally predominate; associated with outwash from surrounding mountain areas; occur in areas which lie between Rocky Mountain appendages which protrude into the Section.
4. Non soil area (N-L): scattered exhumed granitic areas protruding through Tertiary sediments.

Section 10e

1. Non soil area (L-M): associated with granitic core and volcanic rock areas.
2. Clayey soils (L-M): residual soils developed from Triassic shales and Permian limestones.
3. Sandy and silty soils (N-L): associated with residual soils developed from the Cretaceous Dakota Sandstone; this unit encircles the area and gradually merges (topographically) into the surrounding Missouri Plateaus.

Section 10f

1. Sandy to silty (sandy predominating) (M-W): original plains outwash mantle; gravelly textures and clays are occasionally found.
2. Sandy (L-M): corresponds to Nebraska Sand Hills plus several other scattered areas; in part wind reworked.
3. Silty loam to clayey silt loam (silt loam predominating) (L-M): aeolian deposits occur in the northeast portion and extend into the Central Lowland Province.
4. Sandy to clayey (clayey predominating) (N-L): residual soils developed primarily from Brule clay within Goshen Hole Lowland area of Nebraska and Wyoming.

Section 10g

1. Sandy to clayey (M-W): residual soils from Tertiary and Cretaceous sandstones and shales.
2. Clayey (L-M): associated with clay shales.
3. Sandy to silty (sandy predominating) (L-M): variant Great Plains outwash mantle.

Section 10h

1. Sandy to clayey (VW): see comments of Section 10g.
2. Non soil areas (N-L).

Section 10i

1. Sandy to clayey (silt predominating) (VW): residual soils developed from sandstones and shales (minor limestones) of Triassic, Jurassic and Permian age; may be thinly developed and lack any widespread clayey residue.
2. Gravelly to clayey (L-M): valley fill in southern portion.

3. Sandy to silty (sandy predominant) (N-L): isolated areas of Great Plains outwash units.

Section 10j

1. Silty loam to clay silt loam (silty loam predominating) (L-M): aeolian areas overlying bedrock and Plains outwash.
2. Sandy to clayey (clayey predominating) (L-M): residual soils from sandstones, shales and limestones of Cretaceous and Permian age.
3. Sandy loam to loam (N-L): residual soil in Smokey Hills area.
4. Sandy to silty (sandy predominating) (N-L): Tertiary Plains outwash variant to unit.
5. Sandy and gravelly soils (N-L): generally associated with alluvial soils within Arkansas Lowland; portion may be wind reworked.

Section 10k

1. Sandy to clayey (clayey predominating) (L-M): residual soils from Permian sandstones and shales.
2. Stoney sandy loams (L-M): residual soils from granitic type rocks of Llano Uplift.
3. Stoney clays (L-M): residual from Cretaceous limestones.
4. Sands and sandy loams (N-L): residual soils from Pennsylvanian sandstones and shales.
5. Non soil areas (N-L).

Section 10l

1. Stoney clays (M-W): residual soils from Cretaceous limestones.
2. Non soil area (M-W): bare limestone outcrops.

Section 10m

1. Sandy to clayey (clayey predominating) (VW): residual soils from Permian sandstones and shales and Pennsylvanian limestones, sandstones and shales.
2. Stoney clay loams (N-L): residual from cherty limestones in Flint Hills.
3. Clayey (N-L): associated with Pennsylvanian shales in Cherokee Lowland.
4. Non soil area (N-L): Wichita and Arbuckle Mountains.
5. Sands and gravels (N-L): scattered soils of water transported origin.

Poor Subgrade Support Areas

Inorganic Soils

General. Soils are used in two general ways along a highway route. They are either: (a) stressed in place as foundations for structures (including embankments) and in cut slopes or (b) they are excavated and compacted to form embankments, backfills for structures, and subgrades. The poorer soils are wasted, e.g., organics are not used as constructional materials and are often excavated and/or displaced in embankment foundation situations. Local "problem" soils are avoided in subgrade locations, often for the reason that they are difficult to handle and/or compact. A number of soil textures can be troublesome in subgrades, i.e., non plastic silts, micaceous silts, poorly graded sands, but problems of subgrade support are most common with clays. For this reason, the rating of Sections with respect to problems of subgrade support was accomplished by a combined consideration of the clayeyness of surficial soils and the frequency of occurrence of such soils.

The rating is compromised as topography becomes rough and more subgrade soils originate from deposits not mapped in the surficial coverage (Figures 16 to 21). All textural types coarser than (and including) the very fine sandy loam in Table 15 were considered to afford satisfactory subgrade support. Finer textures were grouped into four severity categories based upon the most probable Unified Soil Classification, also given in Table 15. The resulting severity groups are shown in Table 16.

Severity ratings of each Section were then qualitatively formulated by combining textural type and distribution information with the general severity rating of Table 16. The severity ratings and descriptive remarks follow in a sequence identical to that utilized in the discussion of soil origin and texture. Severity rating codes are identical to those used within the soil texture description.

Severity Rating by Basic Report Unit

Province 1
Section 1a (N-L): lean clays developed from residual sandstones and shales may be present in minor portions of the area.
Section 1b (N-L): comments similar to Section 1a.
Section 1c (NE)
Section 1d (L-M): lean clays may be found over a great portion of the area from residual sandstones and shales.
Section 1e (N-L): minor areas of lean to highly plastic clays may be found within the Los Angeles Basin.

Province 2
Section 2a (NE)
Section 2b (N-L): lean and plastic clays may be associated with residual soils from basic igneous rocks on the western flank of the Range.
Section 2c (N-L): minor area of residual soils from granitic rocks may afford lean clay development.
Section 2d (NE)

Province 7
Section 7a (N-L): clay soils generally confined to basin areas.
Section 7b (NE)
Section 7c (NE)

Table 16

Generalized Severity Category of Poor Subgrade

Support Potential by Textural Classification

Category	Textural Classification	Most Probable U.S.C.S. Category	Other U.S.C.S. Categories
1 (Least Severe)	Sandy Clay	SC,CL	
	Sandy Clay Loam	CL	SC
2	Silt	ML	CL
	Silt Loam	CL	ML,ML-CL
	Loam	CL	ML,ML-CL
3	Clay Loam	CL	CH
	Silty Clay Loam	CL	CH
4 (Most Severe)	Silty Clay	CH	CL
	Clay	CH	CL

Province 8
Section 8a (NE)
Section 8b
Section 8c
Section 8d (N-L): lean to plastic clays may be found in minor areas from residual sandstones and shales.
Section 8e (NE)

Province 9
Section 9a (NE)
Section 9b (NE)
Section 9c (NE)

Province 4
Section 4a (NE)
Section 4b (NE)
Section 4c (NE)
Section 4d (N-L): highly plastic clays may be associated with lacustrine areas.
Section 4e (NE)

Province 6
Section 6a (N-L): clays may be associated with shales in southern portion of unit; remainder of soils may be thin and coarse textured.
Section 6b (N-L): highly plastic clays may be associated with shales within the unit.
Section 6c (N-L): clays may be associated with clay shales; sandy texture predominates.
Section 6d (N-L): similar to Section 6c.
Section 6e (N-L): plastic clays may locally be associated with residual soils from volcanic material.
Section 6f (I-M): highly plastic clays are associated with shales and clay shales.

Province 13
Section 13a (N-L): silt loam developed from sedimentary rocks may be of a lean clay variety.
Section 13b (I-M): highly plastic soils may be found throughout the area; however, chert residue in stoney or gravelly form, may increase the subgrade support.
Section 13c1 (I-M): highly plastic residual soils may be associated with the sandstones and shales of the unit.
Section 13c2 (N-L): lean clays are associated with the residual soils and alluvial

deposits of the area; clay shales are also found in the area.

Section 13c3 (L-M): highly plastic soils may develop from residual soils.

Province 14

Section 14a (VW): development of highly plastic residual soils is very widespread in the unit.

Section 14b (VW): same as Section 14a.

Section 14c (L-M): residual soils appear to be less plastic (i.e., more silty and sandy) than in other Sections of Province; lean clays may be associated with residual soils while the more plastic soils are associated with the limited alluvial deposits in the area.

Section 14d (M-W): highly plastic soils may be frequently encountered with residual soils of the unit.

Province 15

Section 15a (N-L): silty loam glacial drift in the valleys may frequently be of a lean clay variety.

Section 15b (L-M): lean clays from glacial drift are present throughout most of the Section; plasticity of the drift may be greater within the western portion of the unit; highly plastic soils are generally not existent within the unit.

Section 15c (L-M): silty clay loam residual soils may generally be a lean to heavy clay material.

Section 15d (M-W): comments similar to Section 15c; in addition, residual soils developed from Conemaugh, Monongahela and Dunkard formations may be highly plastic.

Section 15e (N-L): only clayey type soils within the unit are associated with the variant limestone valleys in the Section; residual soils developed in these limestones may be highly plastic.

Province 16

Section 16a (L-M): lean to heavy plastic clays are generally associated with the limestone and shale residual soils of the valley.

Section 16b (L-M): clayey soils are associated with residual soils of the area; quantity of cherty residue in clay matrix may increase potential subgrade support.

Province 17
Section 17a (NE)
Section 17b (M-W): lean clays are present throughout entire Section; highly plastic soils are associated with residual soils developed from basic igneous rocks.

Province 18 (M-W): lean to highly plastic clay soils are associated with each residual soil type within the unit.

Province 3
Section 3a (N-L): lean to highly plastic clays may be associated with residual basalts.
Section 3b (L-M): highly plastic clays may frequently underlie portions of the flood plains within the unit; similar type clays may be associated with residual soils found in the adjacent border uplands.
Section 3c (M-W): clays of variable plasticity characteristics are quite frequently associated with both alluvium and valley trough soils within the central portion of the valley.

Province 5
Section 5a (L-M): plastic clay soils are generally associated with lacustrine areas occuping the central portions of the basins.
Section 5b (N-L): comments similar to Section 5a except frequency of occurrence is less in this Section.
Section 5c (M-W): highly plastic soils are widely distributed in association with lacustrine and alluvial deposits.
Section 5d (N-L): comments similar to Section 5b.
Section 5e (N-L): clayey soils of unknown plasticity characteristics may be associated with valley fill and

residual soils from limestones.

Section 5f (N-L): comments similar to Section 5e.

Province 20

Section 20a (N-L): highly plastic clays are primarily associated with Cretaceous rocks in the Raritan Lowland.

Section 20b (N-L): clays may be associated with mixed coastal sediments; sand clay of unit not considered as a poor subgrade material in this unit.

Section 20c (L-M): highly plastic clay soils may be residually developed from carbonate rocks in the unit.

Section 20d (L-M): clays developed from limestones and chalks are frequently highly plastic in nature.

Section 20e (N-L): highly plastic clays are generally associated with minor alluvial areas.

Section 20f (VW): highly plastic soils are widespread in the unit from alluvial origin.

Section 20g (M-W): highly plastic clays are widespread from a variety of origins in the unit.

Province 11

Section 11a (M-W): highly plastic clays are widely distributed throughout the area from marine deposits.

Section 11b (M-W): comments similar to Section 11a.

Section 11c (M-W): lean and plastic clays from marine and glacial deposits may be distributed throughout the area; marine clays may be highly plastic.

Section 11d (L-M): major portion of drift may be of a lean clay variety.

Section 11e (L-M): most highly plastic clays are those associated with the lacustrine areas; clayey till appears to be limited to the outer (southern and western) limits of drift; this till is generally of the lean clay variety and not widely distributed; predominating till textures in the unit are coarse textured.

Section 11f (M-W): unit has a more extensive areal distribution of clayey type soils than the Eastern Lakes and Lacustrine Sections; generally the most plastic soils are associated with the oldest drift (Illinoian); these soils, however, are not as plastic as those associated with glacial lacustrine origin; overall a lean clay type of soil may be prevelant throughout most of the entire Section.

Section 11g (N-L): lean clays may occasionally be associated with aeolian deposits; major texture of unit is primarily sandy to silty.

Section 11h (N-L): most plastic soils appear in glacial lacustrine deposits (primarily Lake Aggassiz); major till texture of unit is gravelly loam to loam,with loamy till predominating, somewhat similar in coarseness to that of the Eastern Lakes and Lacustrine Section; lean clays may be associated with the loamy drift.

Section 11i (M-W): lean clay soil is distributed throughout the greatest portion of the unit; less plastic (silty) soils are associated with the loess deposits while highly plastic soils are those associated with the Kansan drift.

Province 12

Section 12a (N-L): highly plastic clays are only associated with minor areas of lake deposits; drift texture is granular in nature.

Section 12b (NE)

Province 19

Section 19a (M-W): highly plastic clays are associated with marine clays widely distributed in area.

Section 19b (N-L): minor areas of marine clays similar to that found in Section 19a may protrude into unit.

Section 19c (NE)

Section 19d (NE)

Section 19e (NE)

Section 19f (N-L): although loam texture predominating in unit has a potential for a lean clay classification, it is generally the finest texture present in the unit; much of the area has a stoney fraction and subgrade support should not be a problem.

Section 19g (NE)

Province 10

Section 10a (L-M): entire till portion may be considered as clayey type; lean clays will be more prominant in the Dakotas while plasticity of the till increases in the Montana portion; most probable clay throughout unit is a lean clay type.

Section 10b (M-W): widely distributed and highly plastic clays are often associated with the clay shales and shales of the area.

Section 10c (N-L): highly plastic clays may frequently be associated with shales of the unit; however, predominant texture is semi-granular.

Section 10d (N-L): comments similar to Section 10c.

Section 10e (N-L): highly plastic clays are associated with shales of the area; clays from residual limestones are frequently less plastic.

Section 10f (N-L): only potential clayey area is that found in Goshen Hole Lowland from shaley bedrock; predominating texture of unit is sandy to silty.

Section 10g (I-M): highly plastic soils are associated with clay shales and shales of the unit.

Section 10h (L-M): comments similar to Section 10g.

Section 10i (N-L): unit generally lacks any regional clay type soils; occasionally, highly plastic soils may be associated with shales.

Section 10j (N-I): most plastic soils associated with residual sandstones and shales in southeast and eastern portions of the unit.

Section 10k (N-I): highly plastic soils are generally confined to the residual soils developed from Permian rocks in the western portion of the unit.

Section 101 (I-M):	plastic clays may be associated with residual limestones found throughout the unit.
Section 10m (M-W):	highly plastic soils may be quite frequently associated with the residual soils throughout much of the area.

Organic Soils

No attempt was made to rate the severity of support problems associated with organic deposits within the Sections. Qualitatively assessed frequency of occurrence ratings have been previously presented under the description of soil textures. The reader is referred to this discussion.

High Volume Change Soils

Engineering Literature

As previously noted, a literature search of high volume change occurrences was undertaken. The fruition of this effort is shown in Figure 22. In these locations the swelling potential was realized. The numbers contained within this diagram are legended to Table 17, which is a summary of the individual references containing the information.

Geologic Investigation

The association of high volume change soils with particular geologic formations was obtained from literature searches. Table 18 summarizes the results by geologic age and formations, as reported and mapped by Jensen (333). Figure 23 illustrates the distribution of these formations within the United States. The base map used by Jensen was reference (384). These are areas of swelling potential.

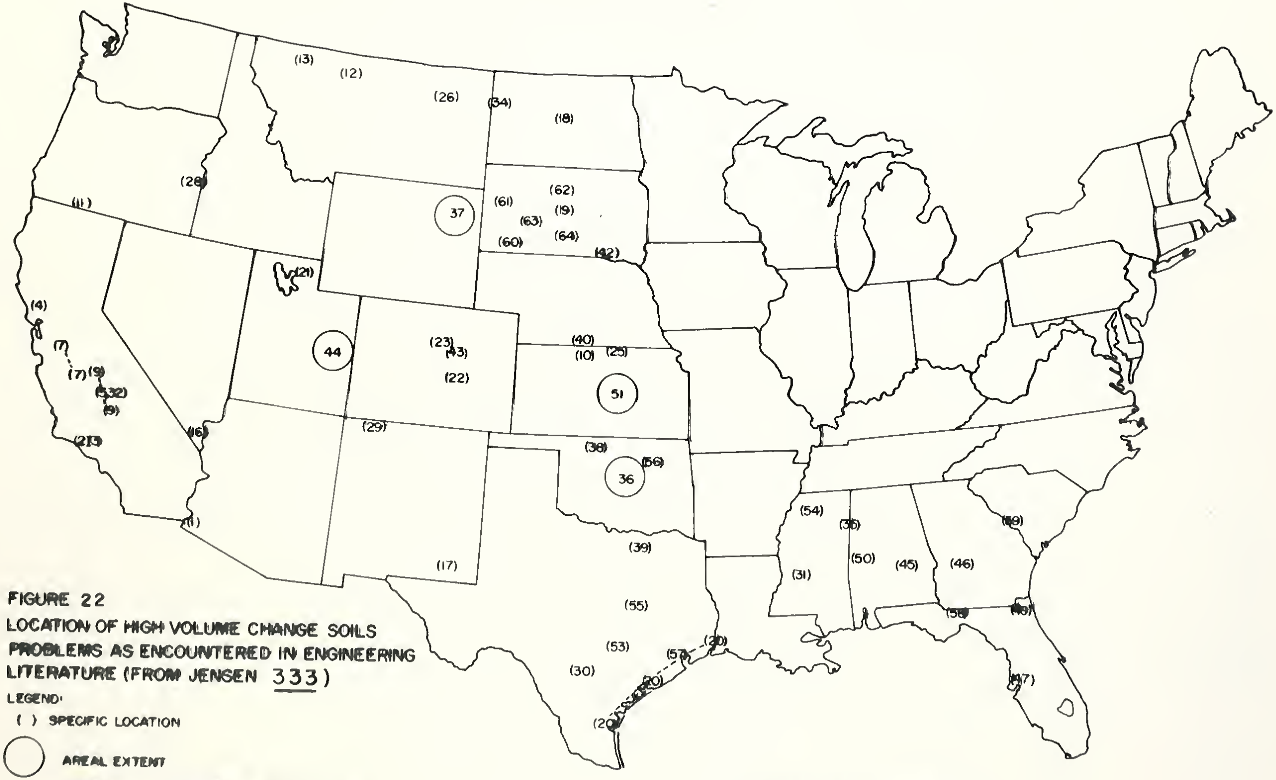


FIGURE 22

LOCATION OF HIGH VOLUME CHANGE SOILS PROBLEMS AS ENCOUNTERED IN ENGINEERING LITERATURE (FROM JENSEN 333)

LEGEND:

( ) SPECIFIC LOCATION

○ AREAL EXTENT

( )--( ) PROBLEM ENCOUNTERED BETWEEN POINTS

NOTE: NUMBERS REFER TO TABLE IN TEXT

Table 17

Reference Summary of High Volume Change Soil Locations Obtained from Engineering Literature

Map Number[1]	Project-Location	Reference[2]
1	Gila - Canals; Arizona	(383)
2	Casitas Canal; California	(383)
3	Ojai Valley Pump; California	(383)
4	Putah Canal; California	(383)
5	Lind-Strath Reservoir; California	(383)
6	Lindmore Reservoir; California	(383)
7	Delta-Mendota Canal; California	(383)
8	Contra Costa Canal; California	(383)
9	Friant Kern Canal; California	(383)
10	Kirwin Dam; Kansas	(383)
11	Emigrant Dam; Oregon	(383)
12	Tiber Dam Spillway; Montana	(383)
13	Shelburne Dam; Montana	(383)
14	BLM-Collins Dam; Montana	(383)
15	Little Porcupine Plant; Montana	(383)
16	Boulder City; Nevada	(383)
17	McMillan Reservoir; New Mexico	(383)
18	McClusky Canal; North Dakota	(383)
19	Oahe Pump; South Dakota	(383)
20	Gulf Coast Canal; Texas	(383)
21	Gateway Canal; Utah	(383)
22	Colorado Springs; Colorado	(383)
23	Denver-Boulder Turnpike; Colorado	(383)
24	Fire Mountain Canal; Colorado	(383)
25	Courtland Canal; Nebraska	(383)
26	Fort Peck Dam; Montana	(383)
27	Ortega Reservoir; California	(383)
28	Malheur River Siphon; Oregon	(383)
29	Navajo Dam; New Mexico	(383)
30	San Antonio; Texas	(368)
31	Jackson; Mississippi	(363)
32	Porterville; California	(346)
33	Bexar County; Texas	(378)
34	Fort Union Dam; North Dakota	(369)
35	West Point; Mississippi	(323, 324)
36	Permian Red Beds; Oklahoma	(352, 353)
37	Heavy Bentonite Areas; Wyoming	(382, 383)
38	Great Salt Plains Dam; Oklahoma	(381)
39	Sherman; Texas	(381)
40	Harlan County Dam; Nebraska	(381)

Table 17 (cont'd.)

Map Number[1]	Project-Location	Reference[2]
41	Kanopolis Dam; Kansas	(381)
42	Fort Randall Dam; South Dakota	(381)
43	Denver; Colorado	(310)
44	East Central Utah	(328)
45	Montgomery; Alabama	(372)
46	Central Georgia	(372)
47	Central Florida	(372)
48	North East Mississippi	(372)
49	North Central Florida	(372)
50	Tombigbee River; Alabama	(372)
51	Kansas	(300)
52	Texas	(322)
53	Austin; Texas	(315, 316)
54	Panola County; Mississippi	(378)
55	Waco, Interstate 35; Texas	(350)
56	Tulsa; Oklahoma	(352, 353)
57	Houston-Urban Freeway; Texas	(329)
58	NW-Limon, Interstate 10; Colorado	(307)
59	Tallahassee; Florida	(372)
60 - 64	Western South Dakota	(370)

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[1] Map number keyed to Figure 22.

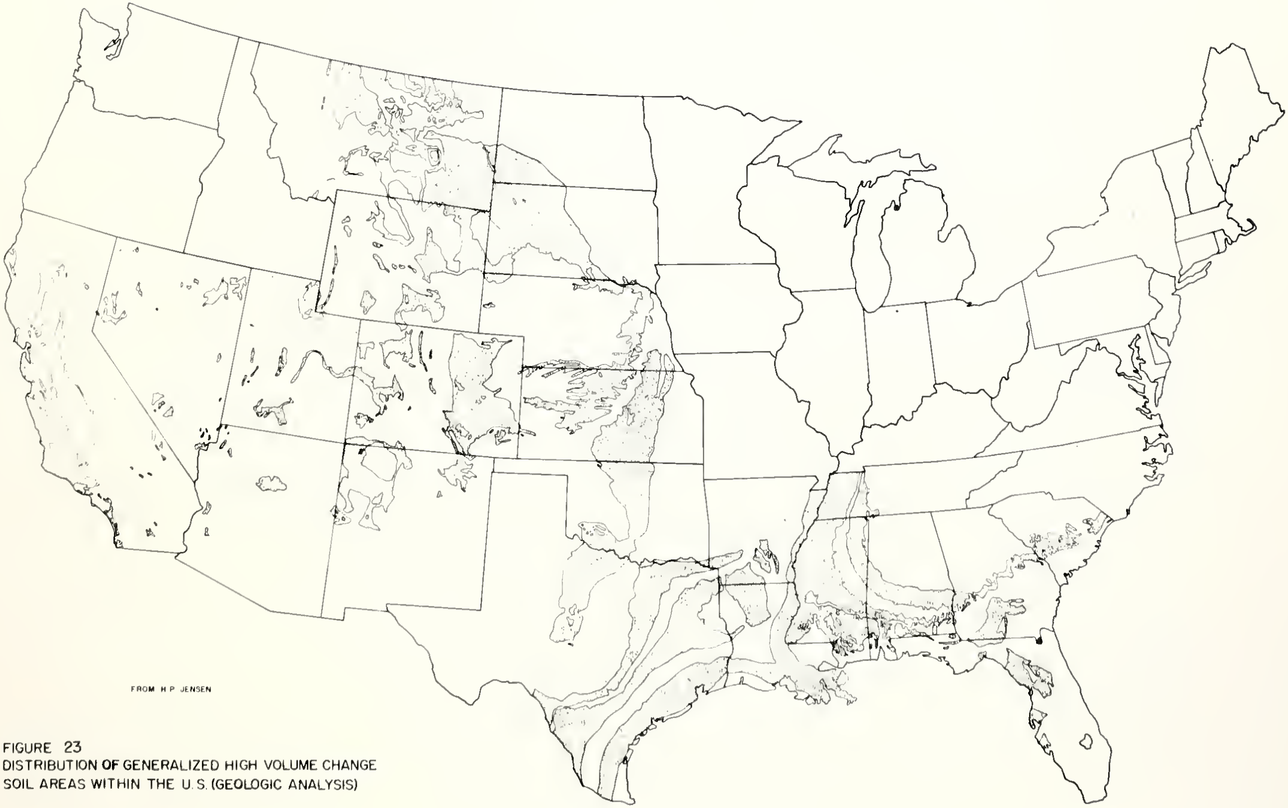
[2] Reference number refers to bibliography number.

Table 18

Geologic Age Summary of High Volume Change Formations

Geologic Age		Description
Quaternary	1.	Mississippi Alluvium
	2.	Alluvial and Lake Laid Deposits
	3.	Houston Fm
Quaternary-Tertiary	4.	Quaternary and Tertiary Marine and Fresh Water Deposits (Alluvial fans, lakebeds)
Tertiary (Undifferentiated)	5.	Jackson, Chickasawhay, Barnwell and Ocalla Fm
	6.	Tampa and Hawthorn Fm
	7.	Jackson Fm
	8.	Ft. Union Shale
Tertiary-Cretaceous	9.	Lower Cretaceous Fm (Porters Creek and Nahoela)
	10.	Laramie and Denver Fm
Cretaceous (Upper)	11.	Selma and Euthaw Fm
	12.	Eagleford and Woodbine Fm
	13.	Taylor and Austin Fm
	14.	Upper Cretaceous Fm (Eagleford, Pierre and Bearpaw)
	15.	Pierre and Bearpaw Shale Fm
	16.	Mesaverde, Mancos and Lewis Shale Fm
	17.	Mesaverde, Mancos, Lewis and Cody Shale Fm
Cretaceous (Undifferentiated)	18.	Cretaceous Fm (Cody, Mowry, Frontier, Benton, Niobrara Fm)
	19.	Cretaceous Fm (Cody and Benton Fm)
	20.	Cretaceous Fm (Mowry and Frontier Fm)
	21.	Cretaceous Marine Shale
Permian	22.	Permian Red Beds

Note: Information summarized from Jensen (333).



FROM H P JENSEN

FIGURE 23
DISTRIBUTION OF GENERALIZED HIGH VOLUME CHANGE SOIL AREAS WITHIN THE U.S. (GEOLOGIC ANALYSIS)

Based upon information obtained from this phase of the project an examination of the occurrence and frequency of high volume change formations within the basic report Sections was undertaken. Table 19 is the result of this effort, and largely rates the potential for volume change problems.

Pedologic Investigation

A comparable study was undertaken with pedologic information. Table 20 summarizes the data based upon parent material-origin considerations. Figure 24 shown the distribution of these areas within the United States. The base map used by Jensen was reference (379).

A frequency of occurrence rating was also established for each Section possessing high volume change soil series, which is given in Table 21. Again the rating is largely one of potential volume change problems.

Adjusted Frequency of Occurrence Rating by Section

The final frequency of occurrence rating for each Section possessing high volume change potential is generally based upon the higher geologic or pedologic rating. Several exceptions occur, however, where transported surficial deposits mantle high volume change geologic formations. An example occurs in the Mississippi Loessial Upland Section. Based upon the pedologic mapping, a Non Existent to Limited rating was obtained.

A frequency rating of Very Widespread was, however, obtained from the geologic phase due to the existence of high volume change formations underlying the loessial

Table 19

Summary of Geologic Formations Showing High Volume Change

by Frequency of Occurrence Within Sections[1]

	Physiographic Unit Description	High Volume Change Formations	Estimated Occurrence Within Section (All Formations Considered)
1d	California Coast Range	1. Quaternary and Tertiary Marine and Fresh Water Deposits (Alluvial fans, lakebeds) 2. Cretaceous Marine Shales	Medium to Widespread
1e	Los Angeles Range	1. Quaternary and Tertiary Marine and Fresh Water Deposits (Alluvial fans, lakebeds)	Limited to Medium
2d	Lower California	1. Quaternary and Tertiary Marine and Fresh Water Deposits (Alluvial fans, lakebeds)	Non Existent to Limited
3c	California Valley	1. Quaternary and Tertiary Marine and Fresh Water Deposits (Alluvial fans, lakebeds)	Limited to Medium
5a	Great Basin	1. Quaternary and Tertiary Marine and Fresh Water Deposits (Alluvial fans, lakebeds)	Limited to Medium
5b	Sonoran Desert	1. Quaternary and Tertiary Marine and Fresh Water Deposits (Alluvial fans, lakebeds)	Non Existent to Limited
6a	High Plateaus of Utah	1. Mesaverde, Mancos and Lewis Shale Fm 2. Quaternary and Tertiary Marine and Fresh Water Deposits (Alluvial fans, lakebeds)	Limited to Medium
6b	Uinta Basin	1. Mesaverde, Mancos and Lewis Shale Fm	Limited to Medium
6c	Canyon Lands	1. Cretaceous Fm (Cody, Mowry, Frontier, Benton and Niobrara)	Limited to Medium
6d	Navajo	1. Mesaverde, Mancos and Lewis Shale Fm 2. Cretaceous Fm (Cody, Mowry, Frontier, Benton and Niobrara)	Medium to Widespread
6e	Grand Canyon	1. Quaternary and Tertiary Marine and Fresh Water Deposits (Alluvial fans, lakebeds)	Limited to Medium
6f	Datil	1. Mesaverde, Mancos and Lewis Shale Fm 2. Cretaceous Fm (Cody, Mowry, Frontier, Benton and Niobrara)	Limited to Medium
10a	Missouri Plat (Glac.)[2]	1. Pierre and Bearpaw Shale Fm 2. Cretaceous Fm (Cody and Benton)	Limited to Medium
10b	Missouri Plat (Unglac.)	1. Pierre and Bearpaw Shale Fm 2. Cretaceous Fm (Cody and Benton) 3. Ft. Union Shale 4. Mesaverde, Mancos, Lewis and Cody Shale Fm	Very Widespread
10c	Bighorn Basin	1. Cretaceous Fm (Cody and Benton) 2. Mesaverde, Mancos, Lewis and Cody Shale Fm	Limited to Medium
10d	Wyoming Basin	1. Ft. Union Shale 2. Mesaverde, Mancos, Lewis and Cody Shale Fm 3. Cretaceous Fm (Cody and Benton)	Limited to Medium

Table 19 (cont'd.)

	Physiographic Unit Description	High Volume Change Formations	Estimated Occurrence Within Section (All Formations Considered)
10g	Colorado Piedmont	1. Mesaverde, Mancos and Lewis Shale Fm 2. Upper Cretaceous Fm (Eagleford, Pierre, Bearpaw) 3. Laramie and Denver Fm 4. Cretaceous Fm (Cody, Mowry, Frontier, Benton, and Niobrara)	Very Widespread
10h	Raton Upland	1. Cretaceous Fm (Cody, Mowry, Frontier, Benton, and Niobrara)	Medium to Widespread
10j	Plains Border	1. Cretaceous Fm (Cody, Mowry, Frontier, Benton, and Niobrara)	Limited to Medium
10k	Central Texas Mineral	1. Permian Red Beds	Limited to Medium
10m	Osage Plains	1. Permian Red Beds	Medium to Widespread
11i	Dissected Loessial and Till Plains[3]	1. Permian Red Beds 2. Cretaceous Fm (Cody, Mowry, Frontier, Benton and Niobrara)	Non Existent to Limited
20b	Sea Island	1. Lower Cretaceous Fm (Porters Creek and Nahoela) 2. Jackson, Chickasawhay, Barnwell and Ocalla Fm	Limited to Medium
20c	Florida	1. Tampa and Hawthorn Fm 2. Jackson, Chickasawhay, Barnwell and Ocalla Fm	Limited to Medium
20d	East Gulf Coast	1. Tampa and Hawthorn Fm 2. Jackson, Chickasawhay, Barnwell and Ocalla Fm 3. Selma and Euthaw Fm 4. Lower Cretaceous Fm (Porters Creek and Nahoela)	Very Widespread
20e	Mississippi Loessial Upland[4]	1. Tampa and Hawthorn Fm 2. Jackson, Chickasawhay, Barnwell and Ocalla Fm)	Very Widespread
20f	Mississippi Alluvial Plain	1. Mississippi Alluvium	Very Widespread
20g	West Gulf Coast	1. Taylor and Austin Fm 2. Eagleford and Woodbine Fm 3. Jackson Fm 4. Houston Fm	Very Widespread

[1] Information summarized from Jensen (333)

[2] Formations overlain by glacial drift within Section

[3] Formations overlain by glacial drift and loessial deposits within Section

[4] Formations overlain by loessial deposits within Section

Table 20

Origin-Parent Material Summary of High Volume Change Pedologic Soil Series

Origin	Soil Series	Parent Material	Typical Soil Properties			
					Approx. % Passing	
			LL	PI	.005mm	.002mm
Residual	Altamont	Metamorphosed Ss/Sh	45	21	65	
	Crawford	Ls and Calcareous Sh	70	40		50
	Crete	Sh and Ls	60	35	50	
	Houston	Ls, Marls, and Chalk	75	45		50
	Iredell	Dark basic Igneous Rocks	50	35	55	
	Kirkland	Calcareous Sh	55	30	50	
	Parsons	Sh	60	30		50
	Pierre	Sh	75	45	90	
	Valera	Ls and interbedded Chalky Marl	60	35	45	
	Vernon	Sh and Clays	55	30	90	
Glacial	Phillips	Calcareous glacial drift	60	35	50	
Water						
(Coastal Plain)	Crowley	Coastal Plain Sediments, Marls and Ls	50	35	55	
	Kathy	Coastal Plain Sediments of clay, sandy clay	65	40	50	
	Lake Charles	Coastal Plain Clays and Marls	75	40		50
	Oktibbeha	Heavy Clays	65	35	60	
	Susquehanna	Sandy Clays and Clays	80	60	70	
	Victoria	Calcareous Clays	70	40		50
(Alluvial fans)	San Joaquin	Alluvial fans (wide range of rock)	65	30	50	
	Placentia	Alluvial fans (granitic type rocks)	70	40	80	
(River Alluvium)	Miller	Fine grained alluvium	75	45	90	
	Sharkey	Fine grained alluvium	85	60		70
	Waverly	Fine grained alluvium	70	35		50
(Lakelaid)	Fargo	Fine textured sediments	60	30		50
	Lahontan	Fine textured sediments	70	40		60

Note: Information obtained from Jensen (333)

FROM H.P. JENSEN

FIGURE 24
DISTRIBUTION OF GENERALIZED HIGH VOLUME CHANGE
SOIL AREAS WITHIN THE U.S. (PEDOLOGIC ANALYSIS)

Table 21

Summary of Pedologic Soil Series Showing High Volume Change
by Frequency of Occurrence Within Sections

	Physiographic Unit Description	High Volume Change Soil Series	Estimated Occurrence Within Section (All Soil Series Considered)
1d	California Coast Range	1. Placentia 2. Altamont	Limited to Medium
1e	Los Angeles Range	1. Placentia 2. Altamont	Non Existent to Limited
2d	Lower California	1. Placentia 2. San Joaquin	Non Existent to Limited
3c	California Valley	1. Placentia 2. San Joaquin 3. Altamont	Limited to Medium
5a	Great Basin	1. Lahontan	Limited to Medium
5b	Sonoran Desert	1. Lahontan	Non Existent to Limited
5d	Open Basin	1. Lahontan	Non Existent to Limited
6d	Navajo	1. Altamont	Non Existent to Limited
6e	Grand Canyon	1. Valera	Medium to Widespread
9b	Western	1. Lahontan	Non Existent to Limited
10a	Missouri Plat (Glac)	1. Phillips	Non Existent to Limited
10b	Missouri Plat (Unglac)	1. Pierre	Limited to Medium
10d	Wyoming Basin	1. Phillips	Non Existent to Limited
10f	High Plains	1. Crete	Non Existent to Limited
10j	Plains Border	1. Crete 2. Miller 3. Vernon 4. Kirkland	Limited to Medium
10k	Central Texas Mineral	1. Valera 2. Crawford	Limited to Medium
10l	Edwards Plateau	1. Valera	Limited to Medium
10m	Osage Plains	1. Vernon 2. Miller 3. Kirkland 4. Crawford 5. Parsons	Very Widespread
11h	Western Lakes and Lacustrine Plains	1. Fargo	Non Existent to Limited
13c2	Arkansas Valley	1. Miller	Non Existent to Limited
17b	Piedmont	1. Iredell	Non Existent to Limited
20d	East Gulf Coast	1. Susquehanna 2. Houston 3. Oktibbeha 4. Crowley	Limited to Medium
20e	Mississippi Loessial Upland	1. Waverly	Non Existent to Limited
20f	Mississippi Alluvial Plain	1. Sharkey 2. Waverly 3. Crowley 4. Miller	Very Widespread
20g	West Gulf Coast	1. Susquehanna 2. Waverly 3. Miller 4. Houston 5. Crowley 6. Lake Charles 7. Kathy 8. Victoria 9. Valera	Medium to Widespread

Note: Information summarized from Jensen (333) mantle. As the basic characteristics of the Section are based upon loessial parent material, and these are not conductive to high volume change, a final rating of Non-Existent to Limited was selected.

Table 22 represents the adjusted frequency of occurrence rating for each Section containing potential high volume change areas.

Frost Action and Frost Susceptible Soils

Physiographic Sections Within the Freezing Zone

The selection of Sections experiencing significant frost was based upon an analysis by Sourwine (90). Figure 25 shows the relationship between Sections considered to be within the freezing zone and the limit proposed by Sourwine. Table 23 summarizes the separation of Sections into groupings where, I. ground freezing is assumed to be a potential hazard, and II. the factor of ground freezing is probably insignificant.

Composite Frost Susceptible Soils Map of the Northern States

Figures 26 through 28 illustrate the composite frost susceptible soils map for the northern United States, using the Corps of Engineer's susceptibility classification. As previously noted, this map is slightly modified from the work of Bloom (90) and Osborne (166).

Distribution of Frost Susceptible Soils by Section

General. For each Section considered to be within the freezing zone, a qualitative assessment of the frequency was made of the frost susceptible soils. The ratings are based

Table 22

Final Adjusted High Volume Change Frequency of Occurrence Ratings by Basic Report Section

Unit (Section) Code	Pedologic Rating	Geologic Rating	Final Rating
1d	L-M	M-W	M-W
1e	N-L	L-M	L-M
2d	N-L	N-L	N-L
3c	L-M	L-M	L-M
5a	L-M	L-M	L-M
5b	N-L	N-L	N-L
5d	N-L	NE	N-L
6a	NE	L-M	L-M
6b	NE	L-M	L-M
6c	NE	L-M	L-M
6d	N-L	M-W	M-W
6e	M-W	L-M	M-W
6f	NE	L-M	L-M
9b	N-L	NE	N-L
10a*	N-L	L-M	N-L
10b	L-M	VW	VW
10c	NE	L-M	L-M
10d	N-L	L-M	L-M
10f	N-L	NE	N-L
10g	NE	VW	VW
10h	NE	M-W	M-W
10j	L-M	L-M	L-M
10k	L-M	L-M	L-M
10l	L-M	NE	L-M
10m	VW	M-W	VW
11h	N-L	NE	N-L
11i*	NE	N-L	NE
13c2	N-L	NE	N-L
17b	N-L	NE	N-L
20b	NE	L-M	L-M
20c	NE	L-M	L-M
20d	L-M	VW	VW
20e*	N-L	VW	N-L
20f	VW	VW	VW
20g	M-W	VW	VW

Note: (*) indicates adjusted rating

Legend:
NE: Non Existent
N-L: Non Existent to Limited
L-M: Limited to Medium
M-W: Medium to Widespread
VW: Very Widespread

FIGURE 25
PHYSIOGRAPHIC SECTIONS CONSIDERED WITHIN THE FREEZING ZONE AND THEIR RELATIONSHIP TO SOURWINE'S FREEZING BORDER

Table 23

Status of Physiographic Sections and Their General Relationship to Ground Freezing

I. Physiographic Sections Analyzed for Distribution and Occurrence of Frost Susceptible Soil Type (Considered, in the main, to be within zone of ground freeze danger).

a. Section Codes Having Entire Area Within Dangerous Freezing Zone

4c
4d
4e
6a
6b
6c
6d
6f
7a
7b
7c
8a
8b
8c
8d
8e
9a
9b
9c
10a
10b
10c
10d
10e
10g
10h
10j
11a
11b
11c
11d
11e
11f
11g
11h
11i
12a
12b
13a
15a
15b
15c
19a
19b
19c
19d
19e
19f
19g

b. Section Codes Having Portion of Area Outside Dangerous Freezing Zone

2a
2b
2c
4a
4b
5a
6e
10f
13b
15d
16a
18

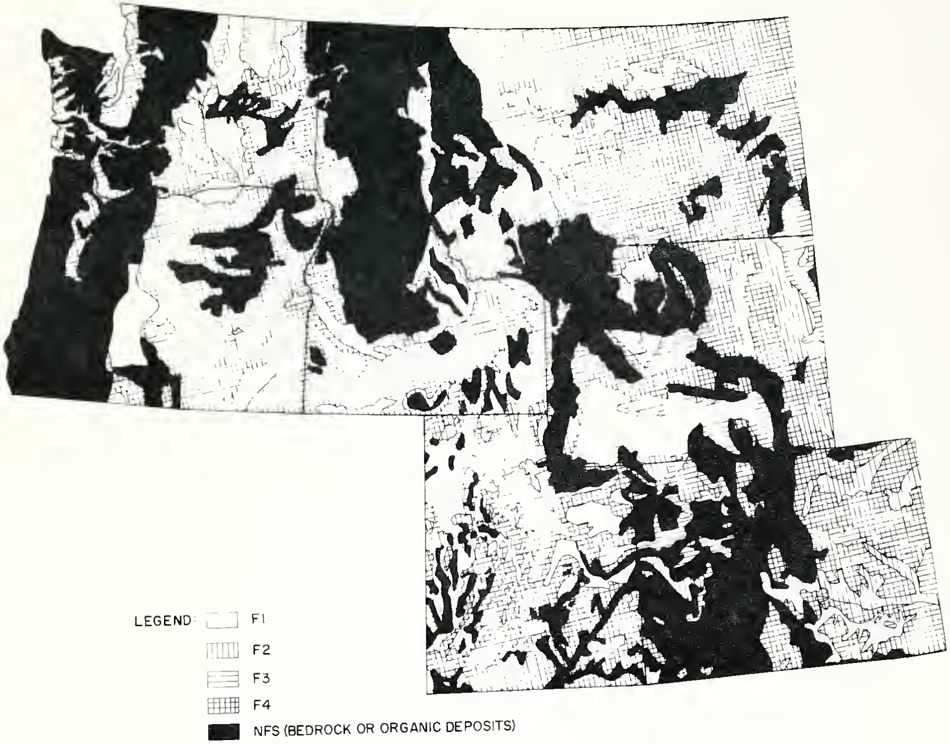
II. Physiographic Sections Not Analyzed for Distribution and Occurrence of Frost Susceptible Soil Type (Considered, in the main, to be outside zone of ground freeze danger).

a. Section Codes Having Entire Area Outside Dangerous Freezing Zone

1a
1b
1d
1e
2d
3a
3b
3c
5b
5c
5f
10k
10l
13c1
13c2
13c3
14b
15e
16b
20b
20c
20d
20e
20f
20g

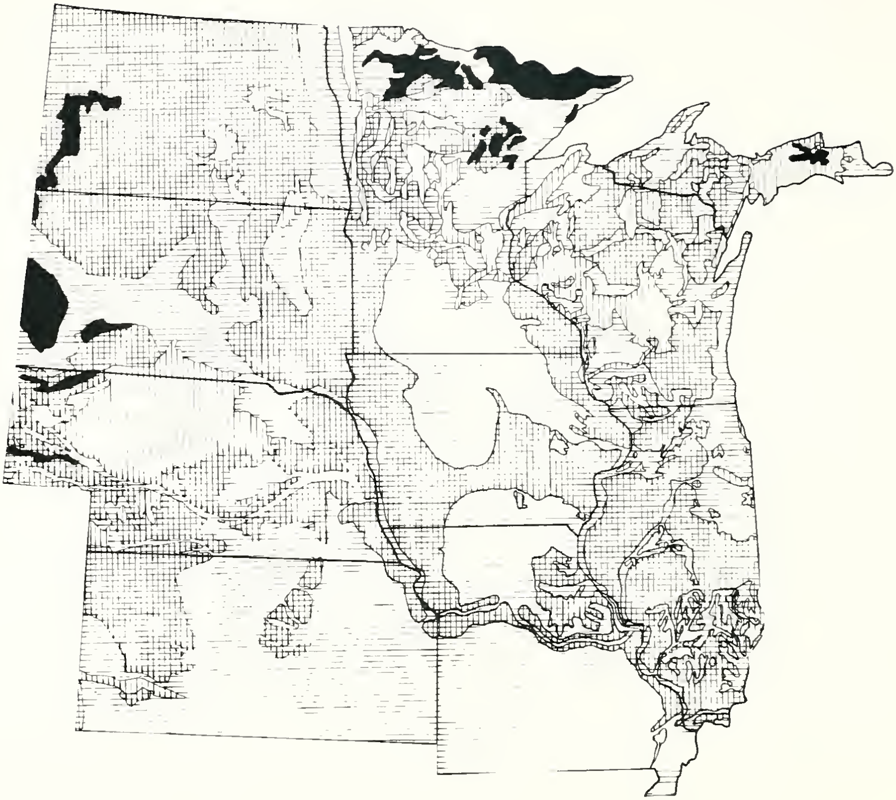
b. Section Codes Having Portion of Area Within Dangerous Freezing Zone

1c
5d
5e
10i
10m
14a
14c
14d
17a
17b
20a



COMPILED AND SLIGHTLY MODIFIED FROM OSBORNE AND BLOOM

FIGURE 26
GENERALIZED FROST SUSCEPTIBLE SOILS MAP OF THE NORTHERN STATES (MAP SHEET I: NORTHWEST U. S.)



NOTE: SEE MAP SHEET I FOR LEGEND

FIGURE 27
GENERALIZED FROST SUSCEPTIBLE SOILS MAP OF THE NORTHERN STATES (MAP SHEET II: NORTH CENTRAL U.S.)

NOTE: SEE MAP SHEET I FOR LEGEND

FIGURE 28

GENERALIZED FROST SUSCEPTIBLE SOILS MAP OF THE NORTHERN STATES (MAP SHEET III: NORTHEAST U.S.)

upon an examination of the frost maps (Figures 26 through 28). For portions of Sections not mapped in (90) or (166), but occurring within the freezing zone, an evaluation of the generalized frost susceptible soil conditions was conducted by the author with the procedure previously described.[1]

Section Distribution. The frequency of occurrence rating of frost susceptible soils within each Section considered to be in the frost zone is shown in Table 24.

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[1] See "Investigation Procedures - Frost Action and Frost Susceptible Soils; Method of Analysis". (pg. 39)

Table 24

Frequency of Occurrence Ratings of Frost Susceptible Soils Within Physiographic Sections Considered in the Freezing Zone

Section Code	Frost Susceptible Soil Category[1]				
	NFS	F1	F2	F3	F4
2a	VW	NE	NE	NE	NE
2b	VW	NE	NE	N-L	NE
2c	VW	NE	NE	NE	L-M
4a	N-L	NE	L-M	N-L	M-W
4b	VW	NE	NE	N-L	L-M
4c	N-L	NE	NE	NE	VW
4d	N-L	NE	N-L	N-L	VW
4e	NE	L-M	NE	NE	M-W
5a	M-W	N-L	N-L	L-M	L-M
6a	N-L	NE	NE	L-M	L-M
6b	L-M	N-L	NE	L-M	L-M
6c	L-M	N-L	N-L	N-L	M-W
6d	N-L	NE	NE	N-L	M-W
6e	N-L	NE	NE	NE	M-W
6f	N-L	NE	NE	L-M	L-M
7a	M-W	NE	NE	NE	L-M
7b	M-W	NE	N-L	N-L	NE
7c	VW	NE	NE	NE	NE
8a	VW	NE	NE	NE	NE
8b	VW	NE	NE	NE	N-L
8c	VW	NE	NE	NE	N-L
8d	L-M	NE	NE	M-W	NE
8e	VW	NE	NE	NE	N-L
9a	VW	N-L	NE	NE	NE
9b	M-W	N-L	NE	NE	L-M
9c	VW	NE	NE	NE	NE
10a	NE	NE	N-L	N-L	VW
10b	N-L	NE	NE	L-M	M-W
10c	L-M	L-M	NE	NE	L-M
10d	N-L	NE	NE	M-W	L-M
10e	M-W	NE	NE	L-M	NE
10f	NE	NE	L-M	NE	M-W
10g	N-L	NE	L-M	NE	M-W
10h	N-L	N-L	NE	NE	M-W
10j	NE	NE	NE	VW	N-L
11a	N-L	N-L	NE	L-M	L-M
11b	N-L	NE	NE	M-W	NE
11c	NE	N-L	NE	L-M	L-M
11d	NE	N-L	NE	NE	M-W
11e	N-L	NE	L-M	L-M	L-M
11f	NE	NE	NE	L-M	L-M
11g	NE	NE	L-M	L-M	L-M
11h	N-L	NE	N-L	L-M	L-M
11i	NE	NE	NE	M-W	M-W
12a	N-L	NE	N-L	L-M	L-M
12b	NE	NE	NE	VW	NE
13a	NE	NE	NE	VW	NE
13b	NE	NE	NE	VW	NE
15a	NE	NE	NE	NE	VW
15b	N-L	N-L	NE	M-W	M-W
15c	L-M	NE	NE	NE	M-W
15d	N-L	NE	NE	M-W	M-W
16a	L-M	NE	NE	L-M	L-M
18	N-L	N-L	NE	N-L	M-W
19a	NE	N-L	N-L	L-M	N-L
19b	N-L	NE	N-L	M-W	L-M
19c	N-L	L-M	NE	NE	L-M
19d	M-W	N-L	N-L	L-M	N-L
19e	M-W	NE	NE	NE	N-L
19f	L-M	NE	NE	NE	L-M
19g	M-W	NE	NE	L-M	NE

Legend: Frequency of Occurrence

NE: Non Existent
N-L: Non Existent to Limited
L-M: Limited to Medium
M-W: Medium to Widespread
VW: Very Widespread

Note: [1] U. S. Corps of Engineers Frost Classification

SUMMARY AND CONCLUSIONS

Generalized Summary Comparison Between Eastern and Western United States

General

Many difficulties are encountered in any attempt to summarize in brief and adequate form the physiographic, geologic and pertinent highway engineering factors peculiar to regional geomorphic units within the continental United States. However, in the author's opinion, ease of discussion occurs if the United States is divided into two major geographic groupings: an eastern and western portion.

The western portion essentially corresponds to the U. S. portion of the North American Cordillera Division suggested by Lobeck. This unit is comprised of physiographic provinces, identified in Table 4, with unit codes 1 through 9. The provinces of the eastern group (unit Provinces codes 10 thru 20) lie east of and including the Great Plains Province. Figure 29 shows this basic grouping as well as generalized locations of the various divisions and provinces of each major group. The identification legend shown on this diagram is keyed to Table 25 which describes the physiographic units in question. Within these two groups, major differences can be characterized in terms of topography,

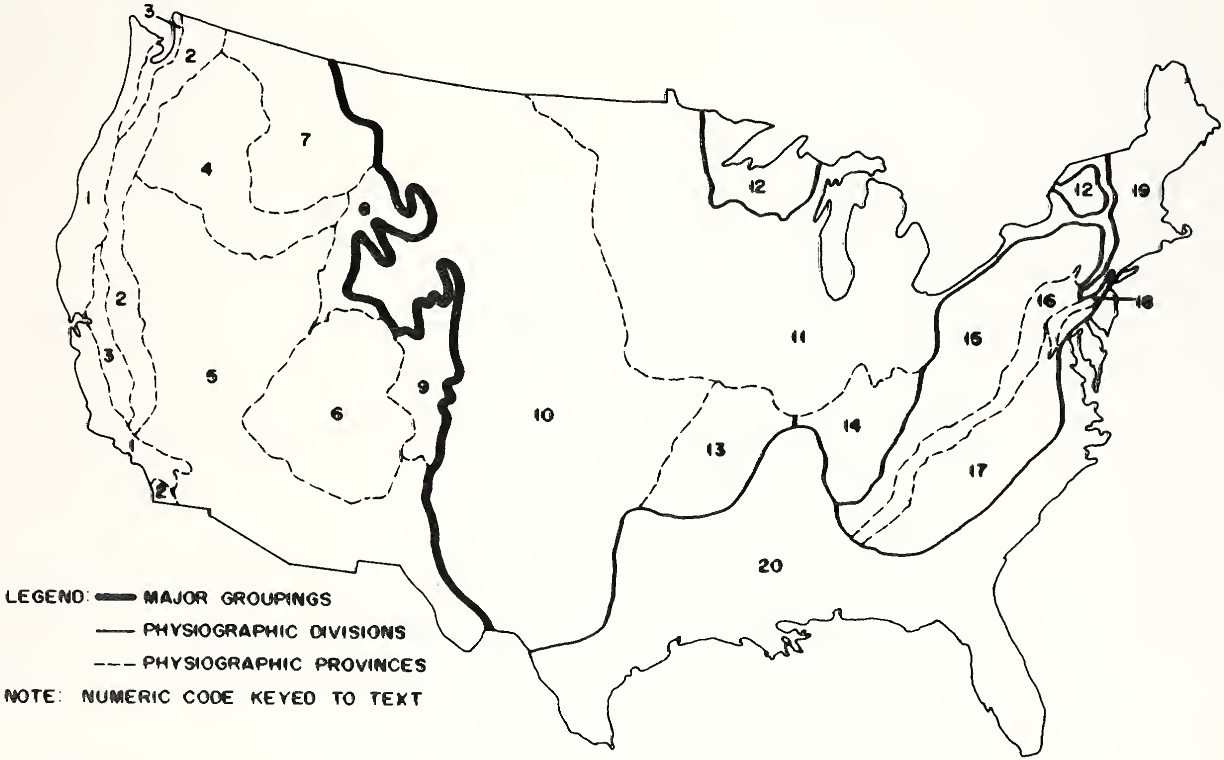

FIGURE 29 LOCATION OF MAJOR PHYSIOGRAPHIC UNIT CATEGORIES WITHIN THE U.S.

Table 25

Classification of Major Physiographic Unit Categories Within the United States

Major U.S. Group	Physiographic Division	Physiographic System	Physiographic Province	Unit Code
West	North America Cordillera	Pacific Mountain	Pacific Coast Ranges	1
			Sierra - Cascade	2
			Pacific Troughs	3
		Intermontane Plateau	Columbia Plateau	4
			Basin and Range	5
			Colorado Plateau	6
		Rocky Mountain	Northern Rocky Mountains	7
			Middle Rocky Mountains	8
			Southern Rocky Mountains	9
East	Interior Plains		Great Plains	10
			Central and Eastern Lowland	11
			Ozark and Ouachita	13
			Interior Low Plateaus	14
	Atlantic Plain		Atlantic and Gulf Coastal Plain	20
	Appalachian Highland		Appalachian Plateau	15
			Triassic Lowland	18
			Ridge and Valley	16
			Old Appalachian	17
			New England Maritime	19
	Canadian Shield		Laurentian Upland	12

population, climate and historical geology.

Topographic Differences

The entire western unit may generally be considered as a highland unit. Elevations in this area are the highest within the continental United States, directly attributable to the two parallel trending mountainous systems found in the area. The orogenies which have occurred have naturally formed areas of high relief. Large changes of elevation are not only common within the mountainous areas but also occur within much of the Intermontane Plateau system. Large changes occur between the basins and ranges proper, characteristic of the Basin and Range Province. Within the Plateau Provinces relief is due primarily to destructional processes leaving some of the most majestic canyon areas found in the world.

In direct contrast to high relief and elevations found in the west, most of the east is of low elevation and relief. The topographic differences are directly related to the presence of the Interior and Atlantic Plains Divisions which are characterized primarily by relatively mild dipping sedimentary strata. In addition, many of the once "mountainous portions" of the area have been leveled by widespread erosion to form plateaus and uplands of mild relief.

Some areas of high relief are found in the east, particularly in the Appalachian Highlands Division. However, much of the "mountainous terrain" has been formed by erosion of flat lying sedimentary strata (Appalachian Plateau Province) or folded sedimentary strata (Ridge and

Valley). The "true" mountainous areas in the east are confined to the Blue Ridge (Old Appalachian Province), portions of the Adirondacks (Laurentian Upland Province) and along the western and northern portions of the New England Maritime Province.

Geologic Differences

One of the more significant geological differences between the eastern and western areas is the rather liberal presence of vulcanism present in the west.[1] Extrusive rocks of Tertiary and Quaternary age are widespread in the west while practically non existent from a regional viewpoint in the east. Granitic type rocks, often associated with the mountain building common to the west, are widely present. Geologically, these rocks are generally confined to Jurassic and/or PreCambrian Periods of time. Within the east, these rocks are generally found in larger areas and occur within the "Crystalline Appalachians" (Old Appalachian and New England Maritime Provinces) as well as the Laurentian Upland Province.

In general, sedimentary strata are more predominant in the eastern U. S. than in the west. Figure 30 illustrates the distribution of Paleozoic strata within the U. S. As can be seen from the diagram, Paleozoic strata form a large portion of the eastern physiography. This broad expanse of

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[1] This fact may be noted by looking at Figures 3 and 4 which show potential crushed stone areas within the United States.

FROM TOLMAN (185)

FIGURE 30 DISTRIBUTION OF PALEOZOIC FORMATIONS OCCURRING AT OR NEAR THE SURFACE WITHIN THE U.S.

strata in the east is directly due to the flat lying to relatively mild dipping strata found in the region. In contrast, Paleozoic strata of the west are scattered in distribution and often occur in highly tilted structure around massive uplifts which are characterized by narrow bands.

Tertiary and Mesozoic sedimentary strata are found distributed throughout both areas. Within the western portion, major areas of occurrence are the California and Oregon Coast Ranges of the Pacific Coast Ranges and much of the flat lying sediments of the Colorado Plateau Province. Within the eastern portion, the greatest concentrations are found in much of the Great Plains Province, the western portion of the Central Lowland Province, Atlantic and Gulf Coastal Plains Province and the Triassic Lowland Province. With the exception of the folded and faulted areas within the Pacific Coast Ranges and scattered areas surrounding the uplifts in the west, most of these strata are relatively undisturbed and horizontal to mildly dipping.

Although continental glaciation has occurred contincusly across the northern tier of the United States, the western portion has relatively little area affected by glaciation in contrast to the east. Figure 31 illustrates the general distribution of continental glaciation in the U. S.. In the western portion, much of the glacial drift veneers rugged mountainous terrain and as a result affords only slight modification to the regional topography. In the eastern U. S., the effect and distribution of glaciation is

FROM TOLMAN (185)

FIGURE 31 DISTRIBUTION OF PLEISTOCENE ICE SHEET IN THE U.S.

such that it becomes the modal characteristic for several Sections of the Central and Eastern Lowland Province.

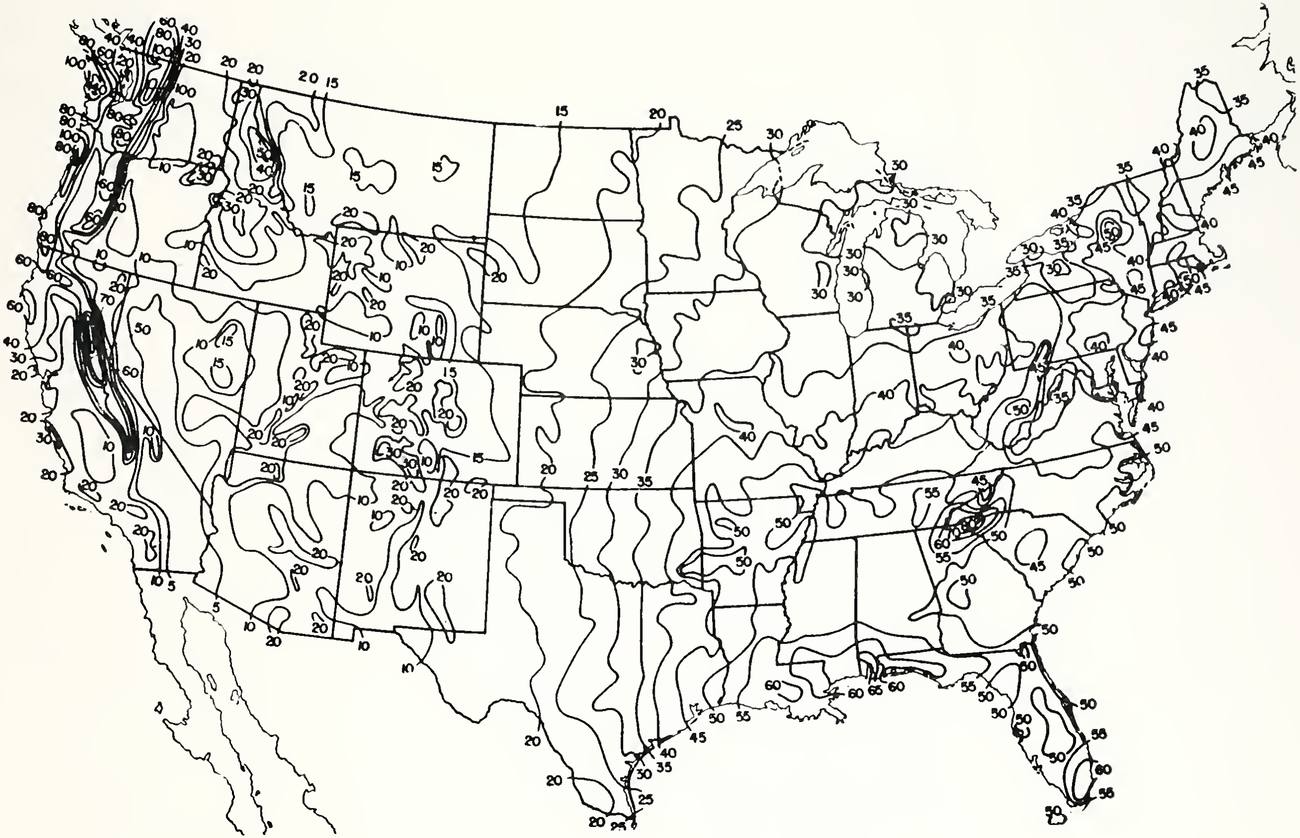
The final geologic difference between eastern and western groupings lies in the rather widespread distribution of valley fill sediments found in the west. In particular, the Basin and Range as well as the Pacific Troughs are characterized by this material. Smaller, scattered areas occur frequently within the mountainous units of the west. The presence of valley fill materials (exclusive of Great Plains Outwash) is generally not existent within the eastern Province groupings.

Climatic Differences

One of the most pronounced differences between the east and west groupings is associated with climatic patterns within these two areas. It should be pointed out that topography exerts a powerful effect upon the overall climatic conditions within a given area. Because of the rather high elevations and relief existent within the western portion relative to the east, much of the west is characterized by large changes in climate within relatively short distances. The climatic pattern associated with the lower relief and elevation of the east is displayed by very gradual, uniform changes over large distances.

Annual Precipitation

Figure 32 shows the distribution pattern of annual precipitation within the U. S.. As can be noted for the western group, much of the area is characterized by 20 inches



FROM (67)

FIG. 32 ANNUAL PRECIPITATION MAP OF THE U.S.

or less of precipitation. This fact is very pronounced for much of the Intermontane Plateau System separating the mountain systems. Exceptions to this occur primarily west of the Sierra-Cascade Province and along the Pacific sides of the higher mountainous locations in the area. It is within the latter area where large variations in precipitation may occur in relatively short distances.

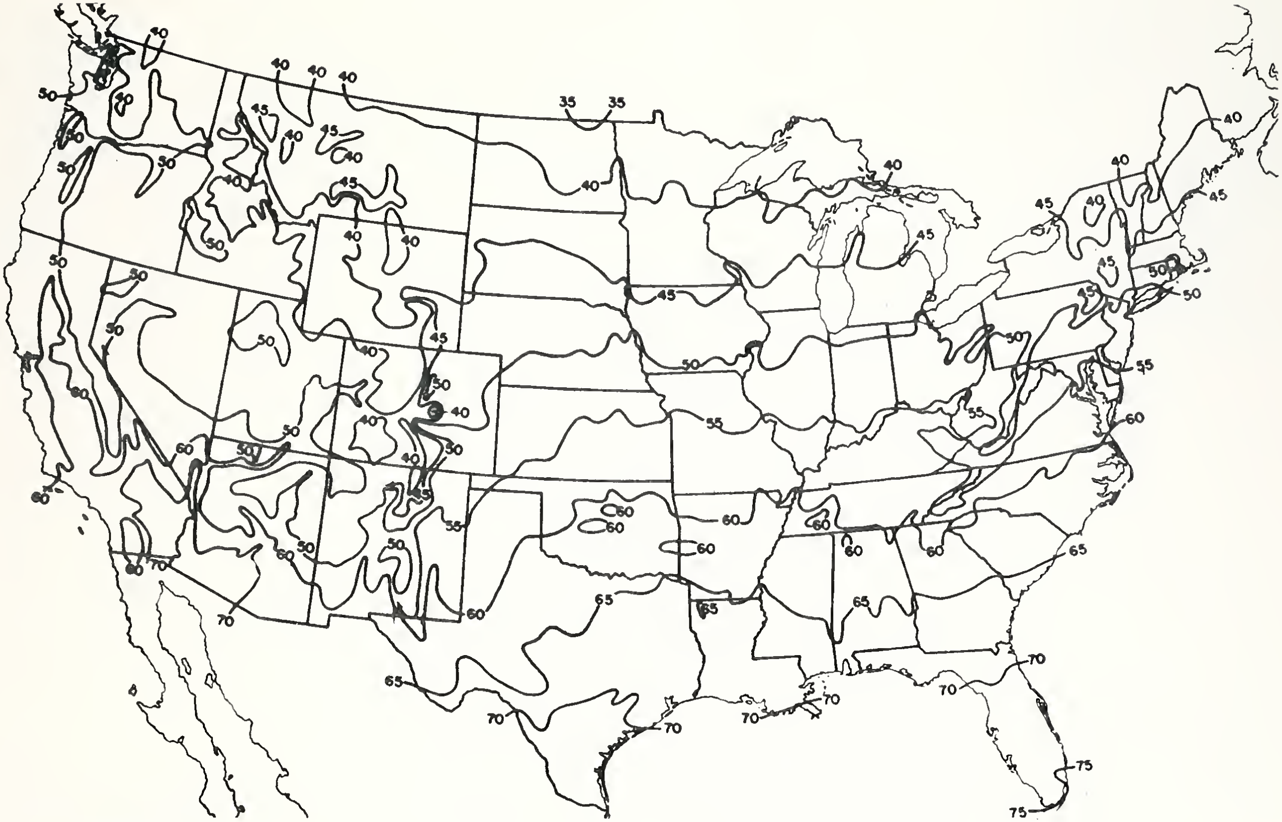
In contrast, most of the eastern grouping has precipitation in excess of 20 inches except along the western edge of the Great Plains Province. In general terms, precipitation tends to gradually increase, from any point in the eastern area, toward the Mississippi and Alabama Gulf coast area. A notable exception to this climatic pattern occurs in the mountainous Blue Ridge area near north-eastern Georgia. Here the topographic effects upon rainfall increase are quite noticeable.

Annual Temperature

If the earth were a flat featureless plain the temperature would vary gradationally from the equator, decreasing as one would proceed to the poles. For most of the eastern portion of the U. S., this fact is quite markedly displayed in Figure 33 which shows distribution of annual temperature. The pattern of temperature for the west, although generally increasing to the south shows a much more disruptive pattern.

Freezing Index

Since temperature is strongly related to the



FROM (67)

FIG. 33 ANNUAL TEMPERATURE MAP OF THE U.S.

Freezing Index, climatic patterns of this variable are quite similar to temperature patterns. Figure 34 illustrates the distribution of freezing index in the United States. Again, the orographic effects of this variable within the mountainous systems of the west illustrate the rather large change in freezing index which may be expected in short distances.

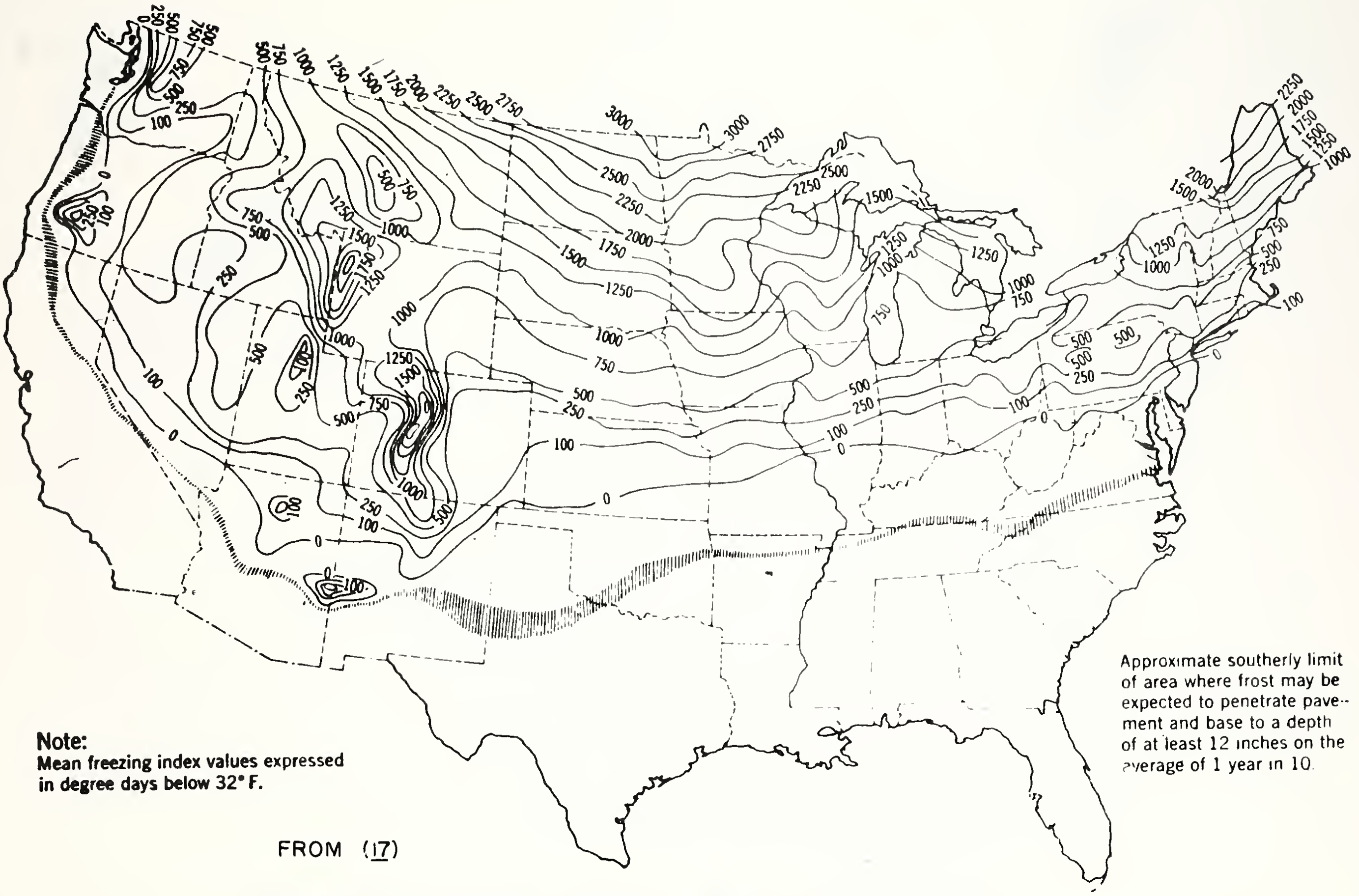
Potential Evaportanspiration

A climatic variable of importance to the high volume change soil problem in the United States is that of potential evapotranspiration. The distribution of this parameter is shown in Figure 35. As can be quite remarkably seen in this diagram, the diagnostic gradual change in the eastern grouping is contrasted to the very sharp changes occurring in rather short distances in the west.

Population Differences

From the standpoint of highway engineering and pertinent to this study, a final, but important difference occurring between the eastern and western Province groupings is that associated with population densities. Figure 36 shows the distribution of the 1960 census for the United States. In the west, the population density is, in general, smaller relative to the east. Major exceptions to this pattern are found, however, in both groupings.

Within the west, extremely high density concentrations are found existent within much of the Pacific Troughs Province, as well as in and around the San Francisco and Los Angeles areas of California. Low density areas within



Note:
Mean freezing index values expressed in degree days below 32° F.

Approximate southerly limit of area where frost may be expected to penetrate pavement and base to a depth of at least 12 inches on the average of 1 year in 10.

FROM (17)

FIG.34 FREEZING INDEX MAP OF THE U.S.

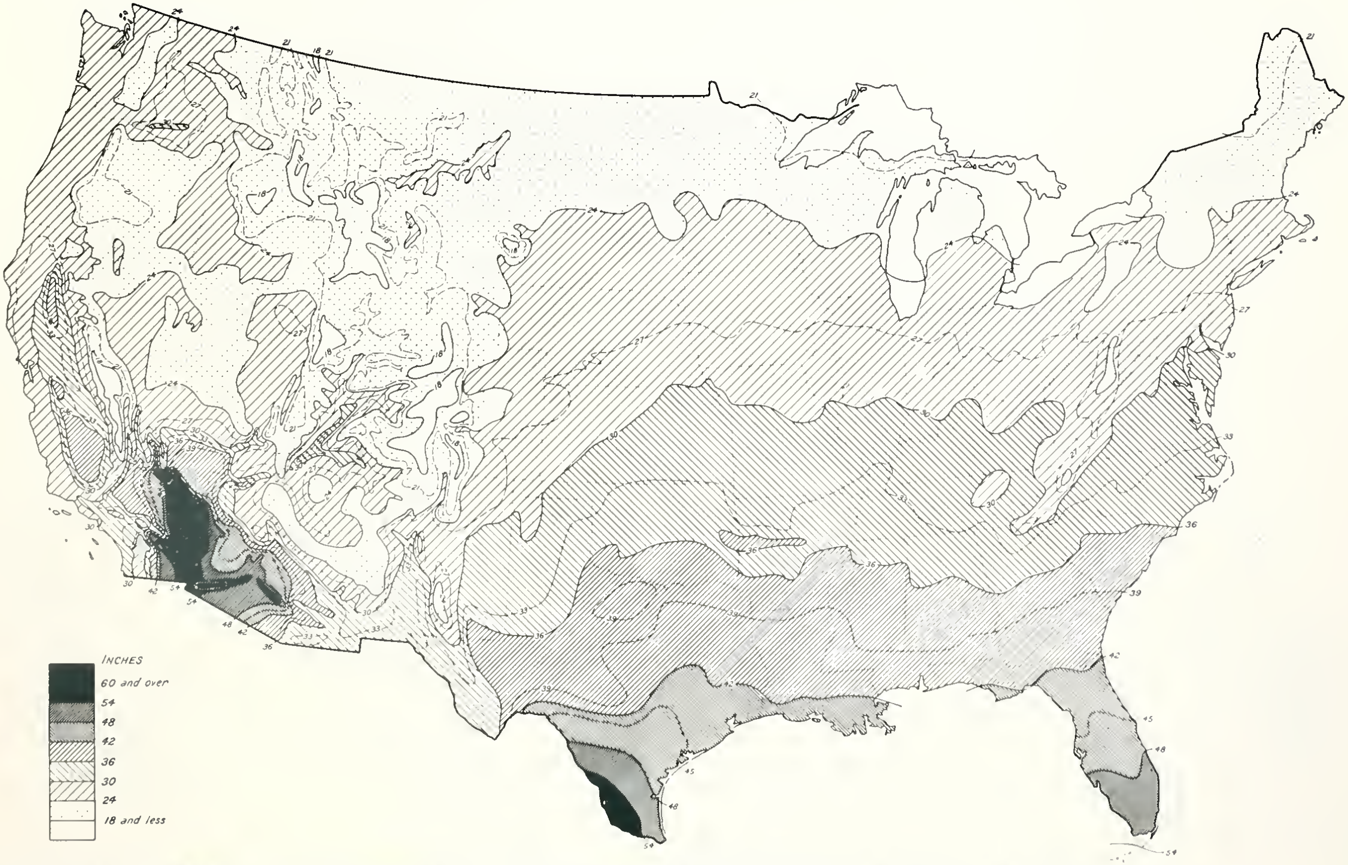
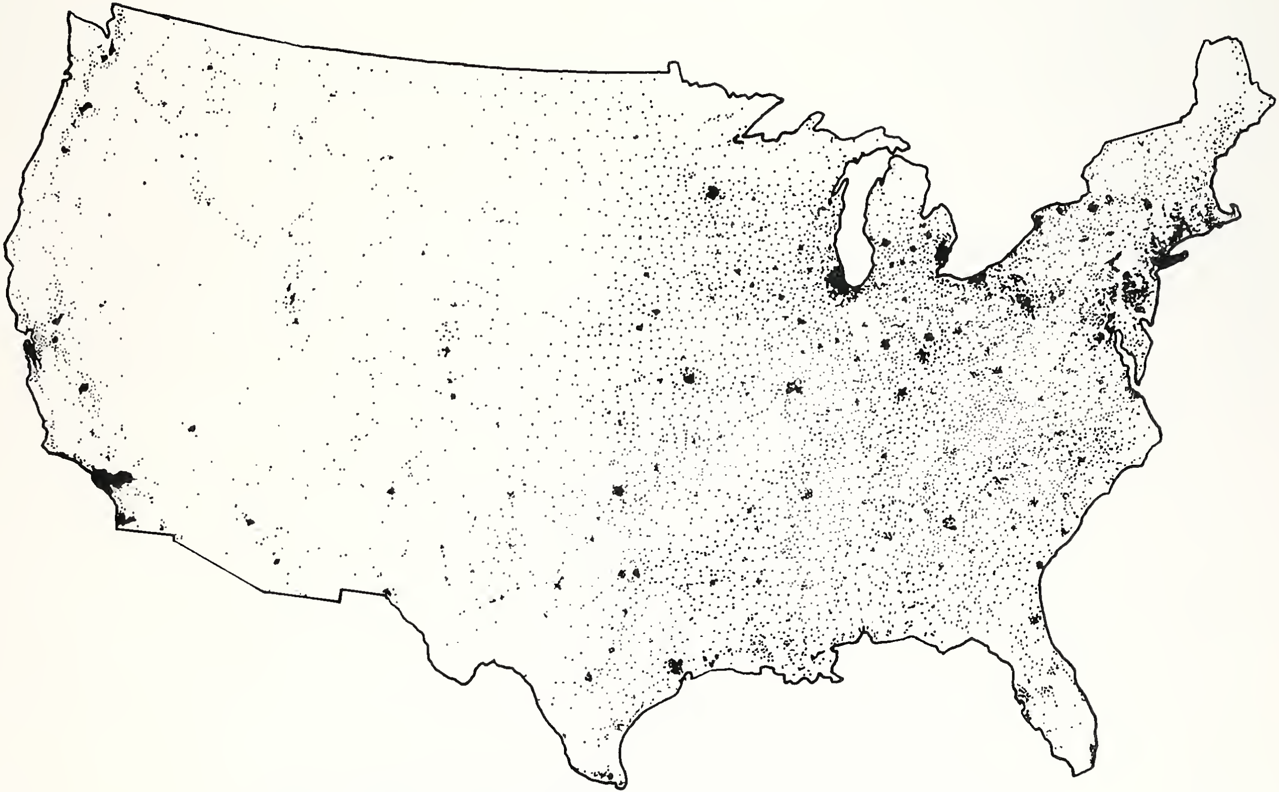


FIG. 35 ANNUAL POTENTIAL EVAPOTRANSPIRATION MAP OF THE U.S.



FROM (45) (BASED ON 1960 CENSUS)

FIG. 36 POPULATION MAP OF THE UNITED STATES the east lie within much of the western portions of the Great Plains Province as well as in isolated northern areas of Minnesota, New York and Maine.

The population density is in many cases strongly related to physiographic classifications. The overall importance of this parameter intuitively implies a higher level of highway engineering activity. This factor may be interpreted generally as a greater demand for mineral aggregates, greater occurrence of highway soil problems, etc.

Summary of Major Difference

In summary, the major significance between the eastern and western groupings can be characterized by pattern differences. The west is characterized generally by abrupt changes in topography, geology and climate within relatively short distances. In direct contrast, these parameters in the east are frequently marked by gradational changes over larger distances or areas. In addition, the gross difference in highway engineering activity related to differences in population concentrations and distributions becomes a very important parameter in the overall effort of utilizing physiographic units to effect generalizations of highway factors of design within the entire United States.

Summary of Individual Subject Areas Considered

Physiography and Regional Physiographic Units

Based upon an examination of the regional physiography (geomorphology) of the United States, the following pertinent facts are presented.

1. Physiography is the science dealing with the description of landforms. Geomorphology is the science dealing with the interpretation or development (genesis) of landforms. However, when both sciences study the regional distribution of landforms, the activities of both resemble each other. This is to say that there are little or no significant differences between a regional geomorphic or physiographic unit.

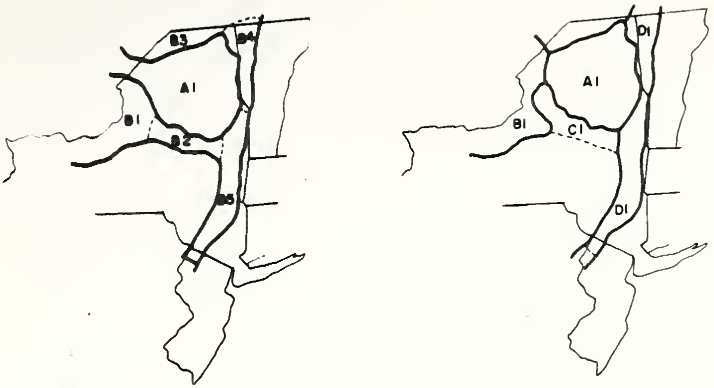
2. Landforms are described in non-genetic and qualitative terms of altitude, relief and type of landform present. However, the development of landforms is due to the combined interaction of geomorphic processes acting over a period of time and under a particular historical climatic environment on a distinct type or set of parent material types existent with its own unique geologic structure.

3. A regional physiographic unit, at any level of examination, attempts to delineate an area possessing a unique or repetitive series of landforms (areas of similar topographic expressions). Variant areas (areas possessing geomorphic control factors which differ from the modal characteristics delineating the regional physiographic unit) may be an inherent part of any level of regional categorization. Generally, the larger the topographic unit examined, the greater the possibility of including more variant types within the defined topographic unit. This is to say, that as larger and larger areas are examined, the

degree of topographic generalization increases.

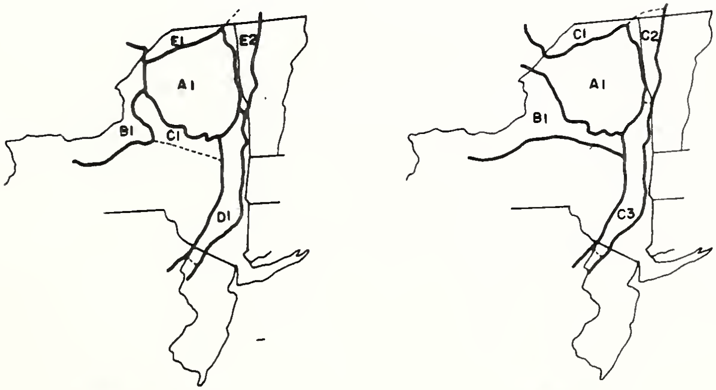
4. Because of the subjectiveness involved in defining physiographic units, no strict or definite criteria is known to place consistantly defined regional units to a particular (common) level of regional physiographic categorization (e.g..Province, Section etc...). As a consequence, it is possible for different physiographers to designate a given unit as a unique province or even as a section of differing provinces. This point is further illustrated by Figure 37. Within this diagram four differing categorization systems are noted for the physiographic units confined to the lowlands and valleys found primarily within the state of New York. It can be noted that the Mohawk Valley unit is considered, by both this report and the Woods-Lovell system, to be a Section of the Central and Eastern Lowland Province; by Fenneman, the combined U.S.G.S.-Fenneman System, and also Thornbury (not shown in the Figure) to be a Section of the Appalachian Plateau Province; while Lobeck does not recognize this as a distinct unit category, but rather as a variant portion of the Eastern Lakes and Lacustrine Section of the Central and Eastern Lowland Province.

5. Physiographic unit borders are quite variable in the degree to which they are definite in delineating adjacent units. In several cases, a given border segment, may in itself, vary gradationally in its degree of noting contrasting units, e.g., units separated by escarpments frequently



I. NCHRP; WOODS-LOVELL (20)

II. FENNEMAN (6)



III. FENNEMAN-USGS (17)

IV. LOBECK (12)

LEGEND

——— PROVINCE BOUNDARY

- - - - SECTION BOUNDARY

NCHRP UNIT CODE

A. LAURENTIAN UPLAND PROVINCE
  1. ADIRONDACK SECTION
B. CENTRAL & EASTERN LOWLAND PROVINCE
  1. EASTERN LAKE & LACUSTRINE SECTION
  2. MOHAWK SECTION
  3. ST. LAWRENCE SECTION
  4. CHAMPLAIN SECTION
  5. HUDSON VALLEY SECTION

NOTE: ALPHA-NUMERIC CODES FOR OTHER CLASSIFICATIONS NOTED (II TO IV) REFER TO PROVINCES (SHOWN BY LETTERS) AND SECTIONS (SHOWN BY NUMBERS) COMPRISING THE EASTERN LOWLAND AND VALLEY SECTIONS

FIGURE 37

COMPARISON OF EASTERN LOWLAND AND VALLEY SECTIONS BETWEEN PHYSIOGRAPHERS possess the characteristic of having the altitude difference between the units decrease gradually until topographic significance is lost . An example of such a border is the western border portion of the Central and Eastern Lowland Province which is adjacent to the Great Plains Province from Kansas north to the Canadian-U.S. border.[1]

6. Physiographic areas delineated at the Province or Section category, from a U.S. level of examination, may not necessarily serve as the "skeleton" framework for physiographic areas delineated at a level of greater detail, e.g., state level. Figure 38 illustrates this for the state of Kansas.

7. In general, regional physiographic units possess a unique type or repetitive types of parent material and geologic conditions. However, uniform topographic expressions are <u>not</u> always indicative of uniform parent material or geologic characteristics. This implies that not all regional physiographic units have a unique parent material type. The most general ways in which this occurs in regional physiographic units in the United States are as follows:

a. Highly faulted areas: The Basin and Range Province is a good example of this. Many of the mountain ranges are highly variable in geologic age and rock type. Likewise, from a mineralogic

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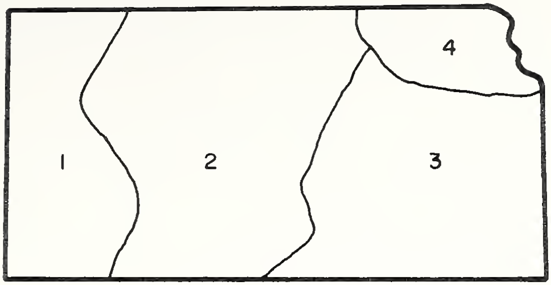
[1] This border segment corresponds to segment #18, Central and Eastern Lowland Province boundary description found in Appendix B.



1. HIGH PLAINS SECTION
2. PLAINS BORDER SECTION
3. OSAGE PLAINS SECTION
4. DISSECTED LOESS/TILL PLAINS SECTION

KANSAS PHYSIOGRAPHY AT U.S. LEVEL OF EXAMINATION

1. HIGH PLAINS
2. BLUE HILLS
3. SMOKEY HILLS
4. RED HILLS
5. ARKANSAS LOWLAND
6. DISSECTED TILL PLAINS
7. FLINT HILLS
8. OSAGE CUESTAS
9. CHEROKEE LOWLAND
10. CHATAGUA HILLS

KANSAS PHYSIOGRAPHY AT STATE LEVEL OF EXAMINATION

FIGURE 38 DIFFERENCE IN REGIONAL PHYSIOGRAPHIC UNIT DELINEATION AT TWO DIFFERENT LEVELS OF EXAMINATION composition the alluvium (valley fill) derived from these ranges is highly variable and complex. Another physiographic unit similar in its geologic and parent material complexity but unique in its topographic expression is that found in the Montana Section (particularly the southwestern portion) of the Northern Rocky Mountain Province.

b. Regional facies changes: Differences in lithology may occur due to facies changes in bedrock type but yet still maintain the overall uniformity of topographic expression of the physiographic unit. An example of this occurs within the Osage Plains Section of the Great Plains Province. This Section possesses a modal topographic expression of north-south trending cuestas. However in the northern portion of the Section, the topography is developed upon shale lowlands and limestone scarps. As one proceeds to the south, the limestone is replaced by sandstone as the ridge makers, maintaining its topographic similarity to the northern portion.

c. Transported soil areas: In areas where a gradational change in origin occurs from a non-transported soil area (bedrock or residual soil) to transported soils (primarily of aeolian and glacial origin), the physiographic units may

may be delineated upon the gross features of the consolidated (bedrock) areas. These units may have transported soils which mantle the bedrock with enough thickness to be significant in highway design and construction considerations but their effect upon the regional physiography is insignificant. An excellent example of this occurrence within a regional scale is the continuous loessial deposits in the midwest. Here the loess occurs in portions of the High Plains and Plains Border Sections of the Great Plains Province and continues into the Central and Eastern Lowland Province, occurring in the Dissected Loessial and Till Plains, Driftless and Central Till Plains Sections of the Province.

8. Distinctive and adjacent unique physiographic units may possess the same general parent material type or types. The major ways in which this can occur are as follows:

a. Differing levels of geomorphic stage: This rather obvious occurrence for differing regional physiographic unit delineation is generally manifested by similarilty of elevation but differing factors of relief. An example of this is found within the Navajo and Canyon Land Sections of the Colorado Plateau Province. In general, both Sections possess similar parent material types of flat lying, relatively soft sandstones and shales primarily of post Paleozoic age. However, because of the perennial source of water (streams) from the Southern Rocky Mountain Province to the east, flowing within the Canyon Lands Section, the subsequent dissection within this unit differs significantly from the Navajo Section to justify, from a physiographic viewpoint, separate regional units.

b. Partial regional peneplation (erosion): A good example of this occurs at the contact of the Seaboard Lowland - New England Upland Sections. The Seaboard Lowland is a topographically lower unit developed by the beveling action of marine erosion upon bedrock similar in type and geologic age to that found in the adjacent New England Upland Section. In some instances, "micro geologic-parent material units", may be continuous through the border segment separating the two units.

Another example where this occurs may be found in the relationship of the Blue Ridge and Piedmont Plateau Sections of the Old Appalachian Province. Here widespread erosion has again beveled parent material in the Piedmont Plateau unit generally similar to that which comprises the Blue Ridge Province. The topographic distinctions between the two units are notably contrasted by the mountainous area of the Blue Ridge and plateau topography of the Piedmont Sections.

Aggregates

Design Factor Rating Summary

Based upon the examination of the potential aggregate availability for the Physiographic Sections comprising the United States, it appears that lack of suitable aggregate sources is an urgent problem facing a substantial percentage of the highway industry. Table 26 summarizes the estimated potential availability ratings of aggregates by Sections, while Figure 39 shows the distribution of these ratings within the continental United States.

As can be noted within the Table, section areas comprising over 26% of the land mass have a poor potential for aggregate resources while Sections totaling almost 6% have a very restricted potential aggregate supply. In addition, it should also be mentioned that the "true" or "realistic" (in contrast to "potential") appraisal of aggregate resources may possibly have a greater percentage of areas where aggregate availability would be a problem. This is due to the fact that in many western areas of the United States, where good potential aggregate sources exist (particularly

Table 26

Summary of Estimated Potential Availability

Ratings of Quality Aggregates Within Sections

Abundant to Adequate		Adequate to Limited		Limited to Problem		Severe Problem	
Section Code	Area[1]	Section Code	Area	Section Code	Area	Section Code	Area
1e	21,790	1a,c	27,130	1b,d	53,840	--	--
2b,c,d	74,530	2a	16,140	--	--	--	--
3a,b,c	42,310	--	--	--	--	--	--
4a,b	61,100	4d	20,560	4c,e	33,190	--	--
5a,b,d,e,f	352,170	--	--	5c	10,520	--	--
6f	9,290	6a,e	41,520	6b,c,d	73,110	--	--
7a	43,800	7b	34,480	7c	27,500	--	--
8b,c,e	16,950	8a,d	28,390	--	--	--	--
9a,b,c	60,450	--	--	--	--	--	--
10c,e,k,l	68,560	10h,m	124,690	10a,d,f,g,i,j	336,200	10b	123,390
11a,b,c,d	11,000	11e,f,i	262,850	11g,h	119,060	--	--
12a,b	72,540	--	--	--	--	--	--
13a	3,790	13b,c3	48,610	13c1,c2	14,090	--	--
14a,b,d	34,840	--	--	14c	16,540	--	--
--	--	15a,b,c,e	56,830	15d	45,930	--	--
16a,b	45,340	--	--	--	--	--	--
17a,b	90,670	--	--	--	--	--	--
18	6,040	--	--	--	--	--	--
19b,c,e,f,g	46,440	19a,d	23,080	--	--	--	--
--	--	20a,b,d,g	319,900	20c,e	57,540	20f	45,700
Total	1,061,610		1,004,180		787,520		169,090
Percent of Continental U.S.	35.1%		33.2%		26.1%		5.6%

Note: 1. Areas given in square miles

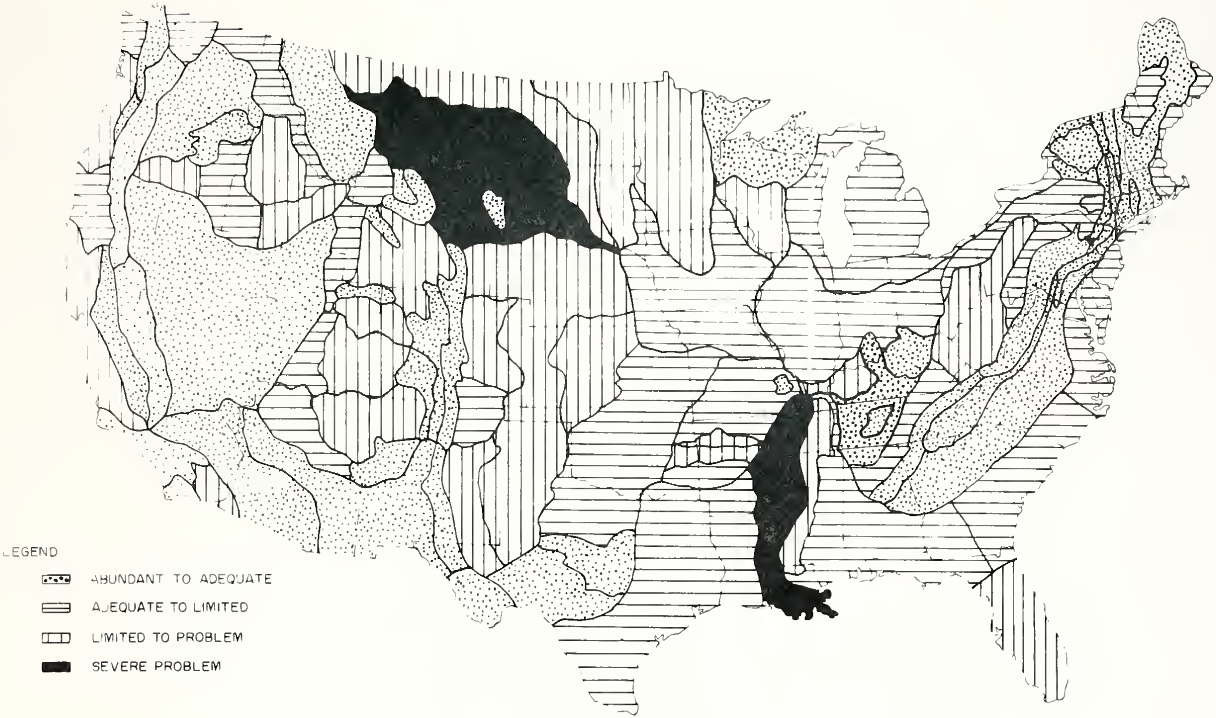


FIG. 39 ESTIMATED POTENTIAL AVAILABILITY RATING OF QUALITY AGGREGATE RESOURCES BY PHYSIOGRAPHIC UNIT

crushed stone), the regions are sparsely populated and in many cases inaccessible due to the extremely rugged, mountainous conditions. In this instance, the ruggedness and inaccessibility of these areas would tend to reduce effectively the potential rating to a more realistic lower supply of aggregates. In contrast many of the areas possessing potentially adequate supplies in the east may be quite restricted in the exploitation and use of aggregates due to urban development associated with the high population densities common to the eastern United States. This would likewise have a similar reductive effect.

Generalized Distribution of Aggregates

General East-West Differences

In discussing the aggregate resources within the United States, utilization of the east-west province grouping provides a convenient first order manner of explaining general distributive characteristics, differences and major types of aggregates utilized within the United States.

From a general viewpoint, both the east and west possess an equivalent potential for crushed stone sources; however, they differ greatly by major type available. Within the east, the greatest source of crushed stone exploited is invariably crushed carbonate with less frequent occurrences of granitic/metamorphic complex and basaltic types being available. In direct contrast, the potential types in the western provinces are associated more frequently with the latter two categories of crushed stone while the carbonates play a role of decreasing importance to the crushed stone industry.

In addition, large areas of sand gravel deposits are found within the valley fill areas of the west; characteristic in many portions of this grouping, but generally non existent in the east. The importance of glacial associated sand gravels is significant in most of the northern glaciated sections found in both the east and west. Isolated regions of coastal plain gravels are also significant within the eastern grouping but are generally absent as a regional source within the west. The role of sand gravels obtained and associated with the rivers and streams of the entire United States is, of course, a very major and prominent one, appearing to be of equitable importance as sources of highway aggregates irrespective of any east-west border separation.

Crushed Stone Distribution

General. Table 27 is a summary of the major types of crushed stone utilized as highway aggregate within sections. The Table is based upon information provided in Table 13. A generalized discussion of each grouping is presented in the following paragraphs.

Carbonate Sources. As previously noted in Table 3, the use of carbonate rocks (limestone and dolomite) for crushed stone far exceeds that of any other major crushed stone type in

Table 27

Summary of Major Crushed Stone Types

Utilized As Highway Aggregate Within Sections

Province Code	No Crushed Stone	Carbonate	Sandstone	Granitic/Meta	Other Igneous
1	c*	d*,e*	a,b,d*	e*	a,b
2		b*,c*	a	a,c*,d*	a,b*
3	c*	None	a	None	a,b
4		None	None	None	(a-e)
5	c*	a*,d*,e*,f*	d*	a*,b*,d*,e*	a*,b*,d*,f*
6	a,b	f	c,d	None	d,e,f
7		a,b	a	a,b	(a-c)
8	e	b,c,d	d	a,c,d	None
9		a,b	None	(a-c)	c
10	a	b-e,f*-h*,i,j* k*,l*,m*	b-d,f*,j*,m*	d,e,f*,m*	c,g,h
11		(a,b,c,d,e,f,g*-i*)	c,e,g*	b,c,g*,h*,i*	None
12		None	None	(a*,b)	(a*,b)
13		(a-c3)	b-c3	a,c2	c2
14		(a-c,d)	d	None	None
15		b,c,d-e	a,b,d,e	None	None
16		(a,b)	(a,b)	b	a
17		(a,b)	None	(a,b)	(a,b)
18		(18)	None	(18)	(18)
19		a,b*,f,g	a	(a,b*,d-g)	a,b*,c,e,g
20	a,b*,e,f,g	c,d	None	None	None

Notes:
1. Data summarized from Table 13; Province/Section code keyed to Table 4.
2. General quality of sources variable, but each major type noted to be used as highway aggregate in Section.
3. Sections noted by (*) indicates Sections for which incomplete data are available.
4. Sections enclosed by parenthesis indicate Provinces for which all Sections utilize crushed stone type.
5. Sections underlined indicate Sections where the only major crushed stone utilized is that shown.

the United States. Based upon the results of this project, forty-one (41) of the forty-eight (48) states utilize this source as highway aggregate.[1] By far the greatest concentration and use of these rocks occur within the vast Paleozoic area in the east shown within Figure 30. In addition, Figure 40 shows the distribution of the twenty leading state carbonate producers for the 1956 to 1958 period. The overall importance of this geologic area can be noted by a general comparison between Figure 2, 30 and 40. California, which is noted on Figure 40 as one of the leading state producers of carbonate stone utilizes only a small portion (approximately 10%) of this for highway aggregate.

In terms of the Physiographic units examined, this vast Paleozoic area forms much of the topography associated with the Ridge and Valley Province, Interior Low Plateau, Appalachian Plateau and Ozark and Ouachita Provinces. However, within the latter two Provinces, sizeable regional areas occur where carbonate stone sources are lacking. In addition, much of the bedrock underlying the Central and Eastern Lowland Province is attributable to the presence of this geologic area.

Carbonate rocks are not only confined to the Paleozoic Era, but occur and are subsequently utilized as

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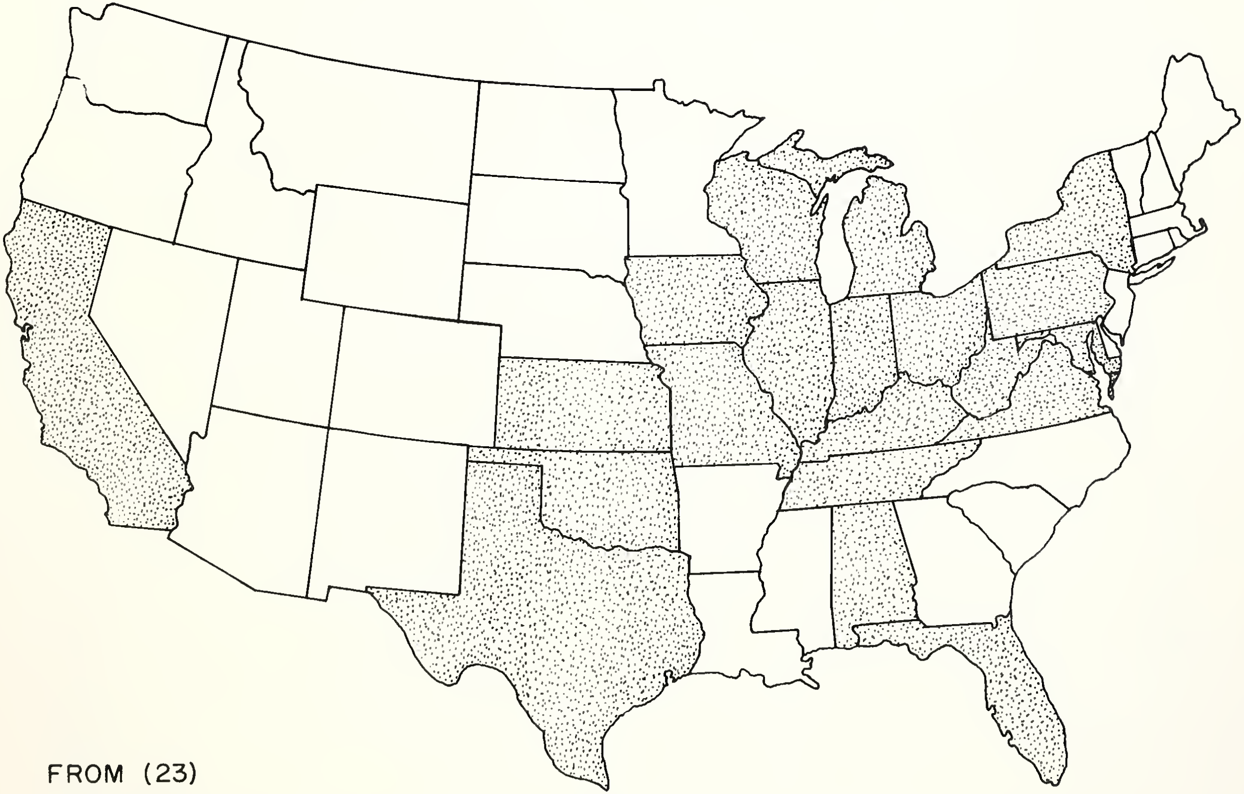
[1] The following states do not utilize carbonate rocks for highway aggregate: Connecticut, Delaware, Louisiana, Mississippi, New Hampshire, North Dakota and Oregon.



FROM (23)

FIGURE **40** DISTRIBUTION OF TWENTY LEADING CARBONATE PRODUCING STATES DURING THE 1956-1958 PERIOD highway aggregate from the Cenozoic and Mesozoic Eras. However, taken as a general rule, the occurrences of quality carbonates in these two Eras are not as widespread as those associated with Paleozoic age.

Within the Mesozoic Era, the largest occurrence of Carbonate rocks is associated with the Cretaceous Period. carbonates of this age are found, to variable degrees within the Atlantic and Gulf Coastal Plain and Great Plains Provinces. Other deposits are associated with many areas surrounding mountainous uplifts of the west. The only location of Cenozoic carbonate deposits, known to the author, that are used as highway aggregate are found within the Atlantic and Gulf Coastal Plain Province (Florida Section primarily).

Sandstone Sources. It has been previously noted that due to the wide variability in properties of sandstone,coupled with rather poor geologic information for noting the location of these potential crushed stone areas, the mapping of this aggregate source was not conducted at a U. S. level. However, the importance of this material as a crushed stone source in many areas cannot be overlooked even with the regional analysis of aggregate availability.

Although crushed sandstone is utilized as highway aggregate within 31 of the 97 sections examined, its use as a concrete mix aggregate occurs only within 11 of these sections. Table 28 is a summary of the major highway functional uses of this aggregate by sections. As can be noted, a major use of this aggregate is related to base/subbase aggregate,

Table 28

Summary of Major Highway Functional Uses of Crushed Sandstone Aggregate Within Sections

	Highway Function Code[1]		
Province Code	BS(only)	B/BS	C/B/BS
1	a,b,d	None	None
2	a	None	None
3	a	None	None
4	None	None	None
5	d	None	None
6	None	c	None
7	None	a	None
8	None	None	d
9	None	None	None
10	m	b,c,f	d,j
11	e,g	None	c
12	None	None	None
13	b	c1	c2,c3
14	None	None	None
15	None	None	a,b,d,e
16	None	b	a
17	None	None	None
18	None	None	None
19	a	None	None
20	None	None	None

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[1] BS indicates base-subbase aggregate
B indicates bituminous mix aggregate
C indicates concrete mix aggregate

reflecting to some degree, the generally lower aggregate quality which may be tolerated in non surficial pavement layers. In the western U. S. Province groups, these areas are generally associated with portions of the Pacific Coast Range Province. The Province in which it appears that crushed sandstone sources are most widely used for concrete aggregate appears in the Appalachian Plateau. This, in part, may be necessitated by the relative lack of any other suitable crushed stone source within the area.[1] A similar analysis may be applied to various other Sections such as the Wasatch (8d), Wyoming Basin (10d), Plains Border (10j), Arkansas Valley (13c2), and Ouachita Mountains (13c3).

Granitic/Metamorphic Sources. The distribution of this grouping as a crushed aggregate source is primarily, but not always, restricted to either Pre Cambrian or Jurassic ages. Within the eastern United States, these areas are located in the Old Appalachian, Laurentian Upland and the New England Maritime Provinces.

Within the central portion of the United States, but still confined to the eastern province grouping, the distribution of these rocks is principally related to several isolated geologic structural uplifts or domes. Although most of these areas are rather small in areal extent, they do frequently serve as important sources of aggregate.

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[1] Crushed carbonates are rather restricted in their distribution and occurrence within this Province.

These areas are found primarily in the Llano Burnet area of Texas (Central Texas Mineral Section), the Wichita and Arbuckle areas of Oklahoma (variant areas of the Osage Plains Section), the St. Francois Mountain Section, the Sioux Uplift in the extreme southwest corner of Minnesota and the Black Hills Section.

In the western province grouping, the occurrences of this potential aggregate source are found principally within portions of each Rocky Mountain Province, as well as in the Northern Cascade, Sierra Nevada and Lower California Sections of the Sierra-Cascade Province. In addition, scattered intrusions are found in many other isolated areas within the west.

Other Igneous Sources. The distribution of this potential crushed stone source is primarily concentrated in the western portion of the United States. The major percentage of this category is basaltic in nature and occurs principally in the Cascade Mountains and the Columbia Plateau Province. In the east, a very small, but important occurrence is found as traprock within the Triassic sediments comprising the Connecticut Lowland Section and the Triassic Lowland Province. Smaller Triassic basins are also found as variant areas within the Piedmont Plateau Section of the Old Appalachian Province.

Sand Gravel Distribution

Because of the complexity involved in the distribution, frequency of occurrence, quality and modes of natural sand gravel deposits existent within the United States, it is quite difficult to formulate a brief yet effective summary relative to the distributive characteristics of this aggregate category. Almost every section contains this source, although quantity as well as mode of occurrence may differ significantly. A general resume may be inferred from the discussions for each section concerning aggregate availability previously stated. In addition, an excellent general summary discussion is found in reference (142) in which the author could afford little or no significant contributions to the information present.

Potential Aggregate Availability Ratings

Potential Ratings Versus Areas Lacking Aggregate

The procedure used in rating potential aggregate availability ratings for each section has been previously discussed. An important source of information which was extensively utilized as a tool for the evaluation rating was the composite map of areas lacking aggregate obtained from the materials questionnaire response and previously shown in Figure 12. In general, there are a few sections in which a poor aggregate availability rating has been assigned while little or no areas have been designated as lacking aggregate within the section. In contrast, other sections showing a good aggregate availability rating possessed areas lacking aggregate resources. Many of these discrepancies may be explained by the presence of variant materials areas within a section and the attempt to designate the generalized potential availability based solely upon a material type, quality distribution combination within a Section. Some deviations, undoubtedly, are due to the lack of definite information utilized to assess the potential rating.

Table 29 summarizes all of the sections having a potential availability rating more severe than an adequate to limited category and lists the pertinent remarks concerning the status of areas lacking aggregate noted by the questionnaire response. In general, it is felt that the following sections show a distributive pattern of areas void of aggregate inconsistent (less areas than would be expected) to the assigned rating: 1b,d; 4e;6b,c; 7c; 10f,i,j and 13c1,c2. The basis for these sections having the assigned ratings is presented within the geologic summary of areas lacking aggregates in the ensuing portion of the report.

Table 30 notes <u>only</u> those sections where areas lacking aggregates were noted by the questionnaire results <u>and</u> which have an availability rating less severe than a limited to problem variety. In general, with the exception of the Grand Canyon Section, the remainder of the sections do not exhibit any gross inconsistencies between the areas lacking aggregate and the assigned rating. The adequate to limited potential availability rating given to the Grand Canyon Section is in direct contrast to the entire Section being designated by Arizona Highway Department personnel in the NCHRP materials questionnaire as lacking aggregate.

Table 29

Summary Comparison Between Occurrence of Areas Lacking Aggregate From Materials Questionnaire and Sections Having an Aggregate Availability Rating More Severe Than Adequate to Limited

Section/Code	Rating[1]	Remarks Concerning Areas Lacking Aggregate From State Materials Questionnaire Response
Unglaciated Mo. Plat (10b)	SP	Very large portion of Section noted as lacking aggregate
Mississippi Alluvial Pl.(20f)	SP	Very large portion of Section noted as lacking aggregate
Oregon Coast Range (1b)	L-P	Scattered, small areas noted in Washington
California Coast Range (1d)	L-P	Small regional coastal area in Southern California
Snake River Plain (4c)	L-P	Significant area noted in western portion of Section
Harney (4e)	L-P	No area noted
Salton Trough (5c)	L-P	Significant area noted in California
Uinta Basin (6b)	L-P	No area noted by Colorado; Utah not answering question
Canyon Lands (6c)	L-P	Same comments as above
Navajo (6d)	L-P	Significant areas within Utah and Arizona noted
Salmon River (7c)	L-P	Scattered areas along western flank of unit in Idaho
Glaciated Mo. Plat. (10a)	L-P	Scattered areas which are generally contiguous with void areas in adjacent Unglaciated Missouri Plateau
Wyoming Basin (10d)	L-P	Very large portion within central portion of Section
High Plains (10f)	L-P	No areas delineated; Texas not answering question
Colorado Piedmont (10g)	L-P	Very large portion noted
Pecos Valley (10i)	L-P	No areas noted by New Mexico
Plains Border (10j)	L-P	No areas noted by all states
Driftless (11g)	L-P	Sizeable area noted in central Wisconsin
West Lakes & Lacustrine(11h)	L-P	Regional areas noted in North and South Dakota; Minnesota not answering question
Boston Mountains (13c1)	L-P	No area noted
Arkansas Valley (13c2)	L-P	No area noted
Shawnee Hills (14c)	L-P	Sizeable area in Indiana portion of Section
Kanawha (15d)	L-P	Large regional area in West Virginia
Florida (20c)	L-P	Significant area noted in Southern Florida
Mississippi Loessial Upl.(20c)	L-P	Several regional areas noted within Mississippi

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[1] SP denotes Severe Problem Aggregate Availability Rating
L-P denotes Limited to Problem Aggregate Availability Rating

Table 30
Summary Comparison Between Sections Possessing Areas Lacking Aggregate From Materials Questionnaire and Sections Having an Aggregate Availability Rating Less Severe Than Limited to Problem

Section/Code	Rating[1]	Remarks Concerning Areas Lacking Aggregate From State Materials Questionnaire Response
Walla-Walla Plateau (4a)	A-A	Very small areas in Idaho portion of Section
Great (Closed) Basin (5a)	A-A	Sizeable area noted in northwest California
Sonoran Desert (5b)	A-A	Regional area noted in Arizona
Piedmont Plateau (17b)	A-A	Very small area in Georgia
Olympic Mountain (1a)	A-L	Several small areas noted in Washington
Northern Cascade (2a)	A-L	Fairly large regional area noted within central portion of unit
Payette (4d)	A-L	Very small areas in Idaho portion
Grand Canyon (6e)	A-L	Entire Section noted by Arizona
Wasatch (8d)	A-L	Small portion in Wyoming continuous with area in Wyoming Basin
Central Till Plain (11f)	A-L	Sizeable areas in western Illinois and southwest Indiana
Dissected Loessial/Till Plains (11i)	A-L	Indefinite areas within Iowa and regional area of northwest Missouri
Cumberland Plateau (15e)	A-L	Large area of Kentucky portion of Section noted
Seaboard Lowland (19a)	A-L	Several isolated areas in Maine portion of Section
White Mountains (19d)	A-L	Regional area in Maine portion noted
Embayed (20a)	A-L	Virginia coastal areas noted
Sea Island (20b)	A-L	Very small area in Florida; South Carolina not answering questionnaire
East Gulf Coast (20d)	A-L	Areas occur within central and outer portions of Section
West Gulf Coast (20g)	A-L	Small coastal area in Louisiana; Texas not replying

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[1] A-A denotes Abundant to Adequate Aggregate Availability Rating
A-L denotes Adequate to Limited Aggregate Availability Rating

Although potential limestone sources do exist in the area, it was noted that no limestone entry was made for the Section. As a result the true potential quality of this area is unknown and it is possible that the areas noted as lacking aggregate may reflect the difficulty of exploiting this deeply dissected canyon portion rather than based upon quality limitations of the limestone source. Based upon this limited information aggregate availability in the area was designated as adequate to limited rather than as a severe problem category.

Geologic Summary of Sections Having Poor Aggregate Availability Ratings

Although each section possessing a limited to problem or severe problem rating had its own peculiar combination of characteristics responsible for its rating; these units can be effectively grouped into three categories denoting general features responsible, in major part, for the poor potential aggregate rating. Table 31 is a general summary of the sections having a poor availability rating grouped according to these three categories.

One of the most significant factors contributing to lack of aggregate within sections can be seen to occur from areas possessing widespread distribution pattern of sandstones and shales. This fact coupled with a relative lack of quality natural sand deposits generally yields areas of extremely poor potential. From Table 31, it can also be noted that most of these areas within the Type I grouping

Table 31

Generalized Summary of the Predominant Geologic Conditions Existent Within Sections Possessing an Aggregate Availability Rating More Severe Than Adequate to Limited

Type I: Sections Possessing Widespread Distribution of Predominantly Sedimentary Sandstone and Shale Bedrock Which Significantly Contributes to a Poor Aggregate Availability Rating

Section/Code	Remarks
Oregon Coast Range (1b)	Tertiary sandstones and shales
California Coast Range (1d)	Tertiary and Mesozoic sandstones, shales and some slates
Uinta Basin (6b)	Tertiary sandstones and shales
Canyon Lands (6c)	Mesozoic sandstones and shales
Navajo (6d)	Mesozoic, Tertiary and late Paleozoic sandstones and shales
Unglaciated Missouri Plateau (10b)	Tertiary and Cretaceous sandstones and shales
Wyoming Basin (10d)	Tertiary sandstones and shales
Colorado Piedmont (10g)	Tertiary and Cretaceous sandstones and shales
Pecos Valley (10i)	Triassic sandstones and shales; Permian sandstones, shales, limestone and gypsum
Plains Border (10j)	Cretaceous and Permian sandstones and shales; Cretaceous limestone
Driftless (11g)	Cambrian sandstone and shales; Ordovician carbonates in southwest may be used as crushed stone
Boston Mountain (13c1)	Pennsylvanian sandstones and shales
Arkansas Valley (13c2)	Pennsylvanian sandstones and shales
Shawnee Hills (14c)	Pennsylvanian sandstones and shales; Mississippian limestones quarried
Kanawha (15d)	Pennsylvanian sandstones and shales; Permian limestones and shales

Type II: Sections Possessing Widespread Distribution of Bedrock With Poor Crushed Stone Capability Other Than That Noted in Type I Which Significantly Contributes to a Poor Aggregate Availability Rating

Section/Code	Remarks
Snake River Plain (4c)	Cenozoic acidic lava plain; regional sand gravel sources generally only available near mountain borders
Harney (4e)	Cenozoic acidic lava plain with widespread pumice deposits and lacking regionally distributed sand gravels
Salmon River (7c)	Jurassic granitic rocks are not suitable for use as highway aggregate

Type III: Sections Generally Possessing a Non Existent to Poor Bedrock Crushed Stone Potential Overlain by Transported Deposits Either Deficient in Quantity or Quality of Natural Granular Deposits

Section/Code	Remarks
Salton Trough (5c)	Widespread presence of fine grained alluvial and lacustrine deposits characterize much of Section
Glaciated Missouri Plateau (10a)	Glaciated region possessing sand gravel deposits of general poor quality underlain by bedrock similar to that found within Unglaciated Section. (See 10b in Type 1 grouping)
High Plains (10f)	Crushed stone potential non existent in Section; major source of aggregates obtained from major rivers and tributaries of Section. Higher density of rivers occur in northern portion of unit; however much of the aggregate lacks coarse fraction and may be reactive with cement.
Western Lakes and Lacustrine (11h)	Western portion of unit possesses Cretaceous sandstones and shales similar in characteristics to those found in Type I grouping. Major areas void of aggregate associated with glacial lacustrine areas (Lake Agassiz and Dakota).
Florida (20c)	Sandy unconsolidated coastal deposits veneer almost entire Section. Regional crushed carbonate zones present in portions of the unit; but much of entire Section lacks coarse aggregate.
Mississippi Loessial Upland (20e)	Widespread loessial deposits overlie non existent crushed stone potential areas
Mississippi Alluvial Plain (20f)	Widespread distribution of fine grained alluvium present throughout most of unit

have geologic ages which correspond to Cenozoic, Mesozoic, late Paleozoic (Permain and Pennsylvanian) and Early Paleozoic (Cambrian) Eras. It is within the Paleozoic periods older than Pennsylvanian in which the majority of the crushed carbonate zones are found within the United States.

The existence of poor sandstone and shale bedrock comprising the modal bedrock within a section is of course not always associated with an overall poor aggregate availability rating for the section in question. Examples of sections which, in general, are characterized by relatively soft sandstone and shale bedrock yet possess abundant to adequate potential for aggregates can be noted within the Bighorn Basin (10c), Triassic Lowland Province (18) as well as the Connecticut Lowland Section (19c). Within these units, the widespread distribution of quality sand gravels and/or crushed stone (obtained from variant bedrock types within the unit) may override the presence of poor quality crushed stone sources attributable to the sandstones and shales.

Soils and Related Factors

Soil Origin

Uniqueness of Origin to Basic Report Provinces/Sections

In general, the physiographic units viewed at a province level show a fair degree of uniqueness of surficial soil origin, although this uniqueness varies considerably within differing provinces. Table 32 summarizes the estimated

Table 32
Summary of Generalized Degree of Homogeneity of Major Soil Origins Found in Sections by Province

Province	Major Mode of Origin: Non Transported B	R	Transported L	G	Wow	Wvf	Wl	Wm	Wal	Wcs	Homogeneity Rating
Colorado Plateau	x	x									Excellent
Ozark and Ouachita		x									Excellent
Ridge and Valley	x	x									Excellent
Old Appalachian	x	x									Excellent
Middle Rocky Mtns.	x	x									Excellent
Southern Rocky Mtns.	x										Excellent
Laurentian Upland				x							Excellent
Pacific Coast Range	x	x				x					Good to Excellent
Sierra - Cascade	x			x							Good to Excellent
Interior Low Plateau		x									Good to Excellent
Triassic Lowland		x									Good to Excellent
New England Maritime	x			x				x			Good to Excellent
Central and Eastern LL		x	x	x			x	x			Fair to Good
Appalachian Plateau		x		x							Fair to Good
Atlantic and Gulf Coastal Plain			x						x	x	Fair to Good
Basin and Range	x	x				x	x				Fair to Good
Northern Rocky Mtns.	x					x					Fair to Good
Pacific Troughs		x		x		x			x		Poor to Fair
Columbia Plateau	x	x	x				x				Poor to Fair
Great Plains	x	x	x	x	x						Poor to Fair

Legend:

Non Transported
B- Bedrock
R- Residual Soil

Transported
L- Loessial
G- Glacial
W- Water
ow- outwash
vf- valley fill
l- lacustrine
m- marine
al- alluvial
cs- coastal sediments

degree of origin homogeneity based upon the major soil origins and their distribution noted within sections of a particular province and previously shown in Table 14.

As can be seen from the table, many provinces exhibit an excellent uniqueness by major mode of origin. In addition, several provinces contain minor variant origins to justify their homogeneity rating being slightly less than completely homogeneous. The Pacific Coast Ranges possess, as a minor variant origin, valley fill deposits found primarily within the Los Angeles Section. This area is regionally extensive but is not the unique origin to the Los Angeles Section. Within the Sierra-Cascade Province only a minor portion of the Northern Cascade Section has been glaciated. The Triassic Lowland Province similarly possesses a glaciated portion occurring in the northern part of the unit. The Interior Low Plateau, predominantly a Province of non transported origin, possesses a loessial covering in a regionally significant portion of the Shawnee Hills Section. Within the New England Maritime Province, sectioning of the Seaboard Lowland and New England Upland Sections generally isolates the marine clays common the the Lowland unit, although the marine origin is not entirely unique within the Section.

Although the Central and Eastern Lowland Province is primarily of glacial origin, residual soils, loess deposits, glacial lacustrine as well as marine deposits occur in the province proper. In general, the examination of origin at the section level only slightly improves the uniqueness of origins at this regional unit category level. Within the Appalachian Plateau Province, sectioning of the glaciated Catskill Mountains and New York Sections provide a perfect uniqueness of origins by Sections of the Province. This uniqueness is also exhibited at the section level for the Atlantic and Gulf Coastal Plain Province. Although the predominant origin is due to coastal sedimentation, sectioning of the province isolates the two major variant origins in the province. These are the loess deposits (Mississippi Loessial Upland Section) and the alluvial deposits which characterize the Mississippi Alluvial Plains Section. The only minor variant origin areas noted after sectioning are found in the glaciated Long Island and Cape Cod areas within the Embayed Section. The major reason for categorizing the Basin and Range Province as a "Fair to Good" rating is due to the repetitive occurrence of valley fill deposits and the non transported origin areas noted by the mountain ranges of the unit. The major variant origin unit is uniquelly delineated by sectioning of the Salton Trough unit. Here the major origins are denoted by lacustrine and alluvial deposition. The Northern Rocky Mountain Province is characterized by a northern tier of continental glaciation and an eastern portion characterized by valley fill and glacial debris. In general, the effect of sectioning improves the uniqueness of origin by physiographic units, particularly for the Montana Section, characterized by the basins and valley systems of the Section.

The provinces felt to possess the greatest variability of origin are the Pacific Troughs, Columbia Plateau and Great Plains Province. In general, although the predominating mode of origin of the Pacific Troughs is transported, non transported areas are found within the northern trough. In addition, valley fill areas, alluvial deposits and glaciated regions are existent in the Province. In general, sectioning of the province increases the uniqueness of origin by physiographic unit, although non-transported areas are common in both Sections of the northern trough. Within the Columbia Plateau Province, non transported origin predominates; however, loessial deposits as well as lacustrine areas are widespread in the Province. Sectioning generally improves the uniqueness of origin by isolating the major loessial deposits to the Walla-Walla Plateau and Snake River Plains Sections, as well as the major lacustrine areas to the Payette Section. However, these Sections do not solely possess these origins. The materials of the Great Plains probably are as variable as the materials within all the provinces of the United States. Non transported areas, water deposited outwash, glacial and loessial deposits exist within the unit. Sectioning of the Province improves the uniqueness of unit origin homogeneity by delineating the glaciated area (Glaciated Missouri Plateau Section) and generally restricting the outwash to the High

Plains Section. However, loessial origin areas are not unique to any particular section. The Plains Border Section, with its alluvial soils, outwash areas, loessial deposits and non-transported origin areas affords the poorest indicator of uniqueness in origin displayed by any of the 97 basic report sections found in the United States.

Relation of Transported Surficial Origin Areas to Regional Physiographic Units

It is apparent that although several provinces are unique in mode of origin, the examination of physiographic units at a greater level of examination, i.e., section level, improves this uniqueness within a given physiographic unit. However, it should be realized that through simple deductive reasoning between the natural laws inherent to material transport and the principles utilized to delineate physiographic units, a total uniqueness of origin for transported soils can never occur within all physiographic units.

The major reason for the above is due to the variable thicknesses associated with deposition (and subsequent erosion) characteristic to aeolian, glacial and water transport. As a result, where "thin" transported soils partially overlie physiographic units formed upon the gross features characteristic of bedrock, little or no relation to regional physiographic units may exist. Example of this are found extensively with the loessial deposits in the Great Plains and portions of the Central and Eastern Lowland Province. In many cases, where a "thin" mantle of transported material completely covers a physiographic unit delineated by the underlying bedrock, a "pseudo uniqueness" of origin for that particular regional unit may occur. This is to say, that if the transported material would be stripped from the area, a new physiographic unit of identical outline would be noted. Many examples of this occurrence can be found associated with the glacial cover of the New England Maritime Province and of the lowlands and valleys in the New York portion of the Central and Eastern Lowland Province as well as the loess deposits found in the Snake River Plains.

The major regional zone where distinctive regional physiography has developed upon relatively "thick" transported material is found within portions of the Central and Eastern Province. In particular, the Eastern and Western Lakes and Lacustrine Sections, Central Till Plain and Dissected Loessial and Till Plains Sections possess modal topography distinctive to glaciation. If the transported material were not present in these areas, delineation of physiographic units would in no way correspond to the present system and, in fact, would be more continuous with the surrounding non-transported physiographic units.

Poor Subgrade Support Areas

Organic Deposits

Design Factor Rating Summary. In general, the presence of organic type deposits is an important highway design factor in only a relatively small portion of the U.S.. Table 33 summarizes the frequency of occurrence rating of this

Table 33

Summary of Estimated Frequency of Occurrence Rating of Organic Poor Subgrade Support Areas Within Sections

Non Existent		Non Existent to Limited		Limited to Medium		Medium to Widespread		Very Widespread	
Section Code	Area	Section Code	Area	Section Code	Area	Section Code	Area	Section Code	Area
1c,e	41,830	1a,b,d	60,930	--	--	--	--	--	--
2a,b,c,d	90,670	--	--	--	--	--	--	--	--
3b	4,700	3a,c	37,610	--	--	--	--	--	--
4a,b,c,d	99,000	4e	15,850	--	--	--	--	--	--
5a,b,c,d,e	362,690	--	--	--	--	--	--	--	--
6a,b,c,d,e,f	123,920	--	--	--	--	--	--	--	--
7a,b,c	105,780	--	--	--	--	--	--	--	--
8a,b,c,e	28,200	8d	17,140	--	--	--	--	--	--
9a,b,c	60,450	--	--	--	--	--	--	--	--
10a-m	652,840	--	--	--	--	--	--	--	--
11i	89,580	11b,c,d,f,g	114,730	11a,h	100,590	11e	88,010	--	--
--	--	--	--	12a,b	72,540	--	--	--	--
13a,b,c1,c2,c3	66,490	--	--	--	--	--	--	--	--
14a,b,c,d	51,380	--	--	--	--	--	--	--	--
15a,c,d,e	80,260	15b	22,500	--	--	--	--	--	--
16a,b	45,340	--	--	--	--	--	--	--	--
17a,b	90,670	--	--	--	--	--	--	--	--
--	--	18	6,040	--	--	--	--	--	--
19e,f,g	8,760	19b,c,d	48,940	19a	11,820	--	--	--	--
20e	22,860	20d,f,g	278,420	20a,b	87,180	20c	34,680		
Total	2,025,420		602,160		272,130		122,690		0
Percent of Continental U.S.	67.0%		19.9%		9.0%		4.1%		0

Note: 1. Areas given in square miles

factor of design by sections. Figure 41 illustrates the distribution of the summary table. In addition, the soil texture maps of the United States, shown in Figures 16 through 21, illustrate the actual regional distribution of these areas. As can be noted from the table, physiographic sections comprising an area of almost 87% of the United States have, at most, a non existent to limited type frequency rating of this factor.

Distribution.

General. From a generalized east-west province grouping the greatest frequency of occurrence of organic soils is found in the eastern grouping. The greatest frequency ratings are found within the Eastern Lakes and Lacustrine Plains Section of the Central and Eastern Lowland Province as well as the Florida Section of the Atlantic and Gulf Coastal Plain Province. It is within these two geomorphic conditions, which characterize these provinces (glaciation and coastal plain development), that the greatest majority of organic type terrain becomes a factor in highway engineering. Table 34 summarizes the Sections by the major geomorphic modes of occurrence.

Glaciated Areas. In the western portion of the United States, the physiographic units possessing organic deposits associated with glaciation were noted to exist only in limited parts of the Puget Sound Section and in the Jackson Hole areas of the Middle Rocky Mountain Province. Within the eastern group every province possessing glaciated areas

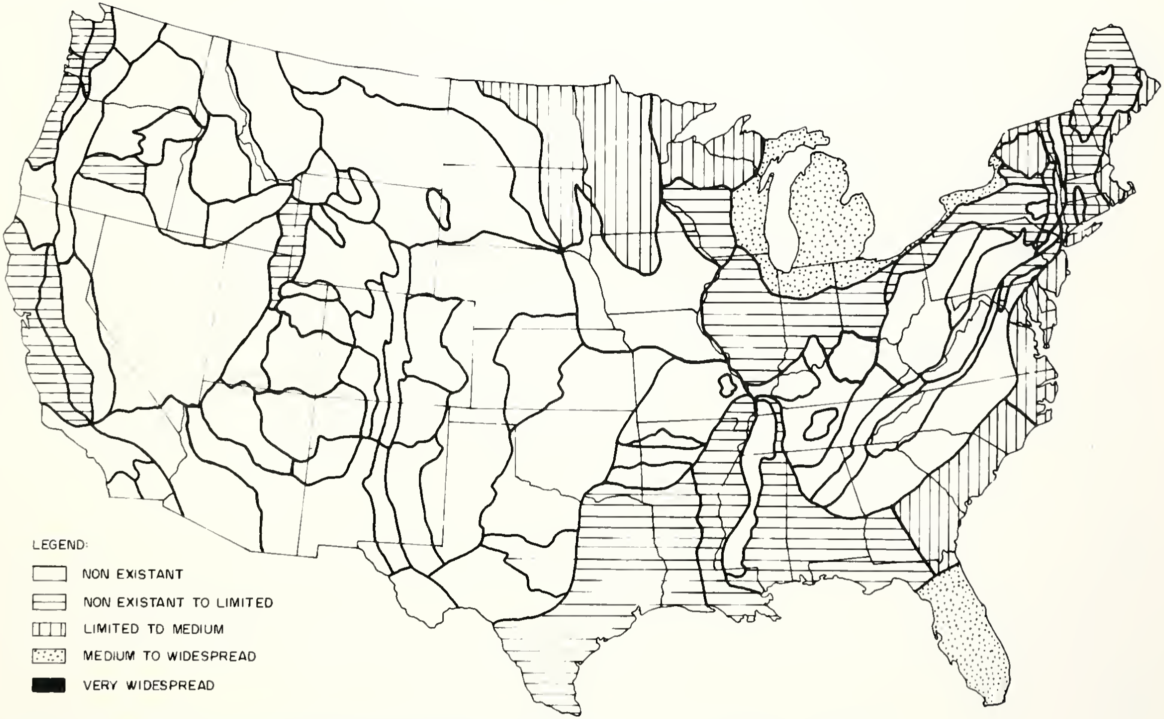


FIGURE 41 ESTIMATED FREQUENCY OF OCCURRENCE RATING OF POTENTIAL POOR SUBGRADE SUPPORT AREAS (ORGANIC DEPOSITS) BY PHYSIOGRAPHIC UNIT

Table 34

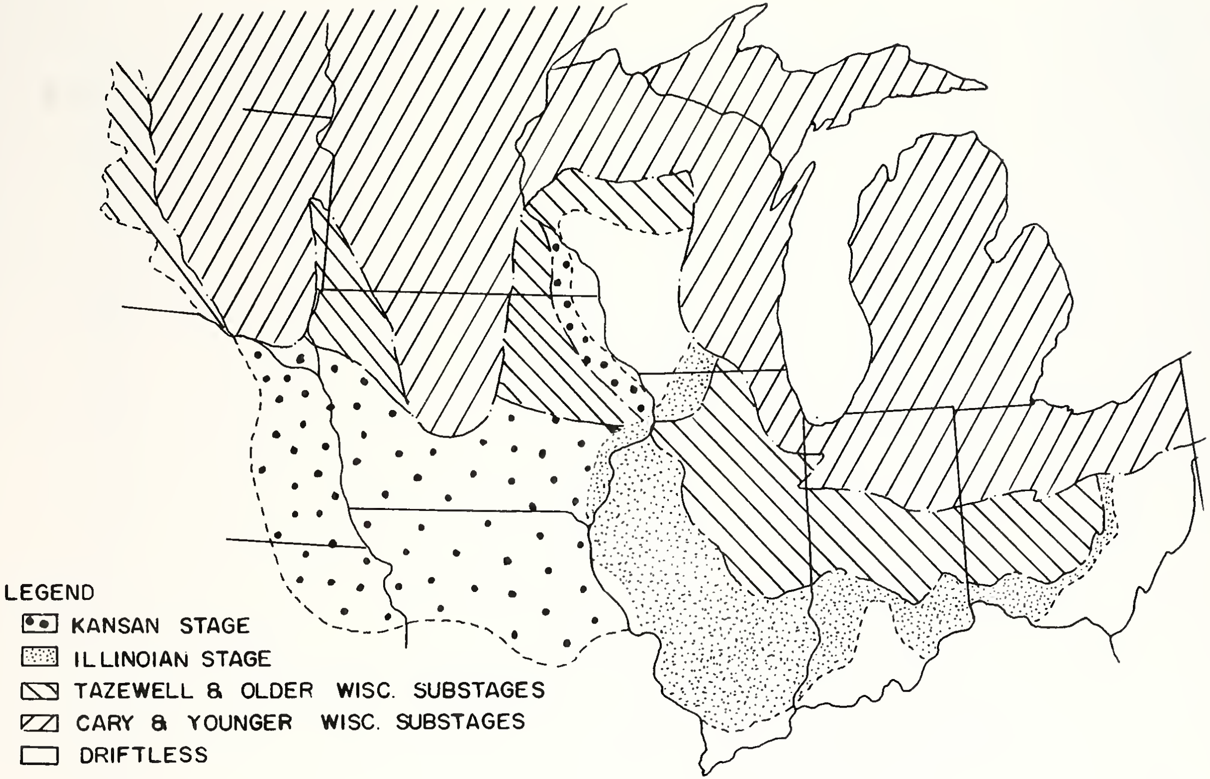
Summary of Sections Possessing Organic Type Deposits Grouped by Major Geomorphic Modes

Section/Code	Rating	Remarks
I. Glaciated Areas		
Puget Trough (3a)	N-L	
Wasatch (8d)	N-L	found with glacial outwash in Jackson Hole area
Champlain Lowland (11b)	N-L	
Hudson River Valley (11c)	N-L	
Mohawk River Valley (11d)	N-L	
Central Till Plain (11f)	N-L	
St. Lawrence Lowland (11a)	L-M	
Western Lakes and Lac. (11h)	L-M	
Eastern Lakes and Lac. (11e)	M-W	
Superior Upland (12a)	L-M	
Adirondack (12b)	L-M	
New York Glaciated (15b)	N-L	
Triassic Lowland (18)	N-L	associated with northern glaciated area
New England Upland (19b)	N-L	
Connecticut Lowland (19c)	N-L	
White Mountain (19d)	N-L	
Seaboard Lowland (19a)	L-M	
II. Coastal and Embayed Areas		
Oregon Coast Ranges (1b)	N-L	found within a small coastal plain areas of Oregon
California Coast Ranges (1d)	N-L	associated with Section (3c) within San Francisco Bay area
California Valley (3c)	N-L	associated with Section (1d) within San Francisco Bay area
East Gulf Coast (20d)	N-L	occurs primarily in outer coastal plain
West Gulf Coast (20g)	N-L	occurs primarily in outer coastal plain
Embayed (20a)	L-M	
Sea Island (20b)	L-M	
Florida (20c)	M-W	possesses largest swamp area in United States
III. Deltaic Areas		
Mississippi Alluvial Plain (20f)	N-L	associated with Mississippi Delta Area

was noted to have an occurrence of organic type deposits. Although the Triassic Lowland is generally characterized as non-transported origin (Tertiary sandstones and shales), the northern portion of the unit is glaciated. It is within this rather small area where the organic deposits may be found.

With the exception of the mountainous Catskill, Green, Taconic and Reading Prong Section, every glaciated physiographic section north and east of the New York Glaciated Section was noted to contain organic type terrain. The pattern of frequency of occurrence and distribution of organic terrain found in the glaciated Sections to the west of this area is of noteworthy significance. It is within the central portion of the Central and Eastern Lowland Province that the presence and frequency of organic terrain may be associated to the various glacial ice stages of the lowland area.

Figure 42 shows the distribution of the major ice sheets within this area. It can be seen from comparing either Figure 41 and/or Figures 19 and 21 to Figure 42 that the greatest frequency of organic deposits is associated with the most youthful glacial substages, Cary and younger Wisconsin age. As this type of terrain forms the modal topography of the Eastern and Western Lakes and Lacustrine Sections, as well as being completely present in the Superior Upland Section, the delineation of these physiographic units creates a uniqueness by separating areas of greatly differing frequency of occurrence ratings for organic



MODIFIED FROM (65)

FIG.42 DISTRIBUTION OF MAJOR ICE SHEETS IN THE CENTRAL PORTION OF THE CENTRAL AND EASTERN LOWLAND PROVINCE deposits.

Similarily, as older glacial terrains are encountered, the frequency of organic terrain decreases. The oldest glacial drift in the area is Kansan. This glacial terrain, with variable loessial cover, forms the diagnostic topography of the Dissected Loessial and Till Plain Section (111). As can be seen from Figure 41, organic deposits are non-existent within this area.

The major geomorphic reason for this feature is due to the fact that youthful glacial terrains are often associated with a poorly intergrated drainage system. The presence of this type of drainage system is subsequently conducive to the formation of organic type deposits within young glacial topography.

Coastal and Embayed Areas. Within the western portion of the United States, the sections associated with organic type terrain are found in a small coastal plain region of Oregon within the Oregon Range Section and Sections in California associated with rather significant organic deposits within the San Francisco Bay area.

Within the eastern United States, the Atlantic and Gulf Coastal Plain Province provides the only physiographic units where occurrences of this geomorphic mode are found. From 18 and 20, as well as Figure 41, it can be seen that within the East and West Gulf Coast Sections, only a limited quantity of organic deposits is encountered. The location of these areas is also notably confined to the outer coastal plain areas of the units.

The Atlantic Plain portion of the Province, particularly the Embayed and Sea Island Sections, generally possesses a greater frequency of organic deposits than the Gulf Sections. The Florida Section, in itself, is the most unique organic area in the United States. This Section possesses the largest continous swampland (Everglades) in the country.

Of final significance, is the fact that the presence of organic type terrain is primarily contained in the outer portions of the entire Province. Because this province is relatively young and the structure of the sediments is mildly dipping to the outer coastal areas, the youngest deposits are found associated with the outer coastal plains. Hence, a general similarity between youthfulness of glacial as well as coastal plain type terrains to the presence and frequency of organic terrains is noted.

Deltaic Areas. As can be seen from Figure 18, the Mississippi River delta area, within the Mississippi Alluvial Plain Section, is a fairly extensive area of organic type terrain.

Inorganic Deposits[1]

Design Factor Rating Summary. Table 35 summarizes the estimated frequency of occurrence- severity rating of clayey soil type areas within the basic report sections of the United

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[1] Throughout this portion of the report, the word "clay" is meant to imply plastic properties of a soil rather than pure textural connotations.

Table 35

Summary of Estimated Frequency of Occurrence-Severity

Rating of Inorganic (Clayey) Poor Subgrade Support Areas Within Sections

Non Existent		Non Existent to Limited		Limited to Medium		Medium to Widespread		Very Widespread	
Section Code	Area[1]	Section Code	Area	Section Code	Area	Section Code	Area	Section Code	Area
1c	20,040	1a,b,e	44,180	1d	38,540	--	--	--	--
2a,d	22,940	2b,c	67,730	--	--	--	--	--	--
--	--	3a	14,510	3b	4,700	3c	23,100	--	--
4a,b,c,e	94,290	4d	20,560	--	--	--	--	--	--
--	--	5b,d,e,f	176,630	5a	175,540	5c	10,520	--	--
--	--	6a,b,c,d,e	114,630	6f	9,290	--	--	--	--
7b,c	61,980	7a	43,800	--	--	--	--	--	--
8a,b,c,e	28,200	8d	17,140	--	--	--	--	--	--
9a,b,c	60,450	--	--	--	--	--	--	--	--
--	--	10c,d,e,f,i,j,k	268,310	10a,g,h,l	150,160	10b,m	234,370	--	--
--	--	11g,h	119,060	11d,e	90,370	11a,b,c,f,i	183,480	--	--
12b	8,990	12a	63,550	--	--	--	--	--	--
--	--	13a,c2	12,300	13b,c1,c3	54,190	--	--	--	--
--	--	--	--	14c	16,540	14d	23,580	14a,b	11,260
--	--	15a,e	23,640	15b,c	33,190	15d	45,930	--	--
--	--	--	--	16a,b	45,340	--	--	--	--
17a	19,770	--	--	--	--	17b	70,900	--	--
--	--	--	--	--	--	18	6,040	--	--
19c,d,e,g	20,160	19b,f	37,540	--	--	19a	11,820	--	--
--	--	20a,b,e	110,040	20c,d	126,920	20g	140,480	20f	45,700
Total	336,820		1,133,620		744,780		750,220		56,960
Percent of Continental U.S.	11.2%		37.6%		24.5%		24.8%		1.9%

Note: 1. Areas given in square miles

States. Figure 43 illustrates the distribution of these ratings. A most notable generalized point of the summary illustrates the relative lack of clayey type areas existent within the western province groupings in contrast to those found in the east. Approximately 75% of the western province grouping area possesses sections having a rating of less than or equal to a non existent to limited severity rating; while only slightly greater than 3% of the area has sections showing a medium to widespread or greater rating. In contrast, the eastern group has almost 40% of its area having sections with a medium to widespread or greater rating.

There are several probable reasons for the above pattern, each perhaps interrelated to the others. It is felt that the major factors are due to the following:

1. The climatic environment (humid type) prevalent in the east is more conducive to chemical weathering processes which generally are associated with clay development in contrast to physical weathering.

2. The overall topographic features (elevation, relief) of the eastern United States are likewise more favorable for chemical weathering in combination with the climatic regime of the area.

3. The grouping of origin-parent material types in the east are conducive to clay deposition and/or development. Within the glaciated northern portion of the area,

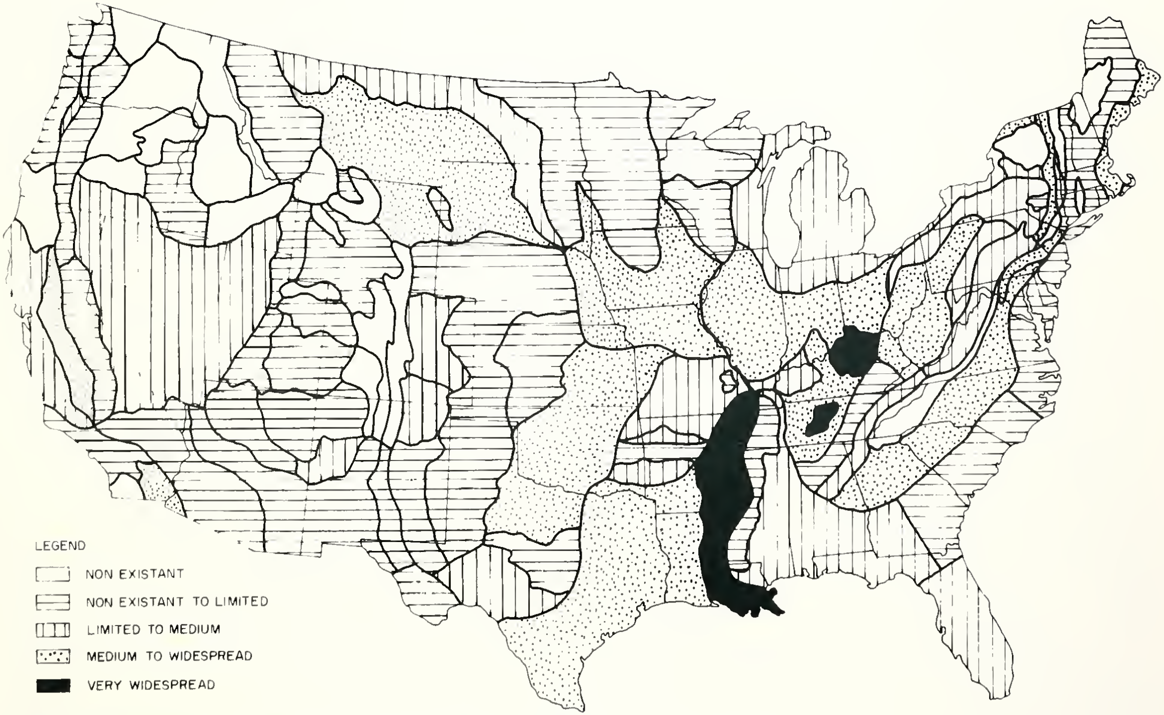

FIGURE 43 ESTIMATED FREQUENCY-SEVERITY OCCURRENCE RATING OF POTENTIAL POOR SUBGRADE SUPPORT AREAS (INORGANIC/CLAYEY DEPOSITS) BY PHYSIOGRAPHIC UNIT

the most highly plastic soils are generally associated with water deposition from glacial lacustrine or marine origin. Likewise the clays of the coastal plain are primarily found associated either with the coastal limestones and chalks or widespread fine grained alluvial deposition. Within these two zones lies the consolidated bedrock region. This area is composed primarily of sedimentary types, in which clayey type residuum is often developed within the climatic and topographic environments peculiar to this region.

Distribution.

General. Within the ensuing discussion on the general distribution of clayey type poor subgrade support areas, the discussion sequence of these areas is conducted by major origin groupings within the east and west province zones. The reader is referred to Table 14 for the general listings of major origin by province.

Western Province Group. Within the mountainous provinces of the west, most potentially poor subgrade support areas are associated with residual soil development. In general, these areas are not widespread relative to the total area comprising the units nor are they generally considered to be of a heavy clay category. The most frequent occurrence of the clayey soils occurs within the California Coast Range Section where the major parent materials are sandstones and shales. Smaller areas of lean clays also exist within the Oregon Coast Range Section and Wasatch Section (Middle Rocky

Mountain Province). Residual lean clays developed from granite may also be found within portions on the western flank areas of the Sierra Nevada Section. Clays of a more plastic nature are found near the western flank of the Southern Cascade Section associated with residual development from basaltic type rocks. These latter two clay areas do not form a significant portion of the modal soil conditions (or lack thereof) that are existent within the particular section in question. The only other regionally defined area of clay soils found in the mountainous provinces of the west are associated with the Montana Section of the Northern Rocky Mountain Province. Within this Section, the clays, frequently of a "varved" nature, are generally confined to the basins which characterize this Section as a unique topographic area.

Within the Columbia and Colorado Plateau Provinces, clayey or poor subgrade soil conditions are generally not very widespread. The lacustrine areas, characteristic to the Payette Section of the Columbia Plateau, may be associated with the most potentially plastic soils of the Province. Plastic clay soils found within the Colorado Plateau Province are generally associated solely with the shales and clay shales of the Province. The occurrence of these soils is common to each section of the Province but the greatest frequency of occurrence is found in the eastern sections. In general, the predominating texture of the residual soils found in both the Columbia and Colorado Plateau Provinces appears to be a thin sandy type residium.

In general, the most potentially severe subgrade support conditions occurring in the western provinces are associated with deposition by water. Plastic soils associated with alluvium and valley fill are frequently encountered within the central portions of the California Valley Section. The Willamette Valley Section in addition to possessing clayey soils from residual basalts and sandstones and shales, also has much alluvial plain deposits of a plastic nature. Within the Basin and Range proper, the major areas of potential clay areas are those associated with the old lacustrine deposits and fine textured valley fill occurring within the central portions of the basins. A fairly significant poor subgrade area is found within the Salton Trough Section from the widespread lacustrine and alluvial deposits of the area.

Eastern Province Group. Within the three Provinces completely veneered (or nearly so) by glaciation (Central and Eastern Lowland Province, Laurentian Upland Province, and New England Maritime Province) the greatest overall frequency of clayey type occurrences is, by far, found within the Central and Eastern Lowland Province. The most highly plastic soils noted within the provinces appear to be uniquely associated with water deposition.

The only occurrence, within the entire New England Maritime Province, of poor subgrade clay areas is associated with the marine deposits found primarily within the Seaboard Lowland Section. Of the two Sections comprising the Laurentian Upland Province, the Adirondack Section completely lacks any regional clayey deposits while the Superior Upland Section possesses only minor areas of clayey soils, associated with lacustrine origin.

The Central and Eastern Lowland Province and the corresponding section level breakdown afford a fairly unique framework for discussion of clayey deposits within the unit. Clay soils within the Province are associated with glacial lacustrine, marine and some glacial drift deposits. However, the most highly plastic deposits are those associated with the glacial lacustrine and marine areas. The lacustrine areas are generally uniquely confined to the Eastern and Western Lakes Sections and are peculiar, like the occurrence of organic deposits, to the Cary and Younger Wisconsin drift areas. The marine deposits are likewise exclusively associated with the eastern sections of the Province; occurring within the St. Lawrence Lowland, Champlain Lowland and Hudson River Valley Sections.

In contrast, the older glacial drift sections (Central Till Plain and Dissected Loessial and Till Plains Sections) lack the highly plastic lacustrine areas, but generally afford a wider distribution of leaner clays attributable directly to the drift texture.

The most plastic till soils appear to be associated with the older (Illinoian and Kansan) drift. These drift sheets are generally found, respectively, within the Central Till Plains and Dissected Loessial and Till Plains Sections of the Province. Drift of a leaner variety comprises the remaining portion of the Central Till Plain Section (Tazewell and Older Wisconsin) and is also found in the western and southern portions of the Western Lakes and Lacustrine Section (Cary and Younger Wisconsin).

Like the wide variety of clay soils and origins common to the Central and Eastern Lowland Province, the Atlantic and Gulf Coastal Plain Province also exhibits this variability. In general, poor subgrade support regions from clayey soils are more pronounced in the Gulf portions rather than within the Atlantic coastal areas. The only potential regional area of clays found in the Embayed Section occurs within the Cretaceous Raritan Lowland Area. Heavy plastic clays are found throughout the Florida Section, generally in conjunction with limestones and marls common to the area. Within the East Gulf Coast Section highly plastic soils are normally associated with the Cretaceous chalks and limestones common to the inner (belted) coastal plain. Similar geologic and geomorphic occurrences of clayey soils are also found in the West Gulf Coast Section. In addition, large areas of marine clays form much of the outer coastal plain within the West Gulf Coast Section. The presence of the latter two types of poor subgrade areas, plus the clayey soils associated with much of the alluvium in the area constitute a very sizeable portion of the total area within this Section. The Mississippi Alluvial Plain Section, within the Coastal Province, constitutes one of the largest and homogeneous poor subgrade support areas in the United States. In general, most of the alluvium is very fine grained and affords highly plastic soil conditions.

A large portion of the concentration of poor subgrade support conditions in the eastern provinces is associated with the residual development of clayey soils. One of the more extensive zones of clayey type soils is that found within the Piedmont Section of the Old Appalachian Plateau Province. Lean to plastic clay soils are derived and widespread from a wide variety of granites, gneisses, schists and basic igneous rocks.

Residual soils, frequently of a highly plastic nature, are associated with limestone in many sections of the east. Extensive areas are found throughout much of the Springfield-Salem Plateau Section of the Ozark and Ouachita Province, Interior Low Plateau Province and Ridge and Valley Province. However, within many of these areas, the limestone is frequently quite cherty and residuum may frequently contain various percentages of these chert, or gravel, particles. Sandstones and shales frequently may also residually weather into poor subgrade support areas. One of the more pronounced examples of this condition occurs within the Kanawha Section of the Plateau Province. Within the Province lean clays are also associated with the glacial drift of the New York

Glaciated Section. In general, the plasticity of this drift texture appears to be greater in the western (Ohio) portion of the unit.

Highly plastic soils may also be associated with the sandstones and shales characteristic to the Triassic Lowland Province, Boston Mountain, Arkansas Valley and portions of the Ouachita Mountain Sections. Within the Great Plains Province, the overall residual character of the sandstone and shale sections appears to be of sandy silt variety; however, soils associated directly with the shales and clay shales are generally plastic. The major exception to this occurs within the Osage Plains Section of the Province. Within this unit much of the residual nature of the soil may be associated with highly plastic soil conditions. Within the glaciated portion of the Province, the overall drift character is of a clayey variety, increasing in plasticity characteristics to the west.

High Volume Change*

Design Factor Rating Summary

Table 36 summarizes the final adjusted frequency of occurrence rating for high volume change soils by section. Figure 44 illustrates the distribution of these ratings within the continental United States. Based upon the analysis, high volume change soils are existent, to some degree, within

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* The material in this portion of the report is primarily based on the work by Jensen (333).

Table 36

Summary of Estimated Frequency of Occurrence Rating

of High Volume Change Soils (Final Adjusted Rating) Within Sections

Non Existent		Non Existent to Limited		Limited to Medium		Medium to Widespread		Very Widespread	
Section Code	Area[1]	Section Code	Area	Section Code	Area	Section Code	Area	Section Code	Area
1a,b,c	42,430	--	--	1e	21,790	1d	38,540	--	--
2a,b,c	83,870	2d	6,800	--	--	--	--	--	--
3a,b	19,210	--	--	3c	23,100	--	--	--	--
4a,b,c,d,e	114,850	--	--	--	--	--	--	--	--
5c,e,f	50,410	5b,d	136,740	5a	175,540	--	--	--	--
--	--	--	--	6a,b,c,f	65,300	6d,e	58,620	--	--
7a,b,c	105,780	--	--	--	--	--	--	--	--
8a,b,c,d,e	45,340	--	--	--	--	--	--	--	--
9a,c	37,960	9b	22,490	--	--	--	--	--	--
10e,i	35,250	10a,f	206,300	10c,d,j,k,l	137,100	10h	13,710	10b,g,m	260,480
11a,b,c,d,e,f,g,i	294,280	11h	98,630	--	--	--	--	--	--
12a,b	72,540	--	--	--	--	--	--	--	--
13a,b,c1,c3	57,980	13c2	8,510	--	--	--	--	--	--
14a,b,c,d	51,380	--	--	--	--	--	--	--	--
15a,b,c,d,e	102,760	--	--	--	--	--	--	--	--
16a,b	45,340	--	--	--	--	--	--	--	--
17a	19,770	17b	70,900	--	--	--	--	--	--
18	6,040	--	--	--	--	--	--	--	--
19a,b,c,d,e,f,g	69,520	--	--	--	--	--	--	--	--
20a	33,850	20e	22,860	20b,c	88,010	--	--	20d,f,g	278,420
Total	1,278,040		573,130		510,840		110,870		538,900
Percent of Continental U.S.	42.8%		18.9%		16.8%		3.7%		17.8%

Note: 1. Areas given in square miles

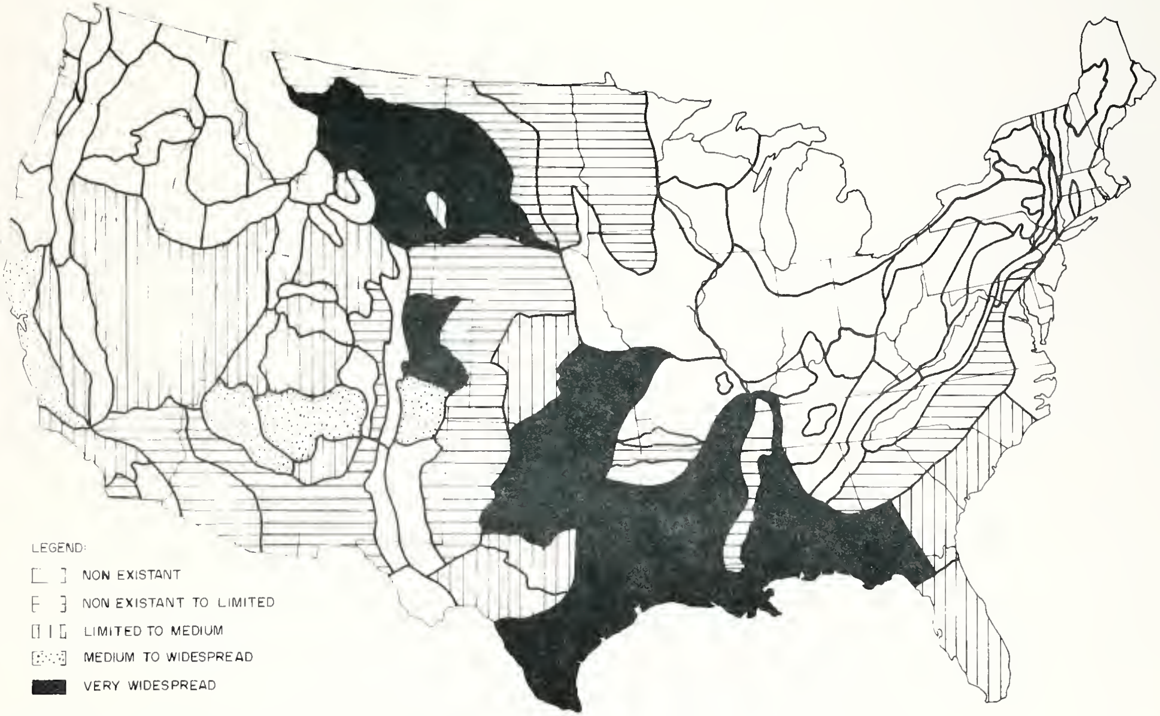


FIGURE 44 ESTIMATED FINAL ADJUSTED FREQUENCY OF OCCURRENCE RATING OF HIGH VOLUME CHANGE SOILS BY PHYSIOGRAPHIC UNIT

sections having a combined area percentage of over 57% of the United States. In addition, sections comprising 22% of the United States have been noted as having a frequency of occurrence rating more severe than limited to medium. In essence, the distribution of this problem and its subsequent importance upon proper highway design and performance is a problem in a sizeable portion of the country.

Distribution

General. Within the twenty (20) Physiographic provinces comprising the United States, high volume change soils have been noted to exist within half of them. The greatest frequency of occurrence of these high volume change soils occurs within the Great Plains and Atlantic and Gulf Coastal Plain Provinces. These Provinces constitute the western and southern areas of the eastern Province grouping. The discussion which follows is grouped according to the generalized east-west province groupings to afford a maxium insight into the distribution of this problem.

Western Province Group. Although seven of the nine provinces comprising the western group were noted to possess high volume change soils, the frequency of occurrence in a large portion of these units is, by no means, widespread.

Within the Southern Rocky Mountain Province, Jensen (222) notes the existence of small scattered areas within the San Luis Valley portion of the Western Section. These areas were mapped on a Pedologic basis and correspond to the Lahontan series which is associated predominantly with identical geomorphic units found in the Closed Basin Section but locally occur within the Sonoran Desert and Open Basin Sections.

The high volume change areas noted within the Pacific coast Range Province are associated primarily with the clayey soils developed residually from the sandstones and shales within the area. The most frequent occurrence of these soils is contained within the California Coast Range Section where these rocks are the modal bedrock to the unit. These same soils however, are continuous along much of the California coast line to Mexico. As a consequence, they are noted to exist within the Los Angeles and Lower California Sections proper; however, they are not considered as the modal bedrock of either of these predominantly granitic units.

Within the Pacific Troughs Province, the California Valley Section, with its associated clayey valley deposits, was noted on the basis of both a geologic and pedologic analysis to exhibit volume change areas. The areas mapped within the Colorado Plateau Province are generally associated with the presence of Cretaceous sandstones and shales and clay shales found throughout the Province. The Medium to Widespread rating within the Grand Canyon Section may not represent the correct potential rating. The area mapped in question is the Valera series, associated with residual limestones. Based upon the basic map reference used by Jensen in the pedologic mapping phase, the Valera series occurs primarily within the Edwards Plateau unit of Texas as well as in the Grand Canyon Section of Arizona. However, based upon work done by the author concerning soil textural distribution within the United States, the residual soil from the limestone in the Grand Canyon Section is silty in nature, in contrast to the clayey residuum noted within the Edwards Plateau limestone.

Eastern Province Group. Within the eastern portion of the United States, four of eleven provinces were noted to possess areas showing high volume change characteristics. Of these four provinces, two are felt to be of rather insignificant magnitude in defining the scope of the high volume change problem. Within the Central and Eastern Lowland Province, the only area noted by Jensen occurred in association with the water deposited clays within old glacial lake Agassiz (Red River Lowland). This occurs within the Western Lakes and Lacustrine Section of the Province and is the only reason for noting this area as a Non Existent to Limited frequency. The rocks within the Piedmont (Iredell soil series). These units were mapped only up to South Carolina by Jensen. The occurrence of this material is generally minor in comparison to the granites, gneiss and schists of the Piedmont Plateau Section; however, it is an important clay soil as it is of the montmorillonite variety.

The two provinces possessing the greatest occurrence of high volume change soils within the entire United States are the Great Plains and Atlantic and Gulf Coastal Plain.

Within the latter the greatest concentration of these soils are associated with the Gulf portion (including Florida Section) of the Province. The major soils associated with potential high volume change within the Florida Section are associated with the plastic clays from the Ocalla and similar limestones of the unit. Within both the East and West Gulf Coast Sections, clayey soils are associated with Cretaceous deposits forming the lowland belts (Selma chalk, Austin chalk and Taylor Marl). In addition, lowlands formed by the Eocene (Tertiary) Jackson formation possess similar high volume tendencies within the East Gulf. The West Gulf Coast Section also has clayey marine deposits along much of its coastline which exhibit this characteristic. The Mississippi Alluvial Plain Section, with its fine textured alluvium, also possesses a very widespread distribution pattern of these potential volume change soils. The non existent to limited rating of the Mississippi Loessial Upland is due solely to the presence of similar type alluvium present in the Section and not the loessial deposits, which form the modal parent material of the unit.

The sections noted to possess the most severest rating of frequency within the Great Plains Province are the Osage Plains, Colorado Piedmont and Unglaciated Missouri Plateau. The parent material with the latter two Sections are characterized strongly by the presence of Tertiary and Cretaceous sandstones, shales and clay shales, not too dissimilar to the high volume change areas associated with much of the Colorado Plateau Province. The most frequent potential soil showing high volume change characteristics in the Osage Plains is the Permian sandstones and shales of the unit. The reason for the non-existent to limited rating associated with the High Plains Section is similar to that explained for the Mississippi Loessial Upland Section. The potential high volume change areas in the High Plains Section are associated with geologic formations common to the Plains Border Section. This unit occurs as an interfingering occurrence across the indefinite border area which separates the two Sections. Hence the rating of the Section is attributable to a variant material rather than the modal Tertiary outwash of the area.

General Geologic-Origin/Parent Material Inferences

As can be noted from Table 18, the summary of geologic formations noted to exhibit high volume change conditions within the United States are primarily associated with geologic youthfulness. Cenozoic and Mesozoic Eras are the most frequent occuring while Permian (late Paleozoic) also exhibits soils of a high volume change nature. However, the reader should not be misled that older geologic formations do not possess the potential for high volume change. The important point to be made is that within the western portion of the United States, most of the older geologic formations are associated with the mountainous topography of the area, generally not conductive to the development of residual clayey soils. Within the eastern United States, it has been previously stated in the discussion of poor subgrade support (clayey) areas that, many regional clay soil areas residually developed from older Paleozoic and even Pre Cambrian formations exist. However, as noted in the general discussion of the influence of the climatic variable upon regional high volume change conditions in the next section, the humid climatic environment found in the location of these soil areas is generally not conducive to the development of high volume change occurrences on a regional level of examination.

From Table 20, it can be noted that a wide variety of origin-parent materials are noted to be of potential high volume soils. An obvious and notable origin not present is that of an aeolian (loessial) nature. The mechanics of aeolian transport generally restrict the occurrence of cohesive or plastic clays within aeolian deposits. Loessial soils are <u>generally</u> uniquely non potential high volume change soils even within very favorable climatic environments to the shrink-swell condition.

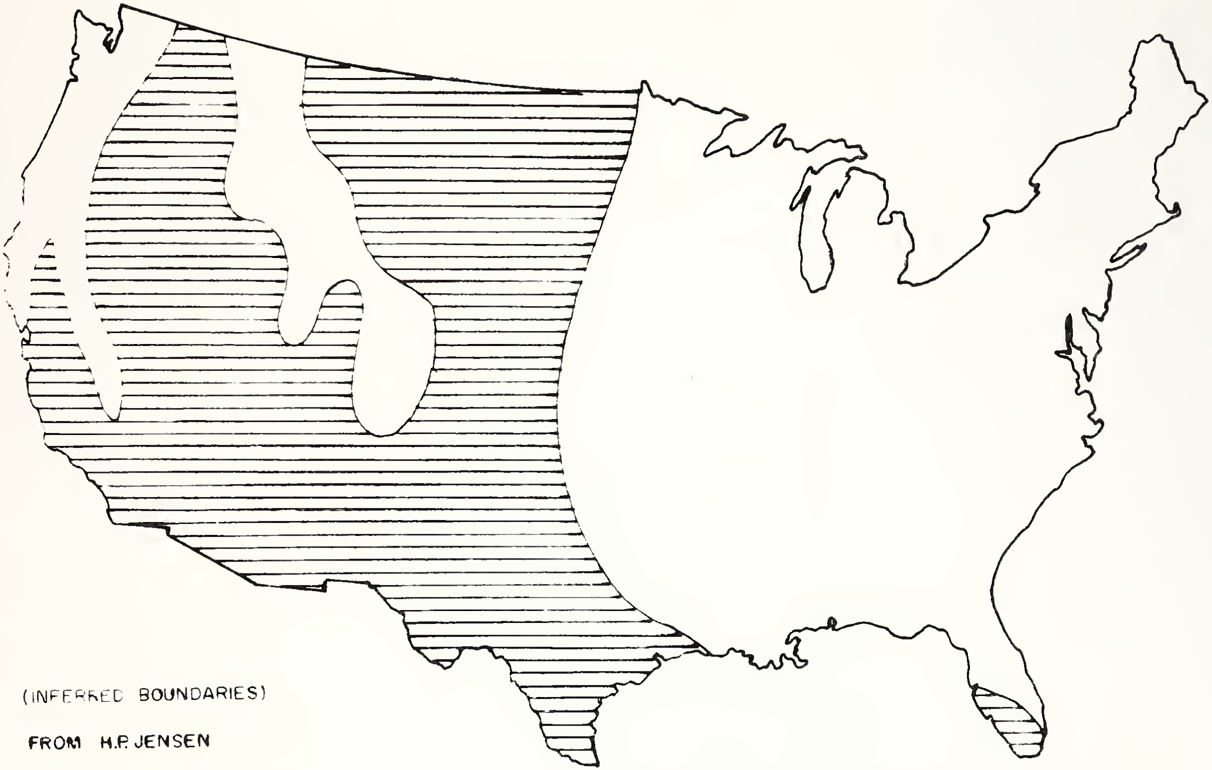
Importance of Climate Upon the Regional Distribution of High Volume Change

The high volume change problem encountered in portions of the country is a phenomena due to the complex interrelationship between a potentially high volume change soil and a variation in the soil-water equilibrium. It is important to recall that the analysis of the high volume problem conducted by Jensen from an engineering case study viewpoint, in essence, reflects the complex combination of both the soil and water-balance factors. As all clayey type soils have a potential for swell, and it has been noted that large areas of clayey soils are found east of the generalized limit of specific high volume change locations noted by Figure 22; the effect of climatic conditions plays a dominate role in the high volume change phenomena.

The ability to collectively determine a single climatic parameter and its distribution in the United States, which takes into account all the inherent factors of the soil-water balance picture, has not been undertaken for the United States. However, some attempt has been made for the eastern United States (375). Jensen has noted that the utilization of combining major variables which measure the major incoming phase (average annual precipitation) and the major outgoing phase (average annual potential evapotranspiration) of the water balance provides a fairly good, but general, indicator of the average water balance for the year.

Figure 45 shows the areas where average annual precipitation is less than the average annual potential evapotranspiration. The major implication of the areas noted within the diagram is that a fairly good probability exists that the soil may be dried out sometimes during the year and hence provide a triggering mechanism for high volume change occurrence.

As can be seen from a generalized comparison between



(INFERRED BOUNDARIES)

FROM H.P. JENSEN

FIG. 45 AREAS WHERE AVERAGE ANNUAL PRECIPITATION IS LESS THAN AVERAGE ANNUAL EVAPOTRANSPIRATION

Figure 22 and 45, a good agreement between most of the case study locations and the area noted in Figure 45 seem to exist. The major area not noted within Figure 45, where the case study indicates a high volume change occurrence has taken place, is found in the eastern gulf coast regions. Jensen, however, has noted that within much of this area a marked summer deficit in the water balance has been reported in the literature (375).

Frost and Frost Susceptible Soils

Distribution

General. The frequency of occurrence rating for each category of frost susceptible soil within a section has been noted in Table 24 of the Results portion of this report. Table 37 summarizes the results by type of frost susceptible soil relative to the frequency rating and section of occurrence. Table 38 summarizes the largest frequency rating and subsequent frost susceptible soil type for each section. Reference to these tables is made within the ensuing discussions.

In general, the western province grouping is characterized, quite extensively, by either non frost susceptible areas (bedrock) or by F4 soils. The eastern province groupings consist of a somewhat equitable distribution of both F3 and F4 soils. These facts are generally apparent from Tables 37 and 38.

These generalized statements are consistent with the discussion previously provided for poor subgrade support

Table 37

Summary of Section Frequency of Occurrence Rating by Frost Susceptible Soil Type

F4 Soils

Province/ Section Code	Frequency of Occurrence Rating				
	NE	N-L	L-M	M-W	VW
2	a,b	-	c	-	-
4	-	-	b	a,e	c,d
5	-	-	a	-	-
6	-	-	a,b,f	c,d,e	-
7	b,c	-	a	-	-
8	a,d	b,c,e	-	-	-
9	a,c	-	b	-	-
10	e	j	c,d	b,f,g,h	a
11	b	-	a,c,e-h	d,i	-
12	b	-	a	-	-
13	a,b	-	-	-	-
15	-	-	-	b-d	a
16	-	-	a	-	-
18	-	-	-	18	-
19	g	a,d,e	b,c,f	-	-

F3 Soils

Province/ Section Code	Frequency of Occurrence Rating				
	NE	N-L	L-M	M-W	VW
2	a,c	b	-	-	-
4	c,e	a,b,d	-	-	-
5	-	-	a	-	-
6	e	c,d	a,b,f	-	-
7	a,c	b	-	-	-
8	a-c,e	-	-	d	-
9	a-c	-	-	-	-
10	c,f-h	a	b,e	d	j
11	d	-	a,c,e-h	b,i	-
12	-	-	a	-	b
13	-	-	-	-	a,b
15	a,c	-	-	b,d	
16	-	-	a		
18	-	18	-	-	
19	c,e,f	-	a,d,g	b	

F2 Soils

Province/ Section Code	Frequency of Occurrence Rating				
	NE	N-L	L-M	M-W	VW
2	a-c	-	-	-	-
4	b,c,e	d	a	-	-
5	-	a	-	-	-
6	a,b,d-f	c	-	-	-
7	a,c	b	-	-	-
8	a-e	-	-	-	-
9	a-c	-	-	-	-
10	b-e,h,j	a	f,g	-	-
11	a-d,f,i	h	e,g	-	-
12	b	a	-	-	-
13	a,b	-	-	-	-
15	a-d	-	-	-	-
16	a	-	-	-	-
18	18	-	-	-	-
19	c,e-g	a,b,d	-	-	-

F1 Soils

Province/ Section Code	Frequency of Occurrence Rating				
	NE	N-L	L-M	M-W	VW
2	a-c	-	-	-	-
4	a-d	-	e	-	-
5	-	a	-	-	-
6	a,d-f	b,c	-	-	-
7	a-c	-	-	-	-
8	a-e	-	-	-	-
9	c	a,b	-	-	-
10	a,b,d-g,j	h	c	-	-
11	b,e-i	a,c,d	-	-	-
12	a,b	-	-	-	-
13	a,b	-	-	-	-
15	a,c,d	b	-	-	-
16	a	-	-	-	-
18	-	18	-	-	-
19	b,e-g	a,d	c	-	-

NFS Soils (Includes Bedrock)

Province/ Section Code	Frequency of Occurrence Rating				
	NE	N-L	L-M	M-W	VW
2	-	-	-	-	a,b,c
4	e	a,c,d	-	-	b
5	-	-	-	a	-
6	-	a,d-f	b,c	-	-
7	-	-	-	a,b	c
8	-	-	d	-	a-c,e
9	-	-	-	b	a,c
10	a,f,j	b,d,g,h	c	e	-
11	c,d,f,g,i	a,b,e,h	-	-	-
12	b	a	-	-	-
13	a,b	-	-	-	-
15	a	b,d	c	-	-
16	-	-	a	-	-
18	-	18	-	-	-
19	a	b,c	f	d,e,g	-

Legend: NE: Non Existent
N-L: Non Existent to Limited
L-M: Limited to Medium
M-W: Medium to Widespread
VW: Very Widespread

Table 38

Summary of Highest Frequency of Occurrence Rating of Frost Susceptible Soil Category By Section

Section Code	Frequency	Soil Type
2a	VW	NFS
2b	VW	NFS
2c	VW	NFS
4a	M-W	F4
4b	VW	NFS
4c	VW	F4
4d	VW	F4
4e	M-W	F4
5a	M-W	NFS
6a	L-M	F3,F4
6b	L-M	F3,F4,NFS
6c	M-W	F4
6d	M-W	F4
6e	M-W	F4
6f	L-M	F3,F4
7a	M-W	NFS
7b	M-W	NFS
7c	VW	NFS
8a	VW	NFS
8b	VW	NFS
8c	VW	NFS
8d	M-W	F3
8e	VW	NFS
9a	VW	NFS
9b	M-W	NFS
9c	VW	NFS
10a	VW	F4
10b	M-W	F4
10c	L-M	F1,F4,NFS
10d	M-W	F3
10e	M-W	NFS
10f	M-W	F4
10g	M-W	F4
10h	M-W	F4
10j	VW	F3
11a	L-M	F3,F4
11b	M-W	F3
11c	L-M	F3,F4
11d	M-W	F4
11e	L-M	F2,F3,F4
11f	L-M	F3,F4
11g	L-M	F2,F3,F4
11h	L-M	F3,F4
11i	M-W	F3,F4
12a	L-M	F3,F4
12b	VW	F3
13a	VW	F3
13b	VW	F3
15a	VW	F4
15b	M-W	F3,F4
15c	M-W	F4
15d	M-W	F3,F4
16a	L-M	F3,F4,NFS
18	M-W	F4
19a	L-M	F3
19b	M-W	F3
19c	L-M	F1,F4
19d	M-W	NFS
19e	M-W	NFS
19f	L-M	F4,NFS
19g	M-W	NFS

Legend: Frequency Rating

L-M: Limited to Medium
M-W: Medium to Widespread
VW: Very Widespread

Soil Type Rating

NFS: Non Frost Susceptible Soil
F1 to F4: Corps of Engineers Frost Susceptible Soil Category

soils (clayey). In this discussion it was noted that the lack of clayey soils was notable in the western province group, while rather adequately distributed throughout much of the eastern province grouping. In addition to this fact, it should also be pointed out that several physiographic units possessing clayey type soils were not considered to be within the defined freezing area (eg...Piedmont Plateau Section, Tennessee Section, Interior Low Plateau Province, and Osage Plains Section). Hence, the rather relative lack of F3 soils in the east contrasted to the presence of clayey soils is due to the subsequent exclusion of many potential F3 soil areas from the freezing zone.

Western Province Group. Within the mountainous portions of the west, the relative lack of substantial soil cover, is responsible for the very widespread pattern of non frost susceptible areas noted for much of the Sierra-Cascade and Rocky Mountain provinces. A similar occurrence is also noted within the Blue Mountain Section of the Columbia Plateau. This unit contrasts rather strongly from neighboring sections. Within these adjacent units, the widespread distribution of silty loessial deposits and sandy to silty residual soil, produce major occurrences of F4 soils. A somewhat similar occurrence of frost susceptible soils is also found within much of the Colorado Plateau Province from the residual sandy to silty soils developed from the sandstones and shales. The major difference between this Province and the Columbia Plateau Province, is the greater frequency of occurrence of

F3 materials attributable directly to the presence of shales and clay shales. The most notable and rather obvious feature of the distribution and occurrence of frost susceptible soils in the Great (Closed) Basin Section is the very large variability by type. This variation in rating reflects the presence of bedrock (ranges) as well as the gradational texture of the basin fill.

Eastern Province Group. The predominating frost susceptible soil type over much of the Great Plains Province is F4 due to the general widespread distribution of sandy silt residual soils from the sandstones and shales, Tertiary outwash deposits in much of the High Plains as well as widespread loessial deposits over much of the central portion. Much of the F3 soils in the area, are attributable to the shales and clay shales found in almost all the sections. The largest distribution of F2 regional frost soils in the United States is found within the Nebraska Sand Hill portion of the High Plains Section.

Within the Sections characterized primarily by residual soil development, much of the F3 soils found in the Triassic Lowland, Ozark and Ouachita and Ridge and Valley Provinces are a result of the plastic residual soils developed from limestones within these areas. Soils associated with an F4 rating in these units appear to be from sandstones and shales. They are found within portions of the Ridge and Valley, Triassic Lowland and Appalachian Plateau Provinces.

The New York Glaciated Section of the latter Province has a F4 rating associated with soils in the eastern portion of the Section while in the western portion, the predominant rating is an F3. This rating is in general agreement with the soil texture descriptions previously provided for this unit.

The glaciated sections found within the freezing zone are generally complex in the distributive characteristics of frost susceptible soil type. Within the New England Maritime Province, the mountainous sections generally possess a combined non frost susceptibility rating as the major type and F4 types as the minor variety. F3 soils are generally restricted to the northern parts of the Seaboard Lowland and the New England Upland Sections. A fairly significant portion of the Connecticut Lowland Section has been categorized as F2 soils. The two glaciated sections of the Laurentian Upland Province show a marked contrast in variability of frost susceptible soil type. Within the Adirondack Section the uniform and widespread occurrence of F3 soils is in strong contrast to the non frost susceptible, F2, F3 and F4 areas common to the Superior Upland Section.

Within the Central and Eastern Lowland Province, the most common frost susceptible soil types are F3 and F4. The distribution of the F4 soils is strongly related to the presence of loessial deposits found in the Driftless, Central Till Plains, and Dissected Loessial and Till Plains Sections of the Province. In addition, F4 type drift is found in the western portion of the Western Lakes Section and in much of the valleys and lowlands of the Eastern Lowland portion of the Province. The distribution of F3 soils is strongly related to the plastic drift found in the eastern portion of the Western Lakes, Dissected Loessial and Till Plains and Central Till Plains Sections of the Province. Distribution of these soil ratings also are associated with the marine deposits of the St. Lawrence and Champlain Lowland Sections. The most extensive deposits of F2 type soils are found in the Central Sand Plain area of the Driftess Sections and within the northern drift areas of the Eastern Lakes and Lacustrine Plains Section.

Composite Factor of Design Summary Rating by Section

Table 39 shows a summary of the ratings for each factor of design considered in this report for each physiographic section in the continental United States. The data in Table 39 form the basis of discussion in subsequent paragraphs relative to the recommended design units within the United States. The ratings given in the Table are those previously presented for each factor.

Limitations Associated With Using Physiographic Units as Unique Highway Engineering Factor of Design Units

General

The major purpose of this research has been to evaluate selected highway factors of design on the basis of regional physiography. The results concerning the factors of design have been described in the form of a severity

Table 39

Composite Factor of Design Summary

Rating by Physiographic Section

Physiographic Unit	Aggregates	Soils and Related Factors								
Section Code	Aggregate Availability	Poor Subgrade Support		High Volume Change Soils	Frost Susceptible Soils					
		Inorganic	Organic		RSFF	NFS	F1	F2	F3	F4
(col 1)	(col 2)	(col 3)	(col 4)	(col 5)	(col 6)	(col 7)	(col 8)	(col 9)	(col 10)	(col 11)
1a	A-L	N-L	N-L	NE	X					
b	L-P	N-L	N-L	NE	X					
c	A-L	NE	NE	NE	X					
d	L-P	L-M	N-L	M-W	X					
e	A-A	N-L	NE	L-M	X					
2a	A-L	NE	NE	NE		VW	NE	NE	NE	NE
b	A-A	N-L	NE	NE		VW	NE	NE	N-L	NE
c	A-A	N-L	NE	NE		VW	NE	NE	NE	L-M
d	A-A	NE	NE	N-L	X					
3a	A-A	N-L	N-L	NE	X					
b	A-A	L-M	NE	NE	X					
c	A-A	M-W	N-L	L-M	X					
4a	A-A	NE	NE	NE		N-L	NE	L-M	N-L	M-W
b	A-A	NE	NE	NE		VW	NE	NE	N-L	L-M
c	L-P	NE	NE	NE		N-L	NE	NE	NE	VW
d	A-L	N-L	NE	NE		N-L	NE	N-L	N-L	VW
e	L-P	NE	N-L	NE		NE	L-M	NE	NE	M-W
5a	A-A	L-M	NE	L-M		M-W	N-L	N-L	L-M	L-M
b	A-A	N-L	NE	N-L	X					
c	L-P	M-W	NE	NE	X					
d	A-A	N-L	NE	N-L	X					
e	A-A	N-L	NE	NE	X					
f	A-A	N-L	NE	NE	X					
6a	A-L	N-L	NE	L-M		N-L	NE	NE	L-M	L-M
b	L-P	N-L	NE	L-M		L-M	N-L	NE	L-M	L-M
c	L-P	N-L	NE	L-M		L-M	N-L	N-L	N-L	M-W
d	L-P	N-L	NE	M-W		N-L	NE	NE	N-L	M-W
e	A-L	N-L	NE	M-W		N-L	NE	NE	NE	M-W
f	A-A	L-M	NE	L-M		N-L	NE	NE	L-M	L-M
7a	A-A	N-L	NE	NE		M-W	NE	NE	NE	L-M
b	A-L	NE	NE	NE		M-W	NE	N-L	N-L	NE
c	L-P	NE	NE	NE		VW	NE	NE	NE	NE
8a	A-L	NE	NE	NE		VW	NE	NE	NE	NE
b	A-A	NE	NE	NE		VW	NE	NE	NE	N-L
c	A-A	NE	NE	NE		VW	NE	NE	NE	N-L
d	A-L	N-L	N-L	NE		L-M	NE	NE	M-W	NE
e	A-A	NE	NE	NE		VW	NE	NE	NE	N-L
9a	A-A	NE	NE	NE		VW	N-L	NE	NE	NE
b	A-A	NE	NE	N-L		M-W	N-L	NE	NE	L-M
c	A-A	NE	NE	NE		VW	NE	NE	NE	NE
10a	L-P	L-M	NE	N-L		NE	NE	N-L	N-L	VW
b	SP	M-W	NE	VW		N-L	NE	NE	L-M	M-W
c	A-A	N-L	NE	L-M		L-M	L-M	NE	NE	L-M
d	L-P	N-L	NE	L-M		N-L	NE	NE	M-W	L-M
e	A-A	N-L	NE	NE		M-W	NE	NE	L-M	NE
f	L-P	N-L	NE	N-L		NE	NE	L-M	NE	M-W
g	L-P	L-M	NE	VW		N-L	NE	L-M	NE	M-W
h	A-L	L-M	NE	M-W		N-L	N-L	NE	NE	M-W
i	L-P	N-L	NE	NE	X					
j	L-P	N-L	NE	L-M		NE	NE	NE	VW	N-L
k	A-A	N-L	NE	L-M	X					
l	A-A	L-M	NE	L-M	X					
m	A-L	M-W	NE	VW	X					
11a	A-A	M-W	L-M	NE		N-L	N-L	NE	L-M	L-M
b	A-A	M-W	N-L	NE		N-L	NE	NE	M-W	NE
c	A-A	M-W	N-L	NE		NE	N-L	NE	L-M	L-M
d	A-A	L-M	N-L	NE		NE	N-L	NE	NE	M-W
e	A-L	L-M	M-W	NE		N-L	NE	L-M	L-M	L-M
f	A-L	M-W	N-L	NE		NE	NE	NE	L-M	L-M
g	L-P	N-L	N-L	NE		NE	NE	L-M	L-M	L-M
h	L-P	N-L	L-M	N-L		N-L	NE	N-L	L-M	L-M
i	A-L	M-W	NE	NE		NE	NE	NE	M-W	M-W

Note: See second page of Table for legend

Table 39 (cont'd.)

(col 1)	(col 2)	(col 3)	(col 4)	(col 5)	(col 6)	(col 7)	(col 8)	(col 9)	(col 10)	(col 11)
12a	A-A	N-L	L-M	NE		N-L	NE	N-L	L-M	L-M
b	A-A	NE	L-M	NE		NE	NE	NE	VW	NE
13a	A-A	N-L	NE	NE		NE	NE	NE	VW	NE
b	A-L	L-M	NE	NE		NE	NE	NE	VW	NE
c1	L-P	L-M	NE	NE	X					
c2	L-P	N-L	NE	N-L	X					
c3	A-L	L-M	NE	NE	X					
14a	A-A	VW	NE	NE	X					
b	A-A	VW	NE	NE	X					
c	L-P	L-M	NE	NE	X					
d	A-A	M-W	NE	NE	X					
15a	A-L	N-L	NE	NE		NE	NE	NE	NE	VW
b	A-L	L-M	N-L	NE		N-L	N-L	NE	M-W	M-W
c	A-L	L-M	NE	NE		L-M	NE	NE	NE	M-W
d	L-P	M-W	NE	NE		N-L	NE	NE	M-W	M-W
e	A-L	N-L	NE	NE	X					
16a	A-A	L-M	NE	NE		L-M	NE	NE	L-M	L-M
b	A-A	L-M	NE	NE	X					
17a	A-A	NE	NE	NE	X					
b	A-A	M-W	NE	N-L	X					
18	A-A	M-W	N-L	NE		N-L	N-L	NE	N-L	M-W
19a	A-L	M-W	L-M	NE		NE	N-L	N-L	L-M	N-L
b	A-A	N-L	N-L	NE		N-L	NE	N-L	M-W	L-M
c	A-A	NE	N-L	NE		N-L	L-M	NE	NE	L-M
d	A-L	NE	N-L	NE		M-W	N-L	N-L	L-M	N-L
e	A-A	NE	NE	NE		M-W	NE	NE	NE	N-L
f	A-A	N-L	NE	NE		L-M	NE	NE	NE	L-M
g	A-A	NE	NE	NE		M-W	NE	NE	L-M	NE
20a	A-L	N-L	L-M	NE	X					
b	A-L	N-L	L-M	L-M	X					
c	L-P	L-M	M-W	L-M	X					
d	A-L	L-M	N-L	VW	X					
e	L-P	N-L	NE	N-L	X					
f	SP	VW	N-L	VW	X					
g	A-L	M-W	N-L	VW	X					

Legend:

Aggregate Factor

A-A: Abundant to Adequate
A-L: Adequate to Limited
L-P: Limited to Problem
SP: Severe Problem

Soil Factors

NE: Non Existent
N-L: Non Existent to Limited
L-M: Limited to Medium
M-W: Medium to Widespread
VW: Very Widespread

Special Frost Susceptible Soils Column Legend

RSFF: Relatively Safe From Freezing
NFS: Non Frost Susceptible Unit
F-1 to F-4: Corps of Engineer's Frost Susceptible Soil Category

and/or frequency of occurrence rating for each of the 97 initial report physiographic sections.

Major emphasis has been concentrated on the ratings established, their distribution, occurrence and any general physiographic and geologic implications developed. However, in so doing, it is acknowledged that within the idealized analysis of assigning a rating to each physiographic section, two important assumptions have been made. The first of these is that the physiographic unit is the optimum unit for cataloging highway engineering problems, performance and subsequently factors of design. The second concept, assumes that the initial physiographic unit classification system utilized is the optimum classification system for highway engineering purposes.

At the level of generalization in which this investigation has been effected the ability to make a precise and detailed summary of every pertinent highway characteristic existing within each physiographic section examined is beyond the scope of the report. The major reasons for this are due to the variable input information regarding geologic, geomorphic and highway engineering facts for the United States as a whole. In addition, it is readily acknowledged that many of the sections examined exhibit a variability in physiographic units which can be subdivided into smaller and more homogeneous units. As a consequence, examples which summarize where physiographic information can be readily tied into the concepts demonstrating the utility of physiographic units for highway engineering purposes are presented in the following paragraphs.

Idealized Concepts of Regionalization

Regionalization Scheme

If one were to consider a highly idealized system for regionalization of a particular factor within a given areal unit, there would be three cogent considerations which should be noted for the regionalization. The first, and perhaps most salient, involves the uniqueness of the areal unit chosen to effect the regionalization; for, it should be readily noted that a generalization or statement of the average condition of any factor can be made within any type of areal unit. This consideration, therefore, reduces to, given a choice of areal unit types, which unit affords the greatest uniqueness or provides the optimum unit for making the generalization. The obvious difficulty in proving the existence of such an optimal unit is apparent. Because of the relative importance of this feature to the overall project, this consideration is discussed in some detail in subsequent paragraphs.

The second point to be considered involves only the factor being investigated. The question of effecting a true or conditional regionalization is answered by examining each pertinent variable affecting the factor in question to determine whether or not each is conducive to regionalization within a given areal unit as well as if all variables are to be considered in the analysis. If a variable does not lend itself to regionalization or is not considered in the analysis, then the type of regionalization effected is conditional in nature. If every variable within the analysis can and is evaluated than the type of generalization is considered a true regionalization.

The final condition to be considered concerns the relative homogeneity of the factor within the areal unit. This is accomplished by examining the distribution of each variable considered in the analysis relative to its homogeneity within the areal unit. It should be noted that complete homogeneity of a factor does not necessarily imply a unique relationship. Similarly, a non homogeneous factor may not necessarily imply a non unique relationship.

It should be apparent that within this idealized scheme there exist several unique types of regionalization combinations which may be obtained for a particular factor. The most ideal combination is a generalization that is unique, true and homogeneous within a given areal unit. In essence this rating would be a precise measure of particular factor which is uniform or constant throughout an areal unit which represents the most unique unit for the generalization to be obtained. The worst type of generalization that may be effected is the non-unique, conditional and non-homogeneous rating.

Basic Concepts of Regionalization Within Physiographic Units

Since physiographic units have been formed, on an ideal basis, from uniqueness of topographic expression, the validity of regionalization within physiographic units seemingly reduces to the relationship of highway factors of design to topographic expression. This may be intuitively derived by the fact that physiographic units are described in terms of a unique topographic expression by non genetic descriptors of altitude, relief and type of landform present.

However one of the most important aspects to be understood by the reader is that the more fundamental questions asks, "What is the relationship between the geomorphic control factors and the design and construction factors considered". It is important to recognize that, in the main, it is a unique combination of a particular type or repetitive types of parent material, its arrangement, the process which act on it to modify, the length of time in which the processes have acted and the historical climatic environment which sculptures the landform or landforms within the physiographic unit.

Each of the factors considered in this report have as a primary variable, either uniquely or in combination with other variables, the element of material type. This is to say, that for each of the factors considered, engineering experience can be directly related in total, or part, to the material type. As a consequence, the basic concept in applying physiographic units to engineering experiences is to formulate an experience with a material condition at a micro level (eg...engineering site or project) and subsequently define the regional extent or macro area of this experience via the application of homogeneous topography, or regional physiographic units.

In the majority of sections considered, the application of this concept is a valid approach to the analysis. However, it has been previously noted within the summary portion of this report dealing with Physiography and Regional Physiographic Units that important exceptions occur within sections and their uniqueness to parent material types. In this summary it has been noted that it is possible for similar material types to be existent with adjacent sections as well as having differing material types within a unique topographic unit.

The implication of the former exception does not provide any gross limitations to the concept of regionalization discussed. In essence; for these units, the major implication is that the chances of having identical generalizations for the adjacent sections is quite high. The immediate implications of the latter exception are, by far, the most important is posing limitations to the concepts noted. In essence, within a uniform topographic unit composed of differing parent material and geologic conditions, the basic concept is not applicable because the generalizations effected on a micro level are <u>not</u> valid for the macro or regional topographic unit.

Utility of Physiographic Units to Factors of Design

Aggregates

Crushed Stone

The results of this study, have suggested that the greatest utility of physiographic units concerning aggregates and their distribution lies in the ability to make effective or unique generalizations concerning the potential of crushed stone areas within the United States. However, not all physiographic sections within the United States afford this uniqueness.

Physiographic sections, showing a non uniqueness to delineating crushed stone areas, are generally characterized by topography formed from transported material but having underlying bedrock at such a depth that the potential of the bedrock as crushed stone sources can still be effectively generalized. For the remaining sections, the uniqueness or utility of formulating generalizations concerning crushed stone sources may generally be considered as good. From an overall viewpoint, sections whose modal characteristics are based upon gross bedrock features, regardless of the presence (either total or partial) or absence of any surficial transported deposits afford cases where unique generalizations can be made. In addition sections having very thick deposits of transported soils are obviously unique for generalizations concerning the distribution of crushed stone areas in the respect that the potential of such sections is uniquely non-existent.

An excellent example of physiographic sections that possess non-unique attributes for the generalization of crushed stone sources is found in the central lowland portion of the Central and Eastern Lowland Province.[1] Within this area lie a large number of the major carbonate producing states in the United States. As the modal characteristics of the Sections comprising this area are based upon differences in glacial terrains, or lack thereof, absolutely no uniqueness of carbonate stone areas can be effectively made within the physiographic units. This is to say that the physiographic sections noted do not afford the optimum unit in these areas for cataloging crushed stone potential.

If one, however, were to follow the underlying bedrock strata from the glaciated Lowland Province to the Interior Low Plateau Province (non transported origin), the utility or uniqueness of using physiographic units becomes rather apparent. Within this Province, regional carbonate zones are found in the Nashville Basin Section, and portions of the remaining sections. Other sections, characterized by non transported origin, where potential carbonate zones occur are found to characterize the Springfield-Salem Plateau Section of the Ozark and Ouachita Province, and the limestone valleys of the entire Ridge and Valley Province.

To further illustrate the utility of filing crushed stone aggregate information within physiographic units; there

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[1] The central portion of the Province is comprised of Sections 11e, f, g, h, i.

exists within the eastern portion of the United States several small, variant, but well defined physiographic units in which the potential for crushed carbonate stone is considered to be good. The physiography of these areas are all similar in the respect that old Paleozoic strata are found within the variant valley units. These areas are the Sequatchie-Wills Creek Valleys of the Cumberland Plateau Section, the Frederick, Conestoga (Lancaster) and Chester Valleys of the Triassic Lowland Province and the Limestone Valley of Vermont of the Taconic Section.[1] It should also be noted that further delineation of units within the Interior Low Plateau Province greatly increases the uniqueness of the crushed carbonate zones found in the area.

Other types of unique potential crushed stone area examples can be found within many of the sections within the United States. Granitic/metamorphic crushed stone areas are uniquely associated with the Black Hills Section or St. Francis Mountain Section while the crushed basalts of the Columbia Plateau and the traprock of the Triassic Lowland Province and Connecticut Lowland Section are examples of sections where other potential igneous crushed zones are distributed.

Sections may also be uniquely categorized as having poor or non existent capabilities for potential crushed

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1. The distribution of the units is shown within the recommended physiographic-highway engineering units introduced in the next portion of this report. They correspond to unit numbers 192, 207, 208, and 214.

stone. Sections such as the Kanawha, Cumberland Plateau, California and Oregon Coast Ranges, and many sections of the Colorado Plateau and Great Plains Province are examples of this. In general the bedrock characteristics within these units are unfavorable for good performance as highway aggregates. Other sections, such as the California Valley, High Plains and most of the Sections of the Atlantic and Gulf Coastal Plains Province, possess a non existent potential due to the widespread presence of relatively thick transported sediments.

Sand Gravel

In discussing the overall utility of cataloging engineering factors relative to sand gravel sources within physiographic units, it is convenient to subdivide this major type source into categories that possess deposits of areal (regional) occurrence and those which are primarily associated with alluvial origin and subsequently possess a more lineal type of distribution.

Within the regional sand gravel categories, the utility of using physiographic units to uniquely note pertinent factors concerning these deposits is considered variable, but generally good. Table 40 summarizes the appraisal of sections where the utility of noting fairly unique sand gravel characteristics are somewhat peculiar to the section. The origins of these regional sand gravel occurrences are generally associated with widely distributed patterns of stratified drift, valley (includes glacial sluiceways) and

Table 40

Summary of Sections Where Uniqueness of Regional Sand Gravel Distribution and Occurrence is Generally Good

Section/Code	Remarks
Eastern Lakes and Lacustrine (11e)	Widespread distribution of stratified drift deposits
New England Upland (19b)	Widespread distribution of stratified drift deposits
Puget Sound (3a)	Widespread distribution of stratified drift deposits
Connecticut Lowland (19c)	Associated with stratified drift and valley terraces
Walla Walla (4a)	Associated with sluiceway and valley terrace deposits
Central Till Plain (11f)	Associated with glacial sluiceway terraces
Montana (7a)	Associated with glacial outwash in basin and valley areas
Bitteroot (7b)	Similar to 7a but generally found with northern portion
California Valley (3c)	Associated with valley fill areas adjacent to mountains
Great (Closed) Basin (5a)	Associated with valley fill areas adjacent to mountains
Sonoran Desert (5b)	Associated with valley fill areas adjacent to mountains
Open Basin (5d)	Associated with valley fill areas adjacent to mountains
Sacramento Highland (5e)	Associated with valley fill areas adjacent to mountains
Great Bend Highland (5f)	Associated with valley fill areas adjacent to mountains

basin deposits generally filled with glacial outwash and potential areas associated with valley fill deposits near mountainous areas.

There also exist smaller regional sand gravel areas within sections, which when further subdivided in subsections; yield a fairly good uniqueness in characteristics similar to those previously noted. These areas are found in the Jackson Hole unit of the Middle Rocky Mountain Province, the North Park,Middle Park and San Luis Valley areas of the Southern Rocky Mountain Province and the Southern Pine Hills Area of the East Gulf Coast Section.[1] Only the latter area directly contributes to the uniqueness of the physiography for the subsection as the gravel cap present in the unit (Citronelle Formation) provides an area of slightly differing relief features with most of the unit relative to its adjacent unit. The other units are delineated primarily because they are intermontane basins veneered by outwash sands and gravels.

Small regional areas of sand and gravel that generally afford little uniqueness within physiographic units are those primarily associated with remnental gravel caps which afford little or no alteration of the regional physiography of the Section where they are found. Examples of these

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[1] The distribution of these units are shown and described within the recommended physiographic - highway engineering units introduced in the next portion of this report. They correspond to unit numbers 75 (Jackson Hole), 59 (North and Middle Parks), 65, 67 (San Luis Valley) and 242 (Southern Pine Hills).

sporadic deposits are associated with many outwash areas adjacent to mountains, areas within both the Glaciated and Unglaciated Missouri Plateau Sections (Flaxville, Cypress Hills) and Osage Plains Section of the Great Plains Province, as well as preglacial and interglacial gravels (Buchanan and Aftonian gravels) found in the Dissected Loessial and Till Plains Section.

The poorest uniqueness of utilizing physiographic units for noting factors relative to sand gravel deposits occurs with alluvial sand-gravel deposits. This factor is unfortunate because the importance of their role in the complex totality of aggregate resources is indeed great. Within many areas of the United States, these sources are the only potential type of aggregate available.

The poor uniqueness of alluvial deposits to physiographic units is most probably related to the direct conflict between conditions necessary to delineate adjacent physiographic units and those necessary for fluvial development. In general, the difference in base levels (ie... elevation difference) necessitated for drainage development and subsequent river and stream development frequently serve as a factor which delineates differing physiographic units. Thus, the streams which radiate from the Front Range flow through the Colorado Piedmont, High Plains, Plains Border Sections and subsequently into the Mississippi River to the Gulf of Mexico. Although generalizations may be made within any of these Sections concerning the alluvial sand gravel sources, they are not uniquely associated with that particular Section.

Soils and Related Factors

All of the soil and related factors of design investigated within the project have had associated with them; either uniquely or in conjunction with other major variables (eg...climate), characteristic properties peculiar to the type of surficial soil textural conditions. Thus the delineation of potentially poor subgrade support areas by physiographic units led to the categorization on the basis of either organic type deposits or clayey areas. The high volume change study likewise noted clayey type soils existent within a very generalized climatic environment suitable for high volume change development. The analysis conducted on frost susceptible soils was related to the textural characteristics of soil units generally associated within the frost zone. As a consequence the general overall uniqueness of physiographic sections to denote potentially unique and homogeneous factors of design is dependent upon the textural consideration relative to the factor of design with the modal characteristics and distribution within the section.

In general, the utility of generalizing soil factors of design is good within most units developed solely from non transported origins. Within these areas, the soil type is developed upon the principles of pedology. Hence units with similar parent material types, topographic patterns, climatic histories, age and vegetation ideally will form similar soil types. With the exception of the vegetation variable, each of the other pertinent factors to soil genesis is also common to the geomorphic control factors which characterize a physiographic unit. The ability to effectively generalize within a large regional area is directly related, in sedimentary areas, to the geologic structure of the strata. In areas underlain by horizontal to slightly dipping strata, the residual soil types within the unit are relatively homogeneous or possess a predictable textural range over large areas. Physiographic units possessing these characteristics are frequently found in the Appalachian Plateau, Interior Low Plateau, Ozark and Ouachita, much of the Great Plains and Colorado Plateau Provinces. Conversely where geologic structure is greatly dipping, the regional (areal) patterns of similar soil type units cover relatively small areas. Examples of this occurrence are generally associated with massive mountainous uplifts which frequently have associated with them highly tilted strata flanking the uplifts. The soil regions found within the Black Hills Section as well as many areas within the Rocky Mountain Provinces exhibit this pattern.

In sections characterized by rugged mountainous areas, the factor of topography appears to have a more predominating effect upon soil development than any of the other factors which effect soil development. Thus, many of the sections found in the mountainous areas of the western United States, as well as much of the Blue Ridge Section of the east are, in general, non soil areas. Thus the mountain ranges of the Basin and Range can effectively be treated as non soil areas even though they are comprised of various parent material types.

The uniqueness afforded by transported origins is highly variable. Where transported soils, in part, overlay a physiographic unit based upon geomorphic factors related to underlying bedrock or different transported origin, the overall utility of the unit to denote soil factors of design is considered to be poor. If transported soils completely overlay a physiographic unit, regardless of the basis for geomorphic unit identification, the utility may be considered as good.

Perhaps the most notable example of this is found with the distribution of regional aeolian (loessial) deposits in the United States and their relationship to physiographic units. In general, the major occurrences of loess are found within the Columbia Plateau Province, the midwest United States (occurs in parts of the Great Plains and Central and Eastern Lowland Provinces) and the Mississippi Loessial Upland Section.

The uniqueness of the Mississippi Loessial Upland Section as a soil unit is considered good because of the fact that, in the main, the basis for sectioning is due to the presence of a unique topographic unit developed from the loess itself.[1] The overall uniqueness of the loessial areas

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[1] This statement is more correct for the western portion of the Section where the thickest loess deposits occur. In the east the thickness of loess decreases and topography is somewhat influenced by the underlying coastal sediments.

of the Columbia Plateau Province are likewise considered good. However, the utility of these loessial areas within the Snake River Plain and Walla-Walla Sections was considered good only because they are pseudo origin units. This is to say that if the loess covering were removed from these areas, the two sections would still be considered as unique physiographic sections because the modal characteristics are based upon the underlying bedrock rather than the loess. In contrast, the loess deposits in the midwest form a completely non-unique correlation to the regional physiography in the area because the modal characteristics are based upon parent material other than the loess and the loess deposits nowhere completely veneer a Section.

The latter example lends itself to a basic point of conflict between the physiographer and the highway engineer. The important question relative to the above as far as the highway engineer is concerned, is to ascertain whether or not the depth of transported soil is sufficient to justify a regional unit attributable to the transported soil, from a highway engineering viewpoint. In areas where this is a factor to be considered, the utility of using transported origin boundaries (even though gradational in nature) would seemingly afford a greater utility for soil related factors of design than borders established on the basic principles of regional physiography.

Composite Utility of Units

Because of the variety of factors which determine physiographic sections, it is not possible to make a blanket conclusion regarding the utility of sections as filing systems for highway factors of design as being either satisfactory or unsatisfactory. The overall utility of a section to serve as a unique filing system depends, upon the factor being regionalized relative to the modal characteristics which define the unit.

The best uniqueness of regionalizing both aggregates (crushed stone) sources and soil related factors appears to occur within a section whose modal characteristics are based upon consolidated (bedrock) material and having no transported material within the unit, or units whose modal topography is formed from very thick transported soils with the depth to underlying bedrock being such that no generalizations can be made concerning it.

Within the former case, crushed stone and soil generalizations may be characterized from the same parent material-topographic pattern. In the latter case, the uniqueness of crushed stone may be considered as good because it is a non existent feature within the unit. Soil factor generalizations may be uniquely formed from an interpretation of the transported soils within the unit.

In sections where the modal characteristics are based upon bedrock material but possess a partial covering of thin transported soil within the Section, the uniqueness of crushed stone sources may be good but the ability to effectively generalize soil factors is considered poor.

Conversely, where transported origins form the major characteristics of the section but underlying bedrock is at such a depth so that generalizations may be made; the uniqueness between crushed stone and soil factors is reversed from the latter case. Here the utility of regionalizing soil factors may be good while the crushed stone generalizations effected are very poor.

Concept of a Unique Highway Engineering - Physiographic Category

From a purely physiographic view point, the concept of a categorization system (ie...Division - Province - Section) is a necessary and integral part of the science. This categorization system places topographic differences at a more detailed level of examination. However, not all sections of a province are geomorphically related. For example, there is more uniqueness or similarity in physiography (geomorphology) between the Uinta Section of the Middle Rocky Mountain Province, the Colorado Front Range Section of the Southern Rocky Mountain Province and the variant Belt Mountain areas of the Northern Rocky Mountain Province than there is with the Uinta and Wasatch Sections of the same Province.

When utilizing physiographic areas as a means of filing particular characteristics (occurrence, distribution, severity, etc.) of design and construction factors, physiographic attributes are translated into engineering factors within a given section. As a consequence, the use of a section level to rate engineering experiences does not and should not imply to the highway engineer a similarity of these engineering experiences for all sections comprising a particular province.

For engineering purposes, the most useful meaning of a physiographic province is associated with using it as an areal unit which is an initial starting or reference point for the analyzation of smaller "engineering" units (sections). Sections should subsequently be viewed as an areal unit which is an initial starting point for the analyzation of smaller units.

Because of these factors, the use of a categorical classification system for engineering purposes is not necessary and may, in fact, be potentially misleading. Consequently the use of the term "highway engineering unit" is recommended in lieu of any Province, Section or subsection category levels utilized in regional physiography. This term may be readily defined as the smallest detailed area within which highway engineering generalizations have been effected.

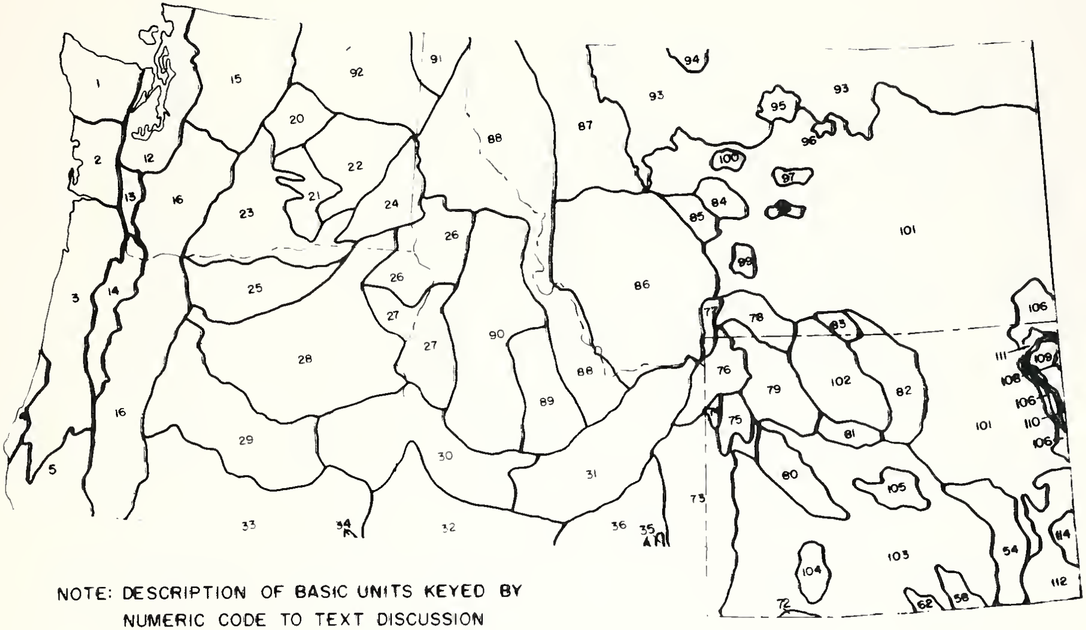
Recommended Physiographic-Highway Engineering Units of the Continental United States

General

The Woods-Lovell physiographic system, patterned and modified slightly after a true regional physiographic classification framework affords some significant engineering differences which improve upon a pure physiographic categorization. However, it should be noted that it is a part of a continental divisioning system, and as such, the degree to which the units (sections) are delineated may in some cases admit excessive variability when viewed at the state level. Therefore many of the generalizations effected at the section level may be too broad for maximum utilization for each state highway department.

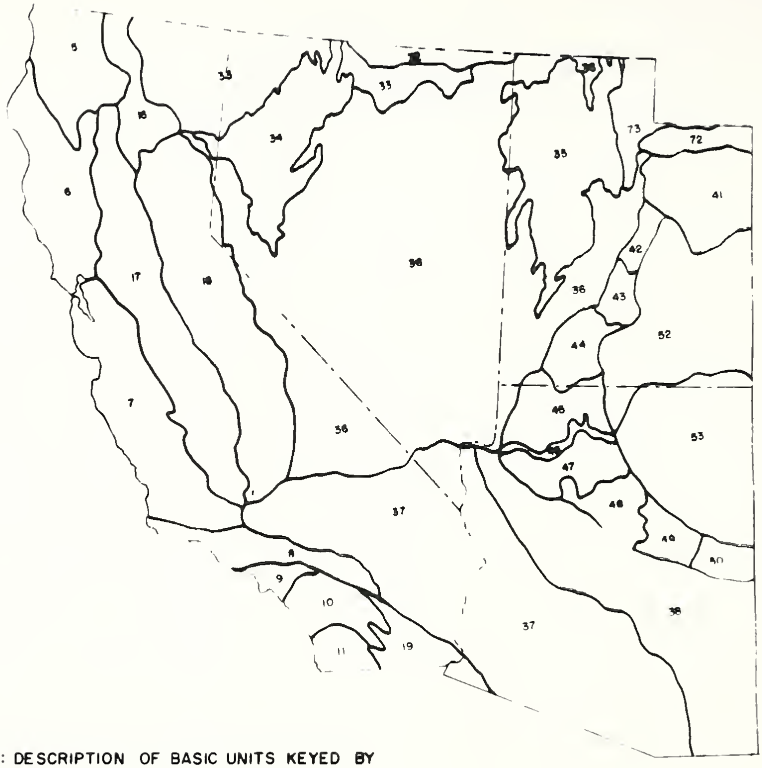
Recommended System

With the previously noted factor in mind, a further subdivision of the United States into a more homogeneous highway engineering - physiographic unit classification system has been made. In so doing, these areas have been delineated with several factors in mind. First, as many individual state physiographic units as possible have been incorporated into the system. Second, because of the overall importance of origin and parent material considerations within highway engineering, major importance in unit delineation has been placed upon these factors as well as isolating variant parent material areas within the sections of the typical physiographic system. The final consideration expresses the opinion that a categorization system of higher order units is not necessary and in fact may be misleading. As a consequence the system is simply composed of 242 highway engineering - physiographic units. Figures 46 thru 51



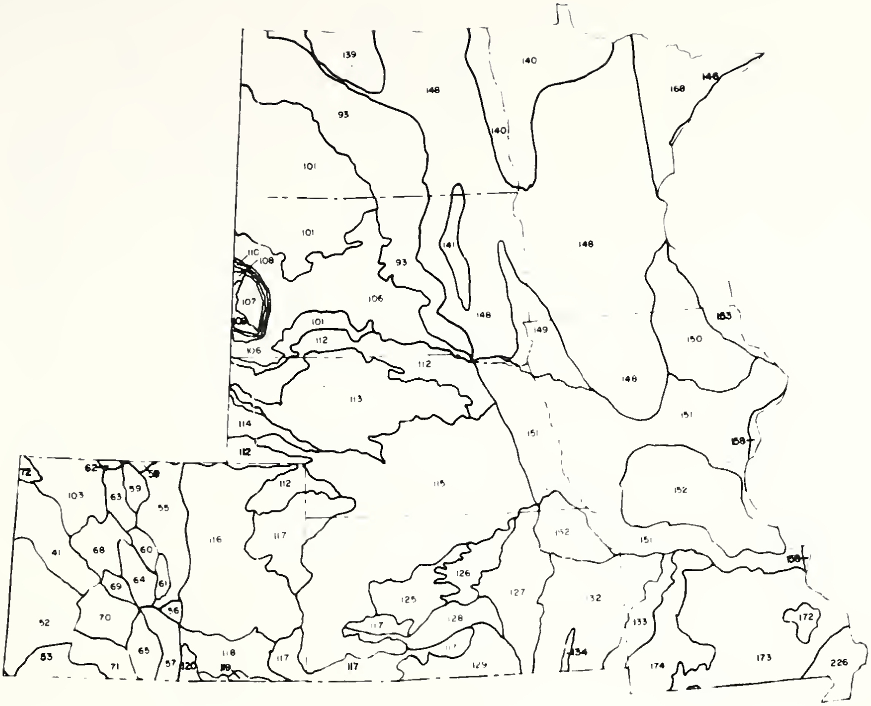
NOTE: DESCRIPTION OF BASIC UNITS KEYED BY NUMERIC CODE TO TEXT DISCUSSION

FIGURE 46
RECOMMENDED PHYSIOGRAPHIC-HIGHWAY ENGINEERING UNITS
OF THE CONTINENTAL UNITED STATES
(MAP SHEET I: NORTHWEST U.S.)



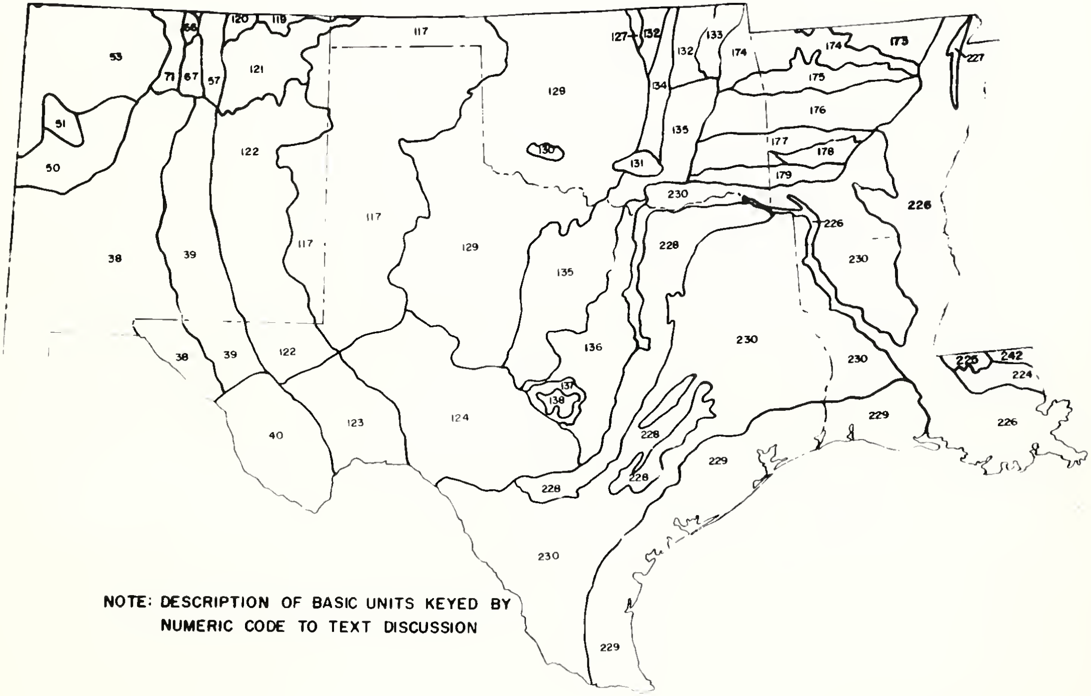
NOTE: DESCRIPTION OF BASIC UNITS KEYED BY
NUMERIC CODE TO TEXT DISCUSSION

FIGURE 47
RECOMMENDED PHYSIOGRAPHIC-HIGHWAY ENGINEERING UNITS
OF THE CONTINENTAL UNITED STATES
(MAP SHEET II: SOUTHWEST U.S.)



NOTE: DESCRIPTION OF BASIC UNITS KEYED BY
NUMERIC CODE TO TEXT DISCUSSION

FIGURE 48
RECOMMENDED PHYSIOGRAPHIC-HIGHWAY ENGINEERING UNITS
OF THE CONTINENTAL UNITED STATES
(MAP SHEET III: NORTH CENTRAL U.S.)



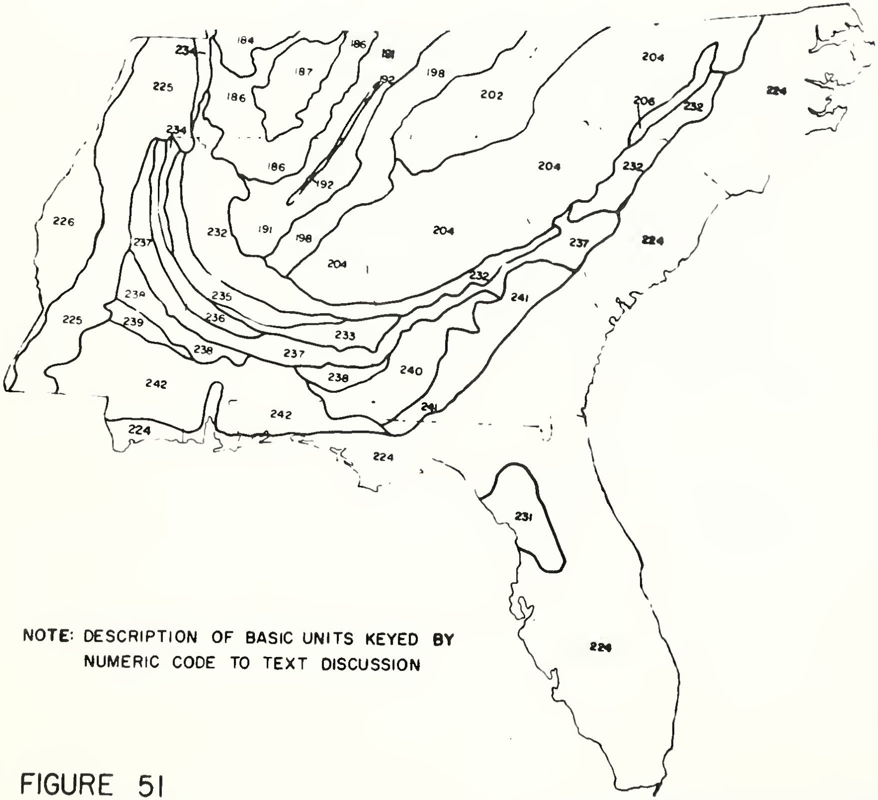
NOTE: DESCRIPTION OF BASIC UNITS KEYED BY NUMERIC CODE TO TEXT DISCUSSION

FIGURE 49

RECOMMENDED PHYSIOGRAPHIC-HIGHWAY ENGINEERING UNITS OF THE CONTINENTAL UNITED STATES (MAP SHEET IV: SOUTH CENTRAL U.S.)

NOTE DESCRIPTION OF BASIC UNITS KEYED BY NUMERIC CODE TO TEXT DISCUSSION

FIGURE 50
RECOMMENDED PHYSIOGRAPHIC-HIGHWAY ENGINEERING UNITS OF THE CONTINENTAL UNITED STATES
(MAP SHEET V: NORTHEAST U.S.)



NOTE: DESCRIPTION OF BASIC UNITS KEYED BY NUMERIC CODE TO TEXT DISCUSSION

FIGURE 51

RECOMMENDED PHYSIOGRAPHIC-HIGHWAY ENGINEERING UNITS OF THE CONTINENTAL UNITED STATES (MAP SHEET VI: SOUTHEAST U.S.)

illustrate the distribution of the recommended units.

For the proposed system, only a generalized description of the factors pertinent to the highway engineer are given. These factors are those of geology, geomorphology and parent material-origin characteristics. The numeric code is keyed to the diagrams which illustrate the occurrence of these areas.

General Description of Recommended Units

1. Olympic Mountains - This unit is a rugged, highly dissected mountainous area with several peaks greater than 7000 feet. The area is heavily glaciated. The major rock types are Cretaceous volcanic and metamorphic sediments. Locally, basalts, volcanic tuffs, breccias and interbedded marine beds of Eocene age as well as Oligocene marine sediments are found.

2. Willapa Hills - This area occurs as the Oregon portion of the Oregon Coast Ranges. The major reason for distinction is the Tertiary volcanic cover overlying the Tertiary sandstones and shales of the Oregon Ranges.

3. Oregon Coast Range - Parallel trending series of north-south ridges and valleys formed by mild folding of relatively weak Tertiary sandstones and shales.

4. Oregon Coastal Plain - Relatively small sandy coastal area of Oregon.

5. Klamath Mountains - Extremely rugged, dissected uplifted plateau composed predominantly of Paleozoic schist flanked on the east by deformed Paleozoic sedimentaries and volcanics and on the west by metamorphic rocks of Jurassic age.

6. Northern California Coast Range - Maturely dissected continuous highland area composed predominantly of Tertiary and Cretaceous sandstones, shales and slates.

7. Southern California Coast Range - Similar to the Northern California Coast Range except faulting is more pronounced in the area resulting in a more noticeable ridge and valley appearance. The predominant rock type is Tertiary sandstones and shales; but Jurassic granites, similar

to those found in the Sierra Nevada, underlie a central portion of the area.

8. Traverse Ranges - Distinctive east-west trending ranges composed primarily of granitic batholithic cores.

9. Los Angeles Basin - Lowland basin area of accumulated marine and continental Tertiary sediments. The eastern portion is generally coarse alluvium from the San Gabriel and San Bernadino Mountains.

10. Faulted Peninsular Range - Highly faulted Jurassic granitic area with aggrading vallys being common.

11. Peninsular Ranges - Westward tilted fault block of Jurassic granite rising to elevations of 10,000 feet. A terraced lowland borders the Pacific Ocean and gradually merges into the broadly dissected granitic upland.

12. Puget Sound Basin - This area is the glaciated area of the Woods-Lovell Puget Trough Section. Topography is predominantly a mixture of morainic hill and outwash or terrace topography.

13. Basaltic Hills Area - This area is the residual area which separates the glaciated Puget Sound Basin to the north from the predominantly alluviated Williamette Valley unit to south. Topography is generally a disconnected series of basaltic hills.

14. Willamette Valley - Fairly flat alluvial plain of the Willamette River and its tributaries overlying Tertiary and Quaternary sediments derived from sedimentary and volcanic rocks. Minor hilly areas similar to those of the Basaltic Hills Area to the north, are located within the area.

15. Northern Cascade Mountains - Rugged, mountainous area composed of Paleozoic sedimentaries and metamorphics intruded by several granitic batholiths. Alpine glaciation is heavy in the area but relief is primarily due to constructional vulcanism rather than destructional processes.

16. Southern Cascade Mountains - Mountainous area similar in topography to the Northern Cascade Mountains but are formed primarily from Tertiary basalts and andesites.

17. California Valley - An immense, flat valley filled with both Recent and Quaternary sediments in the form of alluvial fans, aprons, mudflows and flood plains.

18. Sierra Neveda Mountains - Immense westward tilting fault

block with elevations ranging from 7500 feet to 13,200 feet. The major bedrock type is a Jurassic granitic batholith. Paleozoic and Mesozoic metamorphic slates, phylittes, graywacke and basalt flows are subordinate in the area. Alpine glaciation is intense in the area.

19. Salton Trough - Large basin area formed in part by alluvial deposits of the Colorado River lying over valley outwash.

20. Waterville Plateau - Relatively flat lying basalt flows cut by a number of coulee systems and in part glaciated.

21. Central Plains - Major downwarped area of basalts and related fluviatile lacustrine and aeolian sediments.

22. Channeled Scablands - Areas cut by vast meltwater deposits exposing bare tracts of Columbia River basalt. The uplands are covered by loess deposits.

23. Yakima Folds - Area of high, broad anticlinal ridges and synclinal valleys. Ridges are predominantly basaltic while the valleys are predominantly granular to semi granular sediments and volcanic ash.

24. Palouse Hills - Maturely dissected hills formed on deep loess.

25. North Central Oregon Plateau - Moderately dissected basaltic plateau area.

26. Tristate Uplands - Upwarped lava plateau in which dissection has produced 2000 to 4000 feet canyons.

27. Wallowa/Seven Devils - Complexly folded and faulted area overlain by basaltic flows of variable thickness.

28. Blue Mountains - Area characterized by mountain ranges and dissected plateaus. Bedrock type within the area is quite variable as granitic cores similar to the Rockies, rise as "islands" above the basaltic lavas. Folded Paleozoic and early Mesozoic sedimentary strata are also located within the area.

29. Harney/High Desert - Flat area of recent lava flows, ash deposits and cinder cones.

30. Malheur/Boise Basin - Moderately dissected areas of interbedded lava and lacustrine - fluviatile sediments.

31. Snake River Plain - Structurally depressed area covered with young (Snake River) lava flows which in turn are

overlain by loessial deposits.

32. Owyhee Uplands - Structurally upwarped area of lavas more dissected and of older age than those to the north. Large areas are underlain by rhyolites and quartz latites.

33. Northwest Basaltic Basin Range Area - Somewhat large area comprised in part by plateau topography in the extreme west and basin - range fault controlled topography elsewhere. The major rock type within the area is basaltic lavas, similar to those to the north.

34. Lake Lahontan - One of two large basin areas in the Basin and Range Province characterized by the existence of old Pleistocene lakes. Mountain ranges divide this area into irregular straits where the lake deposits occur.

35. Lake Bonneville - Largest of the two areas noted in unit 34. Characteristics of this area are essentially identical to those noted for Lake Lahontan.

36. Great (Closed) Basins - Numerous mountain ranges of complex geologic age and type, and valleys existing in about equal proportions.

37. Sonoran Desert - Area possessing characteristics somewhat similar to the Great Basin unit except that the general altitude is much lower and valleys and basins occur proportionally greater than the ranges.

38. Mexican Highland - Area possessing characteristics similar to the Great Basin unit except that geologic structure and rock type are more complex and most of the basins have external outlets (open basins).

39. Sacramento Highland - Faulted area producing cuesta or plateau type of topography on Permian limestones and sandstones (predominantly). The area does not exhibit the typical basin-range topography common to other units of the Basin and Range Province; however, basins do occur within the area.

40. Great Bend Highland - Mountainous area comprised of Tertiary Igneous (intrusive and extensive) and Cretaceous sedimentary (primarily limestone) mixed with numerous plains and aggradational basins.

41. Uinta Basin - Dissected plateaus existing within a structural basin filled with tertiary shales and sandstones, with lesser amounts of limestone.

42. Northern Plateau and Valley Area - Exceptionally high

north trending plateau separated by scarps and fault controlled valleys. The horizontal rock strata are primarily Tertiary massive sandstones and some shale, with minor Cretaceous and Jurassic areas present.

43. Central Lava Area - Similar in characteristics to the Northern Plateau and Valley Area except it is capped by Tertiary lavas and is not as dissected.

44. Colored Cliffs - Similar in characteristics to unit 42 except a series of east-west trending cliffs present a "stair step" topography toward the lower Grand Canyon Section (Faulted Plateau unit).

45. Faulted Plateaus - This area, north of the Colorado River, has parallel type faults that divide the area into a series of plateaus developed from young sedimentary rocks which overlook the Grand Canyon area to the south.

46. Grand Canyon - This area represents the majestic canyon area of the Grand Canyon Section.

47. San Francisco Plateau (Western Portion) - Homogeneous plateau area of slight relief on Permian limestones. Dissection and sapping have exposed sandstones and shales in some areas.

48. San Francisco Mountains - Mountainous areas of high relief formed by Tertiary and some Quaternary lava flows.

49. San Francisco Plateau (Eastern Portion) - Similar in characteristics to its western counterpart (unit 47).

50. Datil Volcanic Field - Area characterized by intense volcanic activity in the form of flows, volcanic necks and cones. This volcanic region is primarily on the eastern side of the unit. The remaining area is plateau like derived from horizontal young sedimentary sandstones and shales.

51. Zuni Uplift - Mountainous uplifted area exposing Pre-Cambrian crystalline rocks in its core and typical gradational dip patterns of sedimentary rocks of Carboniferous to Cretaceous age which form cuestas and hogback topography.

52. Canyon Lands - Deeply incised canyon area cut in sandstones and shales of Cretaceous, Triassic and Carboniferous age. A few Tertiary intrusive occur as isolated laccolithic domes in the region.

53. Navajo - Somewhat poorly defined area of scarped plateaus

developed from rock type and ages somewhat similar to the Canyon Lands. The area lacks, however, the extreme dissection characteristic to that unit.

54. Laramie Range - Mountain range consisting of a central PreCambrian igneous (predominantly granitic) - metamorphic complex core with steeply dipping, flanking Paleozoic - Mesozoic sedimentary strata (predominantly sandstone and shale) that often form homoclinal ridges.

55. Colorado Front Range - Similar to Laramie Range.

56. Wet Mountain Range - Similar to Laramie Range.

57. Sangre de Cristo Range - Similar to Laramie Range.

58. Medicine Bow Range - Similar to Laramie Range.

59. North and Middle Parks - Fairly level intermontane basin area covered by granular Tertiary material and glacial outwash. The Parks are separated by a chain of volcanoes known as Rabbit Ears Range. The Middle Park possesses, in general, more relief than North Park.

60. Gore Range - Similar to Laramie Range.

61. South Park - Structural intermontane basin comprised predominantly of granitic rocks.

62. Sierra Madre Range - Similar to Laramie Range.

63. Park Range - Similar to Laramie Range.

64. Sawatch Range - Similar to Laramie Range.

65. Northern San Luis Valley - Relatively level basin area filled with deep deposits of glacial and alluvial outwash.

66. San Luis Hills - Northeast -southwest range of Tertiary basaltic mesas, lower in elevation and less dissected than the San Juan Mountains to the west.

67. Southern San Luis Valley - Topographic area somewhat similar to its northern counterpart. Sediments are primarily Tertiary in age.

68. Western Sedimentary Section - This area is characterized by uplift without folding, resulting in a submature dissected plateau of fairly horizontal Paleozoic - Mesozoic strata. The northern portions are lava covered. In

many respects, this unit bears more of a similarilty to units found in the Colorado Plateau than the Rocky Mountains.

69. Elk Range - Similar to Laramie Range.

70. San Juan Plateau - Basaltic lava covered area lacking the mature dissection characteristic to the San Juan Mountain unit.

71. San Juan Mountains - Maturely dissected plateau area of high relief carved from basaltic lavas and tuffs of Tertiary age.

72. Uinta Mountains - Similar to Laramie Range.

73. Wyomide/Wasatch Mountains - Mountainous areas characterized primarily by complex Paleozoic - Mesozoic sedimentary rocks strongly influenced by thrust faulting.

74. Teton Range - Similar to Laramie Range.

75. Jackson Hole - Downfaulted intermontane basin with Cretaceous - Tertiary sediments covered in the north by glacial till and outwash.

76. Yellowstone Lava Plateau - Plateau surface composed of late Tertiary rhyolitic flows.

77. Gallatin Range - Mountainous area composed predominantly of volcanic breccia.

78. Beartooth Mountains - Similar to Laramie Range.

79. Absarocka Mountains - Heavily dissected plateau composed of late Cretaceous and early Tertiary breccias and basalts.

80. Wind River Mountains - Similar to Laramie Range.

81. Owl Creek Range - Similar to Laramie Range.

82. Bighorn Mountains - Similar to Laramie Range.

83. Pryor Mountains - Small but noticeable uplift that is primarily a dissected plateau of strong limestone.

84. Little Belt Mountains - Similar to Laramie Range.

85. Big Belt Mountains - Similar to Laramie Range.

86. Southwest Montana - Structurally this area differs from its northern counterpart in that basin - range faults

are more conspicuous leaving a random display of ranges and intervening Tertiary basins. The bedrock type within the ranges varies greatly by age and type.

87. Northwest Montana - Like the Southwest Montana unit; the major characteristic of the area is the presence of Tertiary basins. The western portion of this area is characterized by PreCambrian igneous - metamorphic complex while the eastern portion contains Paleozoic strata. A large portion contains linear type ranges due to eastward thrust faulting.

88. Bitterroot - Complex and viverse mountainous area generally comprised of PreCambrian metamorphic rock complexes. The mountains within the area vary from sprawling to linear.

89. Salmon River Meta/Volcanic Area - This area possesses topography not different from the Idaho Batholith unit but carved primarily from Tertiary volcanics.

90. Salmon River (Idaho Batholith) Area - Fairly homogeneous area of sprawling mountains developed on Jurassic granite.

91. Selkirk Mountains - Rugged mountainous area developed primarily on Jurassic granite.

92. Okanogan Highlands - In general, this area is not as rugged as the Selkirk unit. It has been covered by variable thicknesses of glacial drift overlying Jurassic granites (primarily).

93. Glaciated Missouri Plateau - Glaciated plateau area with smooth rolling hills and terraced valleys. Underlying bedrock is predominantly Tertiary and Cretaceous sandstones and shales which form the surficial rock of the unglaciated Missouri Plateau unit.

94. Sweetgrass Hills - Mountainous area formed by PreCambrian intrusives now being exhumed.

95. Bear Paw Mountains - Mountains formed by extinct volcanic group.

96. Little Rocky Mountains - Similar to Laramie Range.

97. Judith Mountains - Mountain group of eroded laccoliths.

98. Big Snowy Mountain - Similar to Laramie Range.

99. Crazy Mountains - Mountains of volcanic origin.

100. Highwood Mountains - Maturely dissected mountains of

101. Missouri Plateau/Badland Complex - Vast plateau like area with large badland topographic features. The majority of the area is underlain by Tertiary and Cretaceous clay shales, shales and sandstones. Infrequently, lignite as well as limestones are found in the area.

102. Bighorn Basin - Basin area filled by fluvial aggradation from surrounding mountain areas during the Great Plains Tertiary alluviation. Bedrock is predominantly sandstones and shales with desert lands, badlands and alkali flats being common.

103. Wyoming Basins - This area is comprised of several individual basin areas whose characteristics are identical to the Bighorn Basin unit.

104. Rock Springs/Leucite Hills - Much eroded domal area with steep hogbacks and cuestas of Cretaceous sandstone. The Leucite Hills area is a volcanic region north of the Rock Springs area.

105. Sweetwater (Granite) Mountains - Scattered granitic core islands surrounded by Tertiary sediments of the basins.

106. Pierre Hills - Rolling topography formed on Cretaceous shale.

107. Black Hills Central Crystalline Area - PreCambrian granitic core of the exposed domal uplift which is the rugged and mountainous area associated with the Black Hills.

108. Black Hills Volcanic Mountains - Series of scattered Tertiary igneous laccoliths found in the northern portion of the Section.

109. Black Hills Limestone Plateau - Plateau area of Permian limestone which encirles (unsymetrically) the older core of the dome.

110. Black Hills Red Valley - Lowland area derived from soft shaley Triassic rocks which encircles the previously described Limestone Plateau unit.

111. Black Hills Hogback Ridges - Narrow cuesta scarp or hogback ridge developed on Cretaceous sandstone. This topographic area gradually merges in all directions into the Missouri Plateau Badland Complex and Pierre Hills units.

112. Arikaree Outwash Area - Greatly eroded older Tertiary

(Arikaree) outwash (unconsolidated).

113. Nebraska Sand Hills - Dunal type topography developed from sand deposits.

114. Goshen Hole Lowland - Denuded badland area developed upon clays (Brule Fm) of Tertiary age.

115. Loess Hills Region - Gently rolling surface developed upon loess. The thickness of loess gradually changes from 100 feet in Nebraska to a thin veneer in Kansas where it eventually disappears.

116. Colorado Piedmont - Denuded basin area with gently undulating topography developed upon Cretaceous clay shales. More highly tilted and dissected rocks occur along the Rocky Mountain foothills. Sandstones, limited limestones and chalks, as well as basalt flows are of subordinate existence in the unit.

117. Ogallala Outwash Area - In essence, this is the original Tertiary outwash mantle which veneered most of the Great Plains Province. Topography is essentially flat upon the younger (relative to the older Arikaree outwash) unconsolidated sands, silts and gravels.

118. Chataqua Plateau - Stripped plain cut by canyons and surrounded by volcanic landforms. Rock types within the plateau are primarily Cretaceous sandstones and shales.

119. Raton Mesa - Somewhat indefinite area delineating lava capped mesas underlying softer horizontal to slightly dipping sedimentary rocks. Dissection, which gradually increases westward, has removed portions of the volcanic cover leaving many gaps between the mesas.

120. Park Plateau - Heavily dissected highland developed upon late Cretaceous to early Tertiary sandstones and shales.

121. Las Vegas Plateau - Similar in characteristics to the Chataqua Plateau.

122. Pecos Valley - Eroded lowland area developed upon Permian and Triassic shales, sandstones, gypsum and some limestone. The Pecos Valley is, in part, deeply filled with alluvium.

123. Stockton Plateau - Predominantly flat plateau developed in Cretaceous limestone.

124. Edwards Plateau - Similar to the Stockton Plateau,

which is separated from it by the Pecos Canyon.

125. Blue Hills - A flat, plateau-like upland surface with occassional buttes and mesas developed from Cretaceous limestone with interbedded shale.

126. Smokey Hills - North-south trending rolling hill area consisting of Cretaceous shales capped by resistant sandstones in places.

127. Flint Hills - Rolling hill area with escarpments developed upon cherty limestones of Permian age.

128. Arkansas Lowland - Flat alluvial plain of the Arkansas River.

129. Permian Rolling Plains - Gently rolling topography developed upon Permian shales with minor sandstone areas. Gypsum occurs along the western portion of the unit.

130. Wichita Mountains - Low mountainous area developed upon PreCambrian igneous rocks and flanking sandstone and limestone of early Paleozoic age.

131. Arbuckle Uplift - Plateau like uplift of slight relief exposing a PreCambrian core of granitic rocks flanked by early Paleozoic limestones and Pennsylvanian shales.

132. Limestone Scarped Plains - Parallel trending cuesta type topography developed upon Pennsylvanian limestone (scarps) and shales (lowlands).

133. Cherokee Lowland - Gently undulating lowland developed upon Pennsylvanian shale.

134. Sandstone Hills - Rolling hills developed primarily from Pennsylvanian sandstones.

135. Sandstone Scarped Plains - This area is the topographic counterpart of the Limestone Scarped Plains to the north. In this unit, sandstone of Pennsylvanian age replaces the limestone of the northern unit as the scarp maker.

136. Grand Prairie - Somewhat topographically diverse area varying from slightly rolling in the north to highly dissected in the central and southern portions of the unit. The distinction of this unit is based primarily upon the Cretaceous limestones and shales which form most of the parent material of the area.

137. Llano Dissected Limestone Plateau - This area has, as

its counterpart, the Black Hill Limestone Plateau unit. The topography is primarily a maturely dissected plateau like area on Cambrian and Cedovician limestones.

138. Llano Uplift - Central basin (topographic) area carved from the old PreCambrian granites, gneisses and schists. This area is the counterpart to the Black Hills Central Crystalline Area.

139. Lake Souris - Lacustrine plain associated with high water phases during Pleistocene glaciation. Lacustrine sediments are primarily very fine textured. Associated with the lacustrine deposits are irregular granular beach deposits marking former levels of the old lake.

140. Lake Agassiz - Similar in characteristics to Lake Souris unit.

141. Lake Dakota - Similar in characteristics to Lake Souris unit.

142. Lake Chicago - Similar in characteristics to Lake Souris unit.

143. Kankakee Sand Basin - Basin area filled by water deposited sands associated with glacial drainage and ponding of several glacial drainage outlets in northern Indiana and Illinois.

144. Lake Saginaw - Similar in characteristics to Lake Souris unit.

145. Lake Green Bay - Similar in characteristics to Lake Souris unit.

146. Lake Duluth - Similar in characteristics to Lake Souris unit.

147. Lake Maumee - Similar in characteristics to Lake Souris unit.

148. Western Lakes Drift Area - Prominant to gently rolling morainic topography with poorly integrated drainage system developed on Cary and younger type of glacial drift.

149. Dissected Loess Covered Iowan Drift Area - This area represents one of two prongs of highly dissected Iowan drift which serve as the northerly extension of the Dissected Loessial and Till Plain Section. This area; however, unlike the eastern extending prong, is covered

by loessial deposits.

150. Dissected Iowan Drift Area - Similar in characteristics to the Dissected Loess Covered Iowan Drift unit except lacking the loess deposits common to that unit.

151. Dissected Loess Covered Kansan Drift Area - This highly dissected unit is similar in characteristic topography to the Dissected Loess Covered Iowan Drift unit except that the glacial till is Kansan in age. The depth of loess is quite variable in thickness overlying the drift.

152. Dissected Kansas Drift Area - These dissected units occur where the loess gradually thins and disappears as the surficial covering over the Kansas drift.

153. Loess Covered Southwest Cuestas - This area, for all practical purposes is the loess covered portion of the Driftless Section. Underlying the loess in cuesta fashion (facing the northeast) are Cambrian sandstones and shales, and Ordovician and Silurian carbonates as one proceeds to the southwest. Geologic structure is influenced by the Wisconsin dome.

154. Central Sand Plain - Relatively flat plain broken by occassional island like buttes of sandstone formed in part by glacial Lake Wisconsin and in part by the residual weathering of soft Cambrian sandstones and shales.

155. Eastern Lakes Drift Area - This unit is quite similar to the Western Lakes Drift unit, except that bedrock slightly effects topography in the form of slightly exposed cuesta areas.

156. Erie-Ontario Rolling Plains - Rolling plain area developed on glacial till. A large portion of the area is dominated by large drumlin topography.

157. Erie- Ontario Lacustrine Plain - Relatively flat lying area whose characteristics are, for the most part, similar to the Lake Souris unit in that it was developed by a former level of the present Lake Erie and Ontario.

158. Loess Plains of Western Illinois - Loess plains of relatively small relief which veneer Illinoian drift and small areas of Tazewell and older Wisconsin drift.

159. Tipton Till Plain - Typical till plain area exhibiting flat to gently undulating terrain developed on Tazewell and older Wisconsin drift.

160. Illinoian Drift Area - Drift plain developed on Illinoian drift. Relief within the area is slightly more excessive than that found in the Tipton Till Plain. The depth of the Illinoian drift gradually thins to the south so that the physiography may in part, reflect the character of the underlying bedrock to a greater degree in these areas.

161. Tug Hill Cuesta - Glaciated cuesta area of moderate relief developed primarily by Ordovician sandstones and shales.

162. Black River Valley - Fairly small valley area underlain by Ordovician limestones and shales. The valley is also surfaced by widespread lacustrine and deltaic deposits deposited during Pleistocene glaciation.

163. Mohawk Lowland - Glaciated plain of high relief due to the slightly dipping sedimentary strata which are continuous with the Appalachian Plateau. The major bedrock underlying the till is Ordovician shale and limestones with subordinate Silurian sandstones locally overlying them.

164. St. Lawrence Lowland - Smooth glacial plain covered for the most part by marine clay deposits. Underlying bedrock is primarily early Paleozoic limestone and sandstone which do not affect relief within the drift.

165. Champlain Lowland - Rolling glaciated lowland, partially covered by marine clays. Bedrock similar in age and type to the St. Lawrence Lowland unit frequently protrudes through the glacial and marine deposits.

166. Glaciated Ridge and Valley - This area exhibits topography as well as a geomorphic history somewhat similar to the unglaciated portions of the Ridge and Valley Province to the south except that is covered by glacial deposits. The ridges are primarily Devonian sandstones while the valleys are primarily Ordovician shales and limestones.

167. Slate Hills Area - Glaciated area exhibiting rounded knoll or "mamilary" topography produced upon glacial drift or slate of Ordovician age. The northern portion of the unit is also covered by marine clays similar to those found in the St. Lawrence and Champlain Lowland units.

168. Superior Upland - Dissected, glaciated peneplain on PreCambrian igneous and metamorphic rocks of complex structure. Glacial drift is similar in age to those

found in the East and West Lakes units (Cary and Younger Wisconsin drift) and in many areas controls the physiographic details.

169. Northwest Lowland - Glaciated lowland area of the Adirondack Section which is due to the poor resistance of the underlying metasedimentary rocks of PreCambrian age.

170. Central Highland Plateau - Uplifted and dissected glaciated peneplain formed on PreCambrian granites and syenite gneisses.

171. High Peaks Region - Glaciated mountainous portion of the Adirondack Section formed by very resistant anorthosites of the Adirondack batholith.

172. St. Francis Mountains - Mountain area developed on the structural crest of the Ozark dome. Cambrian sandstones and carbonates, deposited before the uplift, are now in various stages of erosion thereby exhuming the PreCambrian granitic type core rocks.

173. Salem Plateau - Dissected plateau formed primarily on Ordovician sedimentary rocks. Cherty carbonates predominate in the area.

174. Springfield Plateau - Plateau area formed primarily on Mississippian sedimentary rocks. Similar to the Salem Plateau, carbonates rocks of cherty character are prevalent in the unit.

175. Boston Mountains - Maturely dissected plateau of Pennsylvanian sandstones and shales left as denudation remnants of the Ozark Domal Uplift.

176. Arkansas Valley - East/west trending structural trough formed by the synclinorium of Pennsylvanian sandstones and shales.

177. Fourche Kiamichi Belt - Rugged mountainous area formed upon Carboniferous sandstones and shales.

178. Novaculite Uplift - Area exhibiting ridge and basin topography. Arkansas Novaculite forms the ridges of the unit while the basins are formed on Pennsylvanian shales.

179. Athens Piedmont Area - In essence, the geologic type and age of the bedrock in the unit is similar to the Fourche Kiamichi Belt unit. The major distinctiveness of this unit is the plateau like nature of the bedrock and subsequently does not exhibit the great relief of

of that unit.

180. Southern Illinois Loessial Area - Hilly loess area veneering Mississippian limestones, shales and sandstones at the extreme southern tip of Illinois.

181. Island Hills - This area is characterized by widespread valley alluviation in which remnants of Pennsylvanian sandstones and shales protrude as hills above the flat alluvial terrain.

182. Indiana/Kentucky Coal Fields - Maturely dissected upland formed on Pennsylvanian sandstones, shales and clays.

183. Mammoth Cave Plateau - Heavily dissected plateau exhibiting topography somewhat similar to the Kentucky/Indiana Coal Fields unit. The bedrock, however, is primarily complex Mississippian formations of shale, sandstone and limestone.

184. Western Pennyroyal Limestone Plain - Plain formed primarily on Mississippian limestones. Karst topography is prevalent in much of the unit.

185. Knob Hill - This area generally exhibits conical or hilly type of terrain. Bedrock is primarily Mississippian - Devonian in age. Massive shale with sandstone or limestone caps comprise the higher hill portion while shale predominates in the lower hill area.

186. Kentucky/Tennessee Eastern Pennyroyal - This area is somewhat topographically variable ranging from karst topography on limestone to undulating on shales. The bedrock age is Mississippian.

187. Nashville Basin - Fairly homogeneous topographic basin area of rolling plains and low relief developed on Ordovician limestones and some shale.

188. Outer Blue Grass - Gently rolling topography developed on alternating, thinly bedded shales and limestones of upper Ordovician age.

189. Eden Shale - Throughly dissected plateau developed upon Ordovician shales.

190. Inner Blue Grass - Undulating topography formed primarily on Lower Ordovician limestones.

191. Cumberland Plateau - Submaturely dissected plateau,

similar, but lacking the advance degree of dissection of the Kanawha unit. The area is characterized primarily by strong Pennsylvanian sandstones and to a more limited extent, shales.

192. Sequatchie/Wills Creek Valley - Valleys formed by the erosion of upper strata along the axis of the Sequatchie anticline exposing Ordovician limestones.

193. Kanawha - Maturely dissected plateau formed on predominantly horizontal to slightly dipping sandstones and shales of Pennsylvanian age and soft shales and limestones of Permian age. Toward the outer portions of the Section, Mississippian rocks occur.

194. New York Glaciated Plateau - Maturely dissected plateau of predominantly horizontal to slightly dipping shales, sandstones and some limestones of Devonian (primarily) and Mississippian and Pennsylvanian (minor) age. The area, however, has been significantly modified by late Wisconsin glaciation.

195. Catskill Mountains - Mountainous upland area of Devonian sandstones, conglomerates and shales. The area has been glaciated, but physiographic significance is not as great in comparison to the New York Glaciated Plateau unit.

196. Pocono Mountains - Dissected area of flat lying resistant Mississippian sandstone.

197. Allegheny Mountains - Heavily dissected area that has lost the plateau type characteristics common to the remainder of the Province. Mild folding is evident in portions of the Unit. Primary ridge makers of the unit are sandstones of Pennsylvanian and Mississippian age with Mississippian shales and minor limestone areas being brought to the surface on the slopes of some of the ridges.

198. Tennessee - Series of linear trending ridges and valleys developed primarily from faulting, folding and subsequent erosion of the sedimentary rocks. In the unit, valleys are predominant over ridges. Lowlands are primarily developed on Cambrian and Ordovician carbonates and shales with subordinate areas of Mississippian cherty limestone. Ridges are primarily sandstones of Devonian, Silurian, Mississippian and Pennsylvanian age.

199. Parallel Folded Ridge and Valley Area - Series of linear parallel ridges and valleys developed primarily from folding and erosion of sedimentary rocks of an anticlinorium. Most of the valley areas in this unit are

derived from Cambrian and Ordovician shales. Ridges are primarily Pennsylvanian, Mississippian and Devonian sandstones.

200. Great Valley - Fairly large continuous lowland area developed upon Cambrian and Ordovician limestone. This area is generally developed as the synclinorium portion of the combined anticlinorium - synclinorium combination comprising units 199 and 200.

201. Zig-Zag Mountains - This unit is somewhat similar in bedrock type and age to the Parallel Folded Ridge and Valley Area. The major distinction of this unit is derived from the northeast plunging characteristics of the folds in this area resulting in a series of zigzag ridges in lieu of the parallel ridges noted for the former unit.

202. Southern Blue Ridge - Belt of mountains that are remnants of a former highland antedating the lower peneplains on either side. Rock type and structure within the area is complex with Cambrian metasediments (quartzites, sandstone, graywacke and slates) forming a western strip and the remaining bedrock consisting of PreCambrian gneissic and granitic type of bedrock. Very small areas of Ordovician limestone are found in the region. These areas are called ("coves" or "windows").

203. Northern Blue Ridge - This unit is the northern counterpart of the Southern Blue Ridge area. Differences between this area and the latter are: rock type is primarily PreCambrian gneissic and granitic; the area is not a belt of mountains, but rather a single subdued ridge; and the elevations are, in general, lower than the southern unit.

204. Piedmont Plateau - Broadly undulating to rolling topography created by peneplation upon complex metamorphic and plutonic rocks and structure. PreCambrian and Cambrian granites, gneisses and schist predominate the bedrock.

205. Triassic Lowland - Fairly large basin lowland developed by weak Triassic sandstones and shales. Lowland topography is occassionally modified by igneous "trap ridges".

206. Triassic Lowland Inlier - Small scattered areas having characteristics identical to the Triassic Lowland unit.

207. Frederick Valley - Small lowland area merging in

topographic features with the Triassic Lowland unit, but developed on Crdovician limestone.

208. Chester - Conestoga (Lancaster) Valleys - Similar in characteristics to the Frederick Valley unit.

209. Piedmont Crystalline Inlier - This rather small area is separated from the Piedmont Plateau unit by the Chester - Conestoga Valleys. Its characteristics are identical to those of the Piedmont Plateau unit.

210. Glaciated Triassic Lowland - This area possesses bedrock characteristics similar to the Triassic Lowland unit but having its topographic features modified by Wisconsin glacial drift.

211. Reading Prong - Southwestward extending crystalline prong of the New England Upland composed predominantly of low mountains developed on PreCambrian crystalline rocks. The majority of the unit has been glaciated.

212. Taconic Mountains - Disordered glaciated mountain area developed primarily on metasedimentary schists, slates and phylittes.

213. Rennselear Plateau - Glaciated plateau surface with relief generally expressed by broad swells and long slopes. Rock type is primarily Cambrian quartzites.

214. Limestone Valley of Vermont - This lowland area is not as continuous as noted by the diagram. The valley is underlain primarily by Cambrian limestones, dolomites and marble.

215. Green Mountains - Structurally complex mountainous area of primarily PreCambrian metamorphic rocks (schists, gneisses and quartzites) that have been intruded by granite and basic igneous rocks. The area is glaciated.

216. White Mountains - Somewhat irregular and indefinitely delineated area containing several mountain groups. Continental as well as alpine glaciation covers bedrock of extreme complexity. Rock types are chiefly early Paleozoic and PreCambrian igneous and metamorphic.

217. Northern New England Slate/Shale Area - This area is a maturely dissected peneplained surface which slopes gradually to the southeast. Stoney granular Wisconsin drift overlies bedrock, generally, at very thin depths. The underlying bedrock of this area is primarily developed upon sandstones, shales and slates interrupted by scattered granitic intrusions.

218. Seaboard Lowland - Seaboard sloping margin possessing smoother topography (relative to the Northern and Southern Upland units), underlain by bedrock identical to that found in the adjacent upland units, and characterized, in part, by marine deposits thought to be a result of late Pleistocene submergence.

219. Southern New England Upland - The overall topographic features of this area are similar to the Northern Slate/Shale unit. This area differs, however, from the latter, by being underlain primarily by an uplifted and tilted peneplain of granite and schist. Glacial drift characteristics are also similar to the Northern unit.

220. Connecticut Lowland - Extensively glaciated lowland area underlain by weak Triassic sandstones and shales containing numerous igneous (trap) ridges.

221. Cape Cod - Glaciated area exhibiting hummocky topography underlain by granular unconsolidated coastal plain deposits.

222. Long Island - Similar in general characteristics to the Cape Cod unit.

223. Raritan Lowland - Lowland area developed on weakly resistant Cretaceous clays (for the most part) of coastal plain origin.

224. Atlantic and East Gulf Terraced Coastal Plain - This rather extensive strip of land mass is primarily the terraced (outer) portion of the Coastal Plain. A series of terraces, primarily of granular (sandy) character are evident throughout the area. Extreme outer portions of the unit frequently possess swampy areas due to relatively high ground water zone. In the northern portion of the unit, embayments reach back almost to the fall line border.

225. Mississippi Loessial Upland - Upland area mantled with loessial deposits gradually thinning and disappearing as one proceeds to the east part of the unit.

226. Mississippi Alluvial Plain - Alluvial and deltaic plain area of the Mississippi and Red Rivers. Alluvial terraces are found inland and coastwise deltaic terraces along its seaward margin. The sediments for the most part are fine textured.

227. Crowley's Ridge - Upland area existing within the confines of the Mississippi Alluvial Plain developed by Loess deposits generally overlying granular coastal

sediments.

228. Blackland Prarie - Lowland area of gently undulating character which is developed upon upper Cretaceous limestones and marls of the Coastal Plain.

229. West Gulf Terraced Coastal Plain - This outer coastal plain area consists in general, of marine clays of Quaternary age.

230. West Gulf Coastal Plain - This unit topographically represents a series of alternating inland facing cuesta and lowlands developed primarily on Tertiary coastal plain sediments.

231. Florida Lime Sink Region - This unit, though somewhat indefinite in delineation, represents the area where the Ocalla uplift significantly modifies the terrain in the Florida Section. Karst features are extensively developed in the area and are generally overlain by recently emergent sandy terrace deposits of the coastal plain.

232. Sand and Fall Line Hills - This area is the innermost zone or strip of belted areas quite pronounced in the East Gulf Coast Section and portion of the Sea Island Section of the Woods-Lovell Classification. The unit is primarily a belt of maturely dissected hills produced on the oldest Cretaceous formations of the coastal plain. Texturally, these deposits are primarily quite granular in nature.

233. Ripley Cuesta - This cuesta or escarpment type area is an upland belt formed on the late Cretaceous sandy Ripley formation.

234. Pontotac Ridge - This unit is essentially the same as the Ripley Cuesta unit being only geographically separated due to thinning out of the Ripley formation in west central Alabama.

235. Black Belt - This unit is a lowland unit developed on the weak Cretaceous Selma chalk.

236. Flatwoods - This unit is a lowland developed on Eocene clays (Midway). The character of this formation is not as "clayey" as those to the north in the Black Belt unit and subsequently relief within the area is slightly greater.

237. Red Hills - This upland, or escarpment area is formed on the Eocene Wilcox formation (sandy). Dissection of this formation is variable, ranging from mature to

undissected.

238. Buhrstone Cuesta - This upland area is a cuesta type belt developed upon the very resistant Buhrstone formation of Tertiary age.

239. Jackson Prairie - This lowland belt is developed on clays of the Eocene Jackson formation.

240. Dougherty Plains - This area is a relatively flat plain forming an upland developed on Tertiary limestones. Karst features are evident in the area and in general, the unit is quite similar to the Florida Lime-Sink unit.

241. Tifton Uplands - This upland area is submaturely dissected and exhibits topography which is generally rolling hill type. The parent material of the coastal deposits in this unit are primarily Miocene in age.

242. Southern Pine Hills - This hilly area is the outermost of the cuesta (belted) coastal areas. Coastal sediments are primarily late Tertiary in age and the caprock of the area is generally the gravelly Pliocene Citronelle formations.

BIBLIOGRAPHY

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Because of the rather wide range of subject areas considered in this report, the bibliography is divided into four groupings based upon the major subjects discussed. Within each grouping, references are arranged in alphabetical sequence. The numeric listing of the references is, however, maintained continuously between the subject areas. Multiple listings within different major subject groups, for a particular reference, are made for those references whose contents are pertinent to more than one major subject area. The references cited for high volume change soils are those from an unpublished report by H. P. Jensen.

Regional Physiography (Geomorphology)

1. Agricultural and Industrial Development Board of Kentucky, "Land Areas of Kentucky and Their Potential for Use," Frankfort, 1953.

2. American Geological Institute, "Glossary of Geology and Related Sciences - With Supplement," 2nd Edition, November 1960.

3. Atwood, W. W., "The Physiographic Provinces of North America," Ginn and Company, 1940.

4. Averitt, P., "Coal Reserves of the United States," Progress Report, US. Geological Survey Bulletin 1136, 1960.

5. Baker, R. F., Chieruzzi, R., "Regional Concept of Landslide Occurence," Highway Research Board, Bulletin 216, 1959.

6. Beckman, H. C., Hinchez, N. S., "The Large Springs of Missouri, "*Missouri Geological Survey and Water Resources, Volume 29, 2nd series*, 1944.

7. Belcher, D. J., Gregg, I. E., Woods, K. B., "The Formation, Distribution and Engineering Characteristics of Soils," *Joint Highway Research Project Bulletin No. 87*, Purdue University, 1943.

8. Black, R. F., "The Physical Geography of Wisconsin, "*Reprint from Blue Book*, Department of Geology, University of Wisconsin.

9. Branch, J. R., "The Geology of Flora Quadrangle," *North Dakota Geological Survey Bulletin No. 22*, 1947.

10. Bryan, K., "The Formation of Pediments," *Report 16th International Geological Congress, Part II*, 1935.

11. "Bulletin No. 17, Maryland Department of Geology, Mines, Water Resources," 1956.

12. "Bulletin No. 37, Minnesota Geologic Survey," University of Minnesota, *Minn. Rocks and Waters* (by Sins, P.K.), 1963.

13. Bureau of Mines, Manufacturing and Agriculture, "Minerals of Arkansas," 1925.

14. Carter, R. L., Giddens, J., "Soils of Georgia - Their Formation, Classification and Management," *University of Georgia College of Agriculture, Bulletin No. 52*, January 1953.

15. Cherry, R. N., "Chemical Quality of Water of Georgia Streams - A Reconnaissance Study," *Georgia State Division of Conservation, Geological Survey Bulletin No. 69*, 1961.

16. Cornell University, "Soils and Soil Associations of New York," *Bulletin No. 930*, Revised May 1961.

17. Corps of Engineers, "Engineering and Design, Pavement Design for Frost Conditions" EM-1110-345-306.

18. Fenneman, N. M., "Physiography of Eastern United States," *McGraw - Hill Book Company*, New York, 1938.

19. Fenneman, N. M., "Physiography of Western United States," *McGraw - Hill Book Company*, New York, 1931.

20. Flint, R. F., "Physical Divisions of South Dakota," *Professional Paper No. 262*, U. S. Geologic Survey.

21. Flint, R. F., "The Surficial Geology of the New Haven and Woodmont Quadrangles," State Geological and Natural History Survey of Connecticut, Quadrangle Report No. 18, 1965.

22. Florida Agricultural Experimental Station," Major Land Resources of Florida - General Soil Map of Florida," May 1962.

23. Freeman, O. W., Forrester, J. D., Lupher, R. L., "Physiographic Divisions of the Columbia Intermontane Province," Association of American Geographers, Annals, 1945.

24. Geological Society of America, "Glacial Map of North America," New York, 1945 (Scale 1:4,555,000).

25. Geological Survey of West Virginia, "Physiographic Divisions of West Virginia." (Map)

26. Girralnik, D. B. (Editor-in-Chief) "Webster's New World Dictionary and Student Handbook," The Southwestern Company, 1966.

27. Hammond, E. H., "Classes of Land-Surface Form in the Forty-Eight States, U. S. A., "University of Wisconsin, 1963 (Scale 1;5,000,000).

28. Hardesty, J. S., "Land Resource Areas of Maine," U. S. Department of Agriculture, July 1957.

29. John, R. H., Editor, "Geology of Southern California," Division of Mines, Department of Natural Resources, Bulletin 170, San Francisco, California, September, 1954.

30. Jenkins, D. S., Belcher, D. J., Gregg, I. E., Woods, K. B., "The Origin, Distribution and Airphoto Identification of United States Soils" Technical Development Report No. 52, Civil Aeronautics Administration, 1946.

31. Jenkins, O. P., "Geomorphic Map of California" State of California, Department of Natural Resources Bulletin 188, Plate 2, 1938.

32. Karraker, P. E., "Soils of Kentucky." University of Kentucky, Circular 67 (Revised), June 1955.

33. Kentucky Geological Survey, "Physiographic Divisions of Kentucky." (Map)

34. Latimer, W. J., "Soil Survey of Vermont - Reconnaissance," No. 43, Series 1930, U. S. Dept. of Agriculture.

35. Leighton, M. N., Ekblaw, G. E., Horberg, I., "Illinois State Geological Survey Report of Investigations No. 129."

36. Leighton, M. M., Willman, H. B., "Loess Formations of the Mississippi Valley," Journal of Geology, Vol. 58, 1960.

37. Lobeck, A. K., "Geologic Map of the United States, The Geographical Press, Columbia University, New York, 1941 (Revised 1948).

38. Lobeck, A. K., "Physiographic Diagram of North America," The Geographical Press, C. S. Hammond and Co., Maplewood, New Jersey, 1950 (includes Physiographic Province diagram and accompanying text discussion).

39. Mallott, C. A., "Handbook of Indiana Geology - Part II," Indiana Dept. Cons. Publ. No. 21, 1922.

40. Marbut, C. F., "Atlas of American Agriculture, Part III, Soils of the United States," U. S. Department of Agriculture, 1935.

41. McAlpin, G. W., Hofmann, W. P., "Soil Explorations," Section 10, Highway Engineering Handbook, McGraw - Hill Company, New York 1960.

42. Miles, R. D., Scholer, C. F., Shurig, D. G., Woods, K. B., Yoder, E. J., "Regional Factors Influencing Highway Pavement Design and Performance", unpublished NCHRP Interim Report 1-3(1), September 1965.

43. Miltary Engineering Experimental Establishment, "Field Trials of a Terrain Classification System Organization and Methods," MEXE No. 873, England, August, 1965.

44. Miltary Engineering Experimental Establishment, "Report of the Working Group on Land Classification and Data Storage," MEXE No. 940, England, February 1966.

45. Miller, D. W., "Water Atlas of the United States," Water Information Center, Port Washington, New York, 1962.

46. Neal, J. T., Captain, USAF (Editor), "Geology, Mineralogy, and Hydrology of U. S. Playas," Air Force Cambridge Research Laboratories, Enviromental Research Papers No. 96, April 1965.

47. New York State Museum and Science Service, "Geology of New York - A Short Account," Albany, 1966.

48. North Carolina Agricultural Experiment Station, "The Soils of North Carolina - Their Formation, Identification and Use," December, 1955.

49. Pennsylvania Topographic and Geologic Survey, "Physiographic Provinces of Pennsylvania." (Map)

50. Puri, H. S., Vernor, R. C., "Summary of the Geology of Florida and a Guidebook to the Classic Exposures," Florida Geologic Survey Special Publication No. 5, 1959.

51. Raisz, E., "Landforms of the United States" (to accompany Atwood's Physiographic Provinces of North America), 1957.

52. Reed, R. D., "Geology of California," American Association of Petroleum Geologists, Tulsa, Oklahoma, 1951.

53. Ross, Forrester, "Geomorphic Map of Idaho and Adjacent Areas." Outline of Idaho Geology, Idaho Bureau of Mines and Geology Bullentin No. 15, May 1958.

54. Schoewe, W. H., "The Geography of Kansas, Part 2 - Physical Geography," Kansas Academy of Science Transaction, Volume 52, No. 3.

55. Schwartz, G. M., Prokopovich, N., "Map of Mineral Resources of Minnesota," University of Minnesota, Minnesota Geological Survey, 1956.

56. South Carolina Agricultural Experiment Station, "Soils of South Carolina," Agronomy and Soils Research Series 23, February 1960.

57. "South Dakota State Geologist Report of Investigation - No. 93," Geology of Selected Highway Strips in S.D. (by Cox E.J.)

58. Sparks, B., "Geomorphology," Longmans, Green and Company Ltd., London, England, 1960.

59. Stevant, D. P., "Glacial Geology of Vermont," Vermont Geological Survey Bulletin No. 19, 1961.

60. Storie, R. E., Harradine, F., "Soils of California," Reprint from Soil Science, Volume 85, No. 4, April, 1958.

61. Stose, G. W., Editor, "Preliminary Geologic Map of Washington," State of Washington, Division of Geology, Pullman, Washington, 1936.

62. Swanson, C. L. W., Shearin, A. E., Bourbeau, G. A., "Characteristics of Some Brown Podzolic Profiles in the Central Lowland of Connecticut and Massachusetts," Reprint from Soil Science Proceedings, Volume 16, No. 2, April, 1952.

63. Texas Agricultural Experiment Station, "Land Resources of Texas," No. L-400. (Map)

64. Thornbury, W. D., "Principles of Geomorphology," John Wiley and Sons, New York, 1954.

65. Thornbury, W. D., "Regional Geomorphology of the United States," John Wiley and Sons, New York, 1965.

66. Tolman, C. F., "Ground Water", McGraw - Hill Book Company, New York, 1937.

67. U. S. Department of Agriculture, "Climate and Men," Yearbook of Agriculture, U. S. Printing Office, 1940.

68. U. S. Department of Agriculture - Soil Conservation Service, "Descriptions of Soil Resource Areas in Connecticut," September, 1967.

69. U. S. Department of Agriculture - Soil Conservation Service (in cooperation with Colorado Agricultural Experiment Station) "Land Resource Areas of Colorado," General Series No. 727, April 1960.

70. U. S. Department of Agriculture - Soil Conservation Service, (in cooperation with the Illinois Agriculture Experiment Station), "Soils of Illinois," Bulletin No. 725, July, 1967.

71. U. S. Department of Agriculture - Soil Conservation Service (in cooperation with University of Arkansas Experimental Station), "Soil Association Map - State of Arkansas," April, 1959.

72. U. S. Department of Agriculture - Soil Conservation Service, "Major Land - Resource Areas - Arizona," September, 1964.

73. U. S. Department of the Interior, "Physical Divisions of the United States" (prepared by N. M. Fenneman in cooperation with the Physiographic Committee of the Geological Survey), 1946, (Map).

74. U. S. Geological Survey and American Association of Petroleum Geologists," Tectonic Map of the U. S.," 1962, (Scale 1;2,500,000).

75. U. S. Geological Survey, "Geologic Map of the United States," 1932 (Scale 1;2,500,000).

76. U. S. Geological Survey, "Relief Map of the United States," Department of the Interior. (Scale 1;7,000,000).

77. Virginia Polytechnic Institute, "Soils of Virginia," Bulletin 203, Engineering Extension Series, Revised March 1968

78. Washington Division of Mines and Geology, "Mineral and Water Resources of Washington," Bulletin No. 37, 1960.

79. Widmer, Kemble, "The Geology and Geography of New Jersey," Volume 19, The New Jersey Historical Series, 1964.

80. Wilson, E. D., "A Resume of the Geology of Arizona," Arizona Bureau of Mines Bulletin No. 171, 1962.

81. Winsor, J. H., Bailey, H. H., "A Key to Kentucky Soils." University of Kentucky Agricultural Experiment Station,(Map).

82. Woods, K. B., Lovell, C. W. Jr., "Distribution of Soils in North America," Section 9, Highway Engineering Handbook, McGraw - Hill, New York, 1960.

83. Woods, K. B., Lovell, C. W. Jr., "Physiographic Regions of North America Modified for Engineering Purposes," 1958 (Scale; 1;2,000,000).

84. Wright, H. E., Frey, D. G. et al, "The Quaternary of the United States," Princeton University Press, Princeton, New Jersey, 1965.

Aggregates

85. Alabama: NCHRP State Highway Materials Questionnaire Response, 1967.

86. Arizona: NCHRP State Highway Materials Questionnaire Response, 1967.

87. Arkansas: NCHRP State Highway Materials Questionnaire Response, 1967.

88. Augenbaugh, N. B., Johnson, R. B., Yoder, E. J., "Degradation of Base Course Aggregates During Compaction", NCHRP Report, School of Civil Engineering, Purdue University, May 1963.

89. Balmer, G. G., Colley, B. E., "Laboratory Studies of the Skid Resistance of Concrete", Portland Cement Association D-109.

90. Bloom, M. J., "An Analysis of the Highway Frost Problem in the North Central United States", M. S. Thesis, Purdue University, August, 1965.

91. Bugg, S. L., Firmage, D. A., "Properties of Plain and Reinforced Limerock Concrete", Proceedings Highway Research Board, 1950.

92. California: NCHRP State Highway Materials Questionnaire Response, 1967.

93. Calvin, S., "The Buchanan Gravels: An Interglacial Deposit in Buchanan County, Iowa", American Geologist, Volume 17, 1896.

94. Collett, F. R., Warnick, C. C., Hoffman, D. S., "Prevention of Degradation of Basalt Aggregates Used in Highway Base Construction", Highway Research Board, Bulletin 344, 1962.

95. Colorado: NCHRP State Highway Materials Questionnaire Response, 1967.

96. Connecticut: NCHRP State Highway Materials Questionnaire Response, 1967.

97. Day, H. L., "Progress Report on Studies of Degrading Basalt Aggregate Bases", Highway Research Board Bulletin No. 344, 1962.

98. Delaware: NCHRP State Highway Materials Questionnaire Response, 1967.

99. Fenneman, N. M., "Physiography of Eastern United States", McGraw - Hill Book Company, New York, 1938.

100. Fenneman, N. M., "Physiography of Western United States", McGraw - Hill Book Company, New York, 1931.

101. Florida: NCHRP State Highway Materials Questionnaire Response, 1967.

102. French, R. R., Carr, D. C., "Geologic Factors Affecting the Exploration for Mineral Aggregates in the Indianapolis Area", Proceedings, 18th Annual Highway Geology Symposium, Purdue University, April, 1967.

103. French, R. R., "Crushed Stone Resources of the Devonian and Silurian Carbonate Rocks of Indiana", Department of Natural Resources Geological Survey Bulletin No. 37, 1967.

104. French, R. R., "Indiana's Crushed Stone Industry: 1947-1965", Indiana Business Review, Volume XLII, 1967.

105. Georgia: NCHRP State Highway Materials Questionnaire Response, 1967.

106. Gibson, W. E., "A Study of Map Cracking in Sand-Gravel Pavements," Proceedings, Highway Research Board, 1938, (Part I).

107. Gillson, J. L. et al, "The Carbonate Rocks", Chapter 8, Industrial Minerals and Rocks, American Institute of Mining, Metallurgical and Petroleum Engineers, New York, 1960.

108. Goetz, W. H., Wood, L. E., "Bituminous Materials and Mixtures", Section 18, Highway Engineering Handbook, (Edited by K. B. Woods), McGraw - Hill, New York, 1960.

109. Goodwin, W. A., "Aggregate Characteristics Influencing Skid Resistance," National Limestone Institute, Limestone, Fall, 1968.

110. Gray, J. E., Renninger, F. A., "The Skid-Resistant Properties of Carbonate Aggregates", Highway Research Record No. 120, 1965.

111. Gregg, L. E., Havens, J. H., "Application of Geology to Highway Engineering in Kentucky", Fourth Annual Symposium on Geology as Applied to Highway Engineering, Morris Harvey College, Charleston, West Virginia, 1953.

112. Hadley, D. W., "Alkali Reactivity of Carbonate Rocks", Portland Cement Association, Research Department Bulletin, No. 139.

113. Hansen, W. C., "Attack on Portland Cement Concrete by Alkali Soils and Waters - A Critical Review", Highway Research Record No. 113, 1965.

114. Havens, J. H., Williams, E. G., "A Study of the Properties and Performance of Kentucky (Natural Sandstone) Rock Asphalt", Report, Kentucky Department of Highways, Highway Research Laboratory, University of Kentucky, Lexington, 1956.

115. Highway Research Board, "Report of Committee on Warping of Concrete Pavements", Proceedings, Highway Research Board, 1945.

116. Hveem, F. N., Smith, T. W., "A Durability Test for Aggregates", Highway Research Record No. 62, 1963.

117. Idaho: NCHRP State Highway Materials Questionnaire Response, 1967.

118. Illinois: NCHRP State Highway Materials Questionnaire Response, 1967.

119. Indiana Department of Conservation, "Generalized Geologic Map of Indiana", Survey Report of Progress No. 7, 1956.

120. Indiana: NCHRP State Highway Materials Questionnaire Response, 1967.

121. Iowa: NCHRP State Highway Materials Questionnaire Response, 1967.

122. Iowa State Highway Commission, "Iowa - An Engineering Report on Soils, Geology, Terrain and Climate", Ames, Iowa, 1959.

123. Jenkins, D. S., Belcher, D. J., Gregg, L. E., Woods, K. B., "The Origin, Distribution and Airphoto Identification of United States Soils," Technical Development Report No. 52, Civil Aeronautics Administration, 1946.

124. Jones, T. R., Jr., Hirsch, T. J., "Creep and Shrinkage in Lightweight Concrete", Proceedings, Highway Research Board, 1959.

125. Kansas: NCHRP State Highway Materials Questionnaire Response, 1967.

126. Kentucky: NCHRP State Highway Materials Questionnaire Response, 1967.

127. Kentucky Rock Asphalt Institute, "Kentucky Rock Asphalt - Specifications and Designs", April, 1937.

128. Klinefelter, T. A., "Lightweight Aggregates", Chapter 22, Industrial Minerals and Rocks, American Institute of Mining, Metallurgical and Petroleum Engineers, New York, 1960.

129. Landgren, R., Sweet, H. S., "Investigation of Durability of Wyoming Aggregates", Proceedings, Highway Research Board, 1952.

130. Leighton, M. M., "The Road Building Sands and Gravels of Washington," Bulletin No. 22, Washington Geological Survey, Olympia, Washington, 1919.

131. Lenhart, W. B., "Sand and Gravel", Chapter 41, Industrial Minerals and Rocks, American Institute of Mining, Metallurgical and Petroleum Engineers, New York, 1960.

132. Lewis, D. W., "Research on Concrete Aggregates", Purdue University Engineering Experiment Station, Engineering Reprint No. 61, 1950.

133. Louisiana Geological Society, "Generalized Map of Louisiana Showing Regions of Gravel Exposures", Louisiana Geological Bulletin, No. 19.

134. Louisiana: NCHRP State Highway Materials Questionnaire Response, 1967.

135. Lossing, F. A., "Sulphate Attack on Concrete Pavements in Mississippi", Highway Research Record No. 113, 1965.

136. Maine: NCHRP State Highway Materials Questionnaire Response, 1967.

137. Marbut, C. F., "Atlas of American Agriculture, Part III, Soils of the United States", U. S. Dept. of Agriculture, 1935.

138. Maryland: NCHRP State Highway Materials Questionnaire Response, 1967.

139. Massachusetts: NCHRP State Highway Materials Questionnaire Response, 1967.

140. Maytin, I. L., Gilkeson, R., "Soils of Walla-Walla County", Engineering Soils Manual, Bulletin 257, State College of Washington, Pullman, Washington, 1962.

141. Maytin, I. L., Stan, W. A., "Soils of Yakima County", Engineering Soils Manual, Bulletin 249, State College of Washington, Pullman, Washington, 1960.

142. McLaughlin, J. F., Woods, K. B., Mielenz, R. C., Rockwood, N. C., "Distribution, Production, and Engineering Characteristics of Aggregates", Section 16, Highway Engineering Handbook (Edited by K. B. Woods), McGraw - Hill, New York, 1960.

143. Michigan: NCHRP State Highway Materials Questionnaire Response, 1967.

144. Miles, R. D., Scholer, C. F., Shurig, D. G., Woods, K. B., Yoder, E. J., "Regional Factors Influencing Highway Pavement Design and Performance",unpublished NCHRP Interim Rpt. 1-3(1), September, 1965.

145. Mississippi: NCHRP State Highway Materials Questionnaire Response, 1967.

146. Missouri: NCHRP State Highway Materials Questionnaire Response, 1967.

147. Moavenzadeh, F., Goetz, W. H., "Aggregate Degradation in Bituminous Mixtures", Highway Research Record No. 24, 1963.

148. Montana: NCHRP State Highway Materials Questionnaire Response, 1967.

149. Moultrop, K., "Rhode Island Aggregate Survey", Division of Engineering Research and Development, University of Rhode Island, Kingston, Rhode Island, June 1964.

150. Nebraska: NCHRP State Highway Materials Questionnaire Response, 1967.

151. Neveda: NCHRP State Highway Materials Questionnaire Response, 1967.

152. Neville, A. M., "Properties of Concrete", John Wiley and Sons, 1963.

153. New Hampshire: NCHRP State Highway Materials Questionnaire Response, 1967.

154. New Jersey: NCHRP State Highway Materials Questionnaire Response, 1967.

155. New Mexico: NCHRP State Highway Materials Questionnaire Response, 1967.

156. New York, NCHRP State Highway Materials Questionnaire Response, 1967.

157. New York State Museum and Science Service, "Geology of New York - A Short Account", Albany, 1966.

158. Newlon, H. H., Sherwood, W. C., "An Occurrence of Alkali-Reactive Carbonate Rock in Virginia", Highway Research Board Bulletin No. 355, 1962.

159. North Carolina: NCHRP State Highway Materials Questionnaire Response, 1967.

160. North Dakota: NCHRP State Highway Materials Questionnaire Response, 1967.

161. Ohio: NCHRP State Highway Materials Questionnaire Response, 1967.

162. Oklahoma: NCHRP State Highway Materials Questionnaire Response, 1967.

163. Ontario Department of Highways, "Research on Skid Resistance", Rpt. No. 114, Ontario, Canada, 1966.

164. Orchard, D. F., "Concrete Technology - Volume 2", John Wiley and Sons, 1962.

165. Oregon: NCHRP State Highway Materials Questionnaire Response, 1967.

166. Osborne, A., "Frost Barrier for Highway and Airfield Regional Studies", Part II, Dow Chemical Company, 1967.

167. Pennsylvania: NCHRP State Highway Materials Questionnaire Response, 1967.

168. Pergendoff, R. N., "Research Studies in Connection With Design Features of the Florida Turnpike", Proceedings, Highway Research Board, 1958.

169. Pit and Quarry Publications, "Pit and Quarry Directory of the Non Metallic Minerals Industries", Chicago, Illinois, 1965.

170. Portland Cement Association, "Aggregates for Concrete," Portland Cement Association, 1962.

171. Rhoades, R., Mielenz, R. C., "Petrographic and Mineralogic Characteristics of Aggregates", Special Technical Publication No. 83, American Society for Testing and Materials, 1948.

172. Rigid Pavement Laboratory, Corps of Engineers, "Report of Aggregate Availability in Continental United States", Ohio River Division, Corps of Engineers, Mariemont, Ohio, December, 1952.

173. Schuster, R. L., McLaughlin, J. F., "A Study of Chert and Shale Gravel in Concrete", Highway Research Board Bulletin No. 305, 1961.

174. Schwartz, G. M., Prokopovich, N., "Map of Mineral Resources of Minnesota", University of Minnesota, Minnesota Geological Survey, 1956.

175. Severinghause, N., "Crushed Stone", Chapter 13, Industrial Minerals and Rocks, American Institute of Mining, Metallurgical and Petroleum Engineers, New York, 1960.

176. Shupe, J. W., Goetz, W. H., "A Laboratory Investigation of Pavement Slipperiness", Purdue University Engineering Reprint No. CE 174, June, 1960.

177. Shupe, J. W., "Pavement Slipperiness", Section 20, Highway Engineering Handbook, (Edited by K. B. Woods), McGraw - Hill, New York, 1960.

178. Stephens, J. E., Goetz, W. H., "Designing Fine Bituminous Mixtures for High Skid Resistance," Purdue University Engineering Reprint, CE 181, January, 1961.

179. Stose, G. W., "Preliminary Geologic Map of Washington", State of Washington, Division of Geology, Pullman, Washington, 1936.

180. South Dakota: NCHRP State Highway Materials Questionnaire Response, 1967.

181. Swineford, A., "Cemented Sandstone of the Dakota and Kiowa Formations in Kansas", State Geological Survey of Kansas, Bulletin 70, Part 4, Lawrence, Kansas, 1947.

182. Tennessee: NCHRP State Highway Materials Questionnaire Response, 1967.

183. Texas: NCHRP State Highway Materials Questionnaire Response, 1967.

184. Thornbury, W. D., "Regional Geomorphology of the United States", John Wiley and Sons, New York, 1965.

185. Tolman, C. F., "Ground Water", McGraw - Hill Book Company, New York, 1937.

186. Tremper, B., "Freeze-Thaw Resistance of Concrete as Affected by Alkalies in Cement", Proceedings, American Society for Testing and Materials, 1951.

187. United States Department of Commerce Bureau of Public Roads, "Results of Physical Tests of Road Building Aggregate", Washington, D. C., 1953.

188. United States Department of the Interior, "Volume 1, Metals and Minerals (Except Fuels)", 1964 Minerals Yearbook, Washington, D. C., 1965.

189. United States Department of the Interior, "Volume 3, Area Reports: Domestic", 1964 Minerals Yearbook, Washington, D. C., 1965.

190. United States Geological Survey, "Geologic Map of the United States", 1932.

191. Utah: NCHRP State Highway Materials Questionnaire Response, 1967.

192. Vermont: NCHRP State Highway Materials Questionnaire Response, 1967.

193. Virginia: NCHRP State Highway Materials Questionnaire Response, 1967.

194. Washington: NCHRP State Highway Materials Questionnaire Response, 1967.

195. Washington State Division of Mines and Geology, "Sand and Gravel", Division of Mines and Geology, Bulletin No. 37, Part I, Plate 33 (Sand and Gravel Pits of Washington); Plate 34 (Map Showing Principal Areas of Sand and Gravel).

196. West Virginia: NCHRP State Highway Materials Questionnaire Response, 1967.

197. Wisconsin: NCHRP State Highway Materials Questionnaire Response, 1967.

198. Witczak, M. W., "Physiographic Areas of the United States", Vol. I of a NCHRP Report in Preparation, 1968.

199. Woods, K. B., Johnstone, J. C., Yoder, E. J., "Some Engineering Problems Associated with the Preglacial Marietta River Valley", Fourth Annual Symposium on Geology as Applied to Highway Engineering", Charleston, West Virginia, 1953.

200. Woods, K. B., Lovell, C. W. Jr., "Distribution of Soils in North America", Section 9, Highway Engineering Handbook, (Edited by K. B. Woods), McGraw - Hill, New York, 1960.

201. Woods, K. B., "Materials and Engineering Problems of North America", unpublished course notes, Graduate School of Civil Engineering, Purdue University.

202. Woods, K. B., Sweet, H. S., Shelbourne, T. E., "Pavement Blowups Correlated with Source of Coarse Aggregate", Proceedings, Highway Research Board, 1945.

203. Woolf, D. O., "Field Experience with Alkali - Aggregate Reaction in Concrete: Eastern United States", Highway Research Board, Research Report 18-C, 1958.

204. Wright, H. E., Frey, D. G., et al, "The Quarternary of the United States", Princeton University Press, Princeton, New Jersey, 1965.

205. Wyoming: NCHRP State Highway Materials Questionnaire Response, 1967.

Soils - Origin and Texture

206. Agricultural and Industrial Development Board of Kentucky, "Land Areas of Kentucky and Their Potential For Use", Frankfort, 1953.

207. Alabama Department of Agriculture and Industries, "Soil Map - State of Alabama", Montgomery, Alabama, 1953.

208. Arneman, H. F., "Soils of the Red River Valley", Reprint, Minnesota Farm and Home Science, 1961.

209. Beaumont, A. B., "Soil Associations of Massachusetts", United States Department of Agriculture Extension Service, Massachusetts State College, 1939.

210. Beaumont, A. B., "The Soils of Massachusetts", University of Massachuetts Special Circular No. 64, January, 1950.

211. Belcher, D. J., Gregg, L. E., Woods, K. B., "The Formation, Distribution and Engineering Characteristics of Soils" Joint Highway Research Project Bulletin No. 87, Purdue University, 1943.

212. Bourbeau, G. A., Swanson, C. L. W., "The Morphology, Mineralogy and Genesis of Two Southern New England Soils", Connecticut Agricultural Experiment Station Bulletin 584, June, 1954.

213. Buick, T. R., "Analysis and Synthesis of Highway Pavement Design", Joint Highway Research Project, No. 13, Purdue University, July, 1968.

214. Bunting, B. T., "The Geography of Soil", Aldine Publishing Company, Chicago, Illinois, 1965.

215. Carter, R. L., Giddens, J., "Soils of Georgia - Their Formation, Classification and Management", College Experiment Station Bulletin No. 2, Athens, Georgia, January, 1953.

216. Cline, M. G., "Soils and Soil Associations of New York", Cornell Extension Bulletin 930, May, 1961.

217. Collings, G. H., Montgomery, P. H., "Land Resource Areas - State of South Carolina", South Carolina Experiment Station Circular 112, June 1957.

218. Colorado Agricultural Experiment Station, "Land Resource Areas of Colorado", General Series 727, April, 1960.

219. Corps of Engineers, "Forecasting Trafficability of Soils - Airphoto Approach", Technical Memorandum No. 3-331, Report 6, Volume II, June, 1963.

220. Davisdon, D. T. et al. "Geologic and Engineering Properties of Pleistocene Materials in Iowa", Bulletin No. 20, Iowa Highway Research Board, December, 1960.

221. Donahue, R. L., Templin, E. H., Thornton, M. K., Miller E. A., "The Soils of Texas", Texas Agricultural Experiment Station Bulletin 431, 1948.

222. Dregne, H. E., "Soils of Idaho", Mimeo-Leaflet No. 107, University of Idaho Department of Agronomy, June, 1947.

223. Epperson, G. R., Porter, H. C., "A Key to the Soils of the Southern Piedmont of Virginia", Virginia Polytechnic Institute of Agronomy Circular, No. 3, June, 1962.

224. Fehrenbacker, J. B., "Loess Distribution and Composition in Portions of the Lower Wabash and Chio River Basins", PhD Thesis, Purdue University, June, 1964.

225. Federal Housing Administration, "Engineering Soil Classification for Residential Developments", FHA No. 373, 1961.

226. Federal Housing Administration, "Evaluation of Soils and Use of Soil Surveys for Engineering Purposes in Urban Development", FHA No. 723, October, 1963.

227. Florida Agricultural Experiment Stations, "General Soil Map of Florida", May, 1962.

228. Florida State Geological Survey, "Generalized Soil Map of Florida", 1925.

229. Foss, J. E., Rust, R. H., "Soil Development in Relation to Loessial Deposition in Southeastern Minnesota", Reprint, Soil Science Society Proceedings, Vol. 26, No. 3, June, 1962.

230. Hampton, D., Yoder E. J., Burr, I. W., "Variability of Engineering Properties of Brookston and Crosby Soils", Purdue University Civil Engineering Reprint 199, July, 1963.

231. Hill, D. E., Gonick, W. N., "The Paxton Soils", Connecticut Experiment Station Bulletin 662, December, 1963.

232. Hole, D. F., Beatty, M. T., "Soils of Wisconsin - A Generalized Map", University of Wisconsin, Madison, Wisconsin, 1957.

233. Illinois Agriculture Experiment Station, "Soils of Illinois", Bulletin No. 725, July, 1967.

234. Iowa State Highway Commission, "Iowa - An Engineering Report on Soils, Geology, Terrain and Climate", Ames, Iowa, 1959.

235. Iowa State University Cooperative Extension Service, "Principal Soil Association Areas of Iowa", Ames, Iowa, June, 1950.

236. Jenkins, D. S., Belcher, D. J., Gregg, L. E., Woods, K. B., "The Origin, Distribution and Airphoto Identification of United States Soils", Technical Development Report No. 52, Civil Aeronautics Administration, 1946.

237. Jenny, H., "Factors of Soil Formation", McGraw - Hill Book Co., New York, 1941.

238. Joint Highway Research Project, Purdue University, "Engineering Soil Parent Material Areas of Indiana", (Revised Edition of 1943 Map of Bulletin No. 87), 1950.

239. Karraker, P. E., "Soils of Kentucky", University of Kentucky Agricultural Experiment Station, Circular 67, June, 1955.

240. Latimer, W. J., "Soil Survey of Vermont - Reconnaissance", U. S. Department of Agriculture No. 43, Series 1930.

241. Lee, W. D., Goldston, E. F., "North Carolina Soil Association Map", 1955.

242. Ligon, W. S., Karraker, P. E., "A Key to Kentucky Soils", Kentucky Agricultural Experimental Station Circular 64, November, 1949.

243. Linell, K. A., "Frost Action and Permafrost", Section 12, Highway Engineering Handbook, (Edited by K. B. Woods), McGraw - Hill, New York, 1960.

244. Liu, T. K., "A Review of Engineering Soil Classification Systems", Highway Research Board Record No. 156, 1967.

245. Louisiana Agricultural Extension Service, "Soil Divisions of Louisiana", Agricultural Extension Publication 1217, September, 1961.

246. Mangum, A. W. et al, "Reconnaissance Survey of Southwestern Washington", U.S.D.A. Report, May, 1913.

247. Mangum, A. W. et al, "Reconnaissance Survey of the Western Part of the Puget Sound Basin, Washington", U.S.D.A. Report, June, 1912.

248. Marbut, C. F., "Atlas of American Agriculture, Part III, Soils of the United States", U. S. Department of Agriculture, 1935

249. McMiller, P. R., "Soils of Minnesota", University of Minnesota Agricultural Extension Service Bulletin No. 278, December, 1954.

250. Miles, R. D., Scholer, C. F., Shurig, D. G., Woods, K. B., Yoder, E. J., "Regional Factors Influencing Highway Pavement Design and Performance", unpublished NCHRP Interim Report 1-3 (1), September, 1965.

251. Military Engineering Experimental Establishment, "Field Trials of a Terrain Classification System Organization and Methods", MEXE No. 873, England, August, 1965.

252. Military Engineering Experimental Establishment, "Report of the Working Group on Land Classification and Data Storage", MEXE No. 940, England, February, 1966.

253. Mississippi State Department of Agriculture, "Soil Map of Mississippi", Jackson, Mississippi, 1942.

254. Morse, R. K., Thornburn, T. H., "Reliability of Soil Map Units", University of Illinois Civil Engineering Studies, Soil Mechanics Series No. 5, 1961.

255. Neal, J. T., Captain, USAF (Editor), "Geology, Mineralogy, and Hydrology of U. S. Playas", Air Force Cambridge Research Laboratories, Environmental Research Papers No. 96, April, 1965.

256. New Jersey Agricultural Experiment Station, "Land Type Areas of New Jersey", (Map).

257. New York State College of Agriculture, "Soil Association Map of New York State", Department of Agronomy, Cornell University, 1961.

258. North Carolina Agricultural Experiment Station, "The Soils of North Carolina - Their Formation, Identification and Use", Technical Bulletin No. 115, December, 1955.

259. North Dakota Agricultural College, "General Soil Areas of North Dakota", 1941.

260. Ohio Department of Natural Resources, "Our Ohio Soils", Division of Lands and Soil, April, 1958.

261. Pomerening, J. A., "Soil Association Map of Maryland", Department of Agronomy, 1962.

262. Portland Cement Association, "PCA Soil Primer", Chicago, Illinois, 1962.

263. Prince, A. B., Raney, W. A., (Review Editors), "Some Morphological, Physical, and Chemical Properties of Selected Northeastern United States Soils", University of New Hampshire Agricultural Experiment Station Miscellaneous Publication 1, June, 1961.

264. Quakenbush, G. A., "Our New Jersey Land", New Jersey Agricultural Experiment Station Bulletin 775, January, 1955.

265. Rust, R. H., Farnham, R. S., Robertson, A. S., "The Nebish Rockwood Soils of Northern Minnesota", Reprint, Minnesota Farm and Home Science, Vol. XVI, October, 1958.

266. Smith, J. B., Gilbert, B. E., "Rhode Island Soil Types: Texture and Chemical Composition, and a Utility Index", Rhode Island State College Agricultural Experiment Station Bulletin 296, March, 1945.

267. South Carolina Agricultural Experiment Station, "Soils of South Carolina - Keys for their Identification", Agronomy and Soils Research Series 23, Clemson, South Carolina, 1960.

268. South Dakota Agricultural Experiment Station, "Soils of South Dakota", Soil Survey Series No. 3, March, 1959.

269. State of Ohio Department of Natural Resources, "Know Ohio's Soil Regions", 1962.

270. Stevens, J. C., Maner, A. W., Shelburne, T. E., "Pavement Performance Correlated With Soil Areas", Virginia Council of Highway Investigation and Research, December, 1949.

271. Storie, R. E., Harradine, F., "Soils of California", Reprint, Soil Science Vol. 85, No. 4, April, 1958.

272. Storie, R. E., Weir, W. W., "Generalized Soil Map of California", California Agricultural Experiment Station Manual 6, Berkeley, California, April, 1951.

273. Swanson, C. L. W., Ritchie, A. Jr., "Significance of Sand and Gravel in the Classification, Mapping and Management of Some Coarse - Textured Soils", Connecticut Agricultural Experiment Station, Bulletin 580, January, 1954.

274. Tedrow, J. C. F., "Soils of New Jersey", New Jersey Agricultural Experiment Station, 1962.

275. University of Illinois Agricultural Experiment Station, "Principal Soil Association Areas of Illinois", April, 1962.

276. University of Missouri Agricultural Experiment Station, "Reconnaissance Survey Soil Map of Missouri", 1931.

277. University of Wisconsin Agricultural Experiment Station, "Soils of the North Central Region of the United States", Bulletin No. 544, June, 1960.

278. U. S. Department of Agriculture, "Soil Association Map of New England," 1959.

279. U. S. Department of Agriculture, "Soils and Men", Yearbook of Agriculture, 1938.

280. United States Department of Agriculture Soil Conservation,"A Look at the Caribou Soils", 1962.

281. United States Department of Agriculture Soil Conservation Service, "Description of Soil Resource Areas in Connecticut", September, 1959.

282. United States Department of Agriculture Soil Conservation Service, "General Soil Map - Vermont", 1962.

283. United States Department of Agriculture Soil Conservation Service, "Land Resource Areas of Maine", July, 1957, (Map).

284. United States Department of Agriculture Soil Conservation Service, "Major Land Rescurce Areas, Arizona", September, 1964, (Map).

285. United States Department of Agriculture Soil Conservation Service, "Soil Association Map, States of Arkansas, April, 1959.

286. United States Department of the Interior Geological Survey, "Soil Association Areas of Georgia", 1944,(Map).

287. Virginia Agricultural Experiment Station, "Certain Properties of Selected Southeastern United States Soils and Mineralogical Procedures for Their Study", Southern Regional Bulletin 61, January, 1959.

288. Virginia Agricultural Experiment Station, "Genesis and Morphology of Virginia Soils", Virginia Polytechnic Institute Bulletin 540, April, 1962.

289. Virginia Polytechnic Intitute and the United States Department of Agriculture, "A Key to the Soils of the Coastal Plains of Virginia", Virginia Polytechnic Institute Agronomy Circular, No. 4, February, 1963.

290. Virginia Polytechnic Institute and the United States Department of Agriculture, "A Key to the Soils of the Appalachian Division of Virginia", Virginia Polytechnic Institute Agronomy Circular, No. 2, July, 1960.

291. Virginia Polytechnic Institute and the United States Department of Agriculture, "Soils of Virginia", Virginia Polytechnic Institute Bulletin 203, March, 1958.

292. Wahls, H. E., Buchanan, W. T., Futrell, G. E., Lucas, S. P., "Distribution and Engineering Properties of North Carolina Soils", Engineering Research Department, North Carolina State, June, 1964.

293. Wahls, H. E., Futrell, G. E., "A Comparison of Soil Classification Systems by Analysis of Variance", Proceedings, National Conference on Statistical Quality Control Methodology in Highway and Airfield Construction, University of Virginia, 1966.

294. Washington State University, "Soils of the Western United States (exclusive of Hawaii and Alaska)", September, 1964.

295. Woods, K. B., Lovell, C. W. Jr., "Distribution of Soils in North America", Section 9, Highway Engineering Handbook, (Edited by K. B. Woods), McGraw - Hill, New York, 1960.

296. Woods, K. B., Miles, R. D., Lovell, C. W. Jr., "Origin, Formation and Distribution of Soils in North America", Chapter 1, Foundation Engineering (Edited by G. A. Leonards), McGraw - Hill Book Co., 1962.

297. Wright, H. E., Frey, D. G. et al., "The Quaternary of the United States", Princeton University Press, Princeton, New Jersey, 1965.

298. Yoder, E. J., "Principles of Pavement Design", John Wiley and Sons, 1959.

Soils - High Volume Change

299. Alabama Geological Survey, "Geology of Alabama", Alabama Geological Survey Special Report No. 14, 1926.

300. "Anonymus", "Homebuilders Protest New Slab Design Criteria", Engineering News - Record, January, 1966.

301. Bates, T. F., "The Application of Electron Microscopy in Soil Clay Mineralogy" in"Soil Clay Mineralogy - A Symposium" by Rich, C. I., Kunze, G. W., University of North Carolina, Chapel Hill, 1964.

302. Benson, J. R., Discussion of Holtz, W. G., "Expansive Clays - Properties and Problems", Quarterly Colorado School of Mines Vol. 54, No. 4, October, 1959.

303. Bolt, G. H., "Physico - Chemical Analysis of the Compressibility of Pure Clays", Geotechnique, 6:86, 1956.

304. Bradley, W. F., "X-Ray Diffraction Analysis of Soil Clays and Structure of Clay Minerals" in "Soil Clay Mineralogy - A Symposium" by Rich, C. I., Kunze, G. W., University of North Carolina, Chapel Hill, 1964.

305. Brindley, G. W., "Identification of Clay Minerals by X-Ray Diffraction Analysis" in "Clays and Clay Technology" Bulletin 169, Dept. of Natural Resources, State of California, 1955.

306. Brown, J. L., "Laboratory Techniques in the Electron Microscopy of Clay Minerals" in "Soil Clay Mineralogy-A Symposium", by Rich, C. I., Kunze, G. W., University of North Carolina, Chapel Hill, 1964.

307. Budge, W. D., Sampson, E., Jr., Schuster, R. L., "A Method of Determining Swell Potential of an Expansive Clay", HRB - Record No. 119, 1966.

308. Carson, A. B., "Foundation Construction", McGraw - Hill, New York, 1965.

309. Carter, W. T., "The Soils of Texas", Texas Agriculture Experiment Station Bulletin 431, 1931.

310. Chen, F. H., "The Use of Piers to Prevent the Uplifting of Lightly Loaded Structures Founded on Expansive Clays", International Research and Engineering Conference on Expansive Clay Soils, Texas A&M College Station, 1965.

311. Collins, L. E., "Some Observations on the Movement of Buildings on Expansive Soils in Vereeninging and Odendaalsrus", Symposium on Expansive Clays, The South African Inst. of Civil Engineers, 1957-58.

312. Department of Highways, State of Colorado and the University of Colorado, "A Review of Literature on Swelling Soils", Colorado, 1964.

313. Croney, D., Lewis, W. A., Coleman, D., "Calculation of the Moisture Distribution Beneath Structures", *Civil Engineering and Pudlic Works Rev. London, Vol. 45, No. 524*, 1950.

314. Croney, D., Coleman, D., Black, W. P. M., "Movement and Distribution of Water in Soil in Relation to Highway Design and Performance", *HRB - Special Report 40*, 1958.

315. Dawson, R. F., "Movement of Small Houses Erected on an Expansive Clay Soil" *Proc. 3rd International Conference - Soil Mechanics and Foundation Engineering, Vol. 1,* Switzerland, 1953.

316. Dawson, R. F.,"Modern Practices Used in the Design of Foundations for Structures on Expansive Soils", *Quarterly, Colorado School of Mines, Vol. 54, No. 4,* October, 1959.

317. Dodd, C. G., "Dye Absorption - A Method of Identifying Clays" in *Clays and Clay Technology, Bulletin 169*, Department of Natural Resources, State of California, 1955.

318. Dunnewald, T. J., "Wyoming Soils and Soil Materials", University of Wyoming Agricultural Experiment Station Bulletin 349, April, 1957.

319. Felt, E. J., "Influence of Soil Volume Change and Vegetation on Highway Engineering", *26th Highway Conference, University of Colorado Engineering Experiment Station Circular 26*, 1953.

320. Frye, J. C., Leonard, A. B., "Pleistocene Geology of Kansas", State Geological Survey of Kansas, *Bulletin 99*, 1962.

321. Giddens, J., Perkins, H. F., Carter, R. L., "Soils of Georgia", *Soil Science, Vol. 89*, 1957.

322. Giesecke, S. E., "Columns and Walls Lifted by Swelling Clay Under Floor" *Engineering News - Record, Vol. 88*, 1922.

323. Griffin, J. G., "Studies on Soil Movement Due to a Change in Moisture Content as It Affects Foundation Construction of Farm Houses", *Mississippi State University Agriculture Experiment Station Information Sheet 687*, December, 1960.

324. Griffin, J. G., "Soil Movement and Moisture Change as They Affect Footings and Foundations for Dwellings in Heavy Clay Soils", Mississippi State University Agriculture Experiment Station Information Sheet 767, June, 1962.

325. Grim, R. E., "Clay Mineralogy", McGraw - Hill, New York, 1953.

326. Grim, R. E., "Petrographic Study of Clay Minerals", Clays and Clay Technology, Department of Natural Resources, State of California, Bulletin 169, 1955.

327. Hardy, R. M., "Identification and Performance of Swelling Soil Types", Canadian Geotechnical Journal, Vol. II, No. 2, May, 1966.

328. Hepworth, R. C., "Heaving in the Subgrade of Highways Constructed on the Mancos Shale", Transactions AIME, Vol. 231, 1965.

329. Holtz, W. G., Gibbs, H. J., "Engineering Properties of Expansive Clays", Transactions ASCE, Vol. 121, 1956.

330. Holtz, W. G., "Expansive Clays - Properties and Problems", Quarterly of the Colorado School of Mines, Vol. 54, No. 4, October, 1959.

331. Jackson, M. L., MacKenzie, R. C., "Chemical Analysis in the Quantitative Mineralogical Examination of Clays" in "Soil Clay Mineralogy - A Symposium", by Rich, C. I., Kunze, W. C., University of North Carolina, Chapel Hill, 1964.

332. Jennings, J. E. B., Knight, K., "The Prediction of Total Heave from the Double Oedometer Test", Symposium on Expansive Clays, The South African Institute of Civil Engineering, 1957-58.

333. Jensen, H. P., "High Volume Change Soils - Distribution and Engineering Experience, U. S.", unpublished report, Purdue University, May, 1967.

334. Johnstone, J. G., Ramarathnan, S., Richards, D. B., "The Soils of Eastern Colorado, Their Origin, Distribution and Engineering Characteristics", Quarterly of the Colorado School of Mines, Vol. 57, No. 3, July, 1962.

335. Kassiff, G., Wiseman, G., "Control of Moisture and Volume Changes in Clay Subgrades by Subdrainage", HRB - Record No. 111, 1966.

336. Keller, W. D., "Processes of Origin and Alteration of Clay Minerals" in "*Soil Clay Mineralogy - A Symposium*" by Rich, C. I., Kunze, G. W., University of North Carolina, Chapel Hill, 1964.

337. Kelley, W. P., "Interpretation of Chemical Analysis of Clays" in "*Clays and Clay Technology", Bulletin 169*, Department of Natural Resources, State of California, 1955.

338. Kerr, P. F., "Formation and Occurrence of Clay Minerals" in "*Clays and Clay Technology", Bulletin 169*, Department of National Resources, State of California, 1955.

339. Kunze, G. W., Oakes, H., Bloodworth, M. E., "Grumusols of the Coast Prairie of Texas", *Soil Science Society of America, Proceedings 27:412*, 1951.

340. Ladd, C. C., "The Identification and Behavior of Expansive Clays", *Proceedings 5th International Conference on Soil Mechanics and Foundation Engineering*, Paris, 1961.

341. Ladd, C. C., Lambe, T. W., "Mechanism of Swelling by Compacted Clay", *HRB Bulletin 245*, 1960.

342. Ladd, E. F., "North Dakota Soils", *North Dakota Agriculture Experiment Station, Bulletin 24*, 1896.

343. Lambe, T. W., Whitman, R. V., "The Role of Effective Stress in the Behavior of Expansive Soils", *Quarterly of the Colorado School of Mines, Vol. 54, No. 4*, 1959.

344. Lambe, T. W., "The Character and Identification of Expansive Soils", *FHA - Bulletin 701*, Federal Housing Adm., December, 1960.

345. LeClerc, R. V., "How to Handle Swelling Soils", *Proceedings, 1954 Northwest Conference on Road Building,* University of Washington, Seattle, 1954.

346. Logan, J., "Clay Foundation Problem, Friant - Kern Canal, California", *Bulletin, Geological Society of America, Vol. 61, Part 2, No. 12,* December, 1950.

347. Lyon, R. J. P., "Infrared Analysis of Soil Minerals" in "*Soil Clay Mineralogy - A Symposium*" by Rich, C. I., Kunze, G. W., University of North Carolina, Chapel Hill, 1964.

348. MacKenzie, R. C., "The Thermal Investigation of Soil Clays", in "*Soil Clay Mineralogy - A Symposium*" by Rich, C. I., Kunze, G. W., University of North Carolina, Chapel Hill, 1964.

349. Marbut, C. F., Bennett, H. H., Lapham, J. E., Lapham, M. H., "Soils of the United States", U. S. Bureau of Soils, *Bulletin 96*, 1913.

350. McDowell, C., "The Relation of Laboratory Testing to Design for Pavements and Structures on Expansive Soils", *Quarterly of the Colorado School of Mines, Vol. 54, No. 4*, 1959.

351. McLean, E. O., Baker, F. E., "Cationic Activities as Indexes for Characterizing Five Arkansas Soils Occurring in the Southern Region", *Proceedings, Soil Science Society of America, Vol. 18*, 1954.

352. Means, R. E., "Soil Investigation for Building Foundation", *Engineering Experiment Station, Oklahoma A&M College, Publ. 94*, Stillwater, 1955.

353. Means, R. E., "Buildings on Expansive Clay", *Quarterly of the Colorado School of Mines, Vol. 54, No. 4*, 1959.

354. Means, R. E., Parcher, J. V., "Physical Properties of Soils", Merrill Books, Inc., Columbus, Ohio, 1963.

355. Mielenz, R. C., King, M. E., "Physical - Chemical Properties and Engineering Performance of Clays" in *Clays and Clay Technology, Dept of Natural Resources, Bulletin 169*, State of California, 1955.

356. Morgan, E. L., "Volume Changes in Soils", *The Structural Engineer*, October, 1958, pp. 345-351.

357. Nahin, P. G., "Infrared Analysis of Clays and Related Minerals", in "*Clays and Clay Technology", Bulletin 169*, Department of Natural Resources, State of California, 1955.

358. "Swelling Measurement and Prediction of Heave for a Lacustrine Clay", *Canadian Geotechnical Journal, Vol. II, No. 1*, February, 1966.

359. "Dark-Clay Soils of Warm Regions Variously Called Rendzina, Black Cotton Soils, Regur or Tirs", *Soil Science Society of America, Proceedings, Vol. 15*, 1960.

360. Osthaus, B. B., "Interpretation of Chemical Analysis of Montmorillonites", in Clays and Clay Technology", Bulletin 169, Department of Natural Resources, State of California, 1955.

361. Peterson, R., Peters, N., "Heave of Spillway Structures on Clay Shales", Canadian Geotechnical Journal, Vol. I, No. 1, September, 1963.

362. Philbrick, S. S., "Foundation Problems of Sedimentary Rocks", in "Trask: Applied Sedimentation", John Wiley and Sons, 1950.

363. Redus, J. F., "Experience with Expansive Clays in the Jackson, Mississippi Area", HRB - Bulletin 313, 1962.

364. Ring, G. W., III, "Shrink - Swell Potential of Soils", Public Roads, Vol. 33, No. 6, 1965.

365. Scott, R. F., "Principles of Soil Mechanics", Addison - Wesley, 1963.

366. Seed, H. B., Mitchel, J. K., Chan, C. K., "Studies of Swell and Swell Pressure Characteristics of Compacted Clays", HRB - Bulletin 313, 1961.

367. Seed, H. B., Woodward, R. J. Jr., Lundgren, R., "Prediction of Swelling Potential for Compacted Clays", Transactions, ASCE, Vol. 128, Part I, 1963.

368. Simpson, W. E., "Foundation Experience with Clay in Texas", Civil Engineering, Vol. 4, No. 1, November, 1934.

369. Smith, C. K., "Soil Properties of Fort Union Clay Shales", Proceedings, 3rd International Conference on Soil Mechanics and Foundation Engineering, Vol. 1, Switzerland, 1953.

370. South Dakota Geological Survey, "Geology of Selected Highway Strips in South Dakota", South Dakota Geological Survey Report of Investigation No. 93, 1963.

371. Southern Cooperative Series, "Certain Properties of Selected Southeastern United States Soils and Mineralogical Procedure for their Study", Southern Cooperative Series, Bulletin 61, U.S.D.A., 1959.

372. Sowers, G. F., Dalrymple, G. B., Kennedy, C. M., "High Volume Change Clays of the Southeastern Coastal Plain", Unpublished Report, Law Engineering Testing Co. Atlantic, Georgia, 1961.

373. Storie, R. E., Weiv, W. W., "Key to the Soil Series of California", University of California, College of Agriculture, April, 1941.

374. Thornbury, W. D., "Regional Geomorphology of the United States", John Wiley and Sons, 1965.

375. Thornthwaite, C. W., Mather, J. R., Carter, D. B., "3 Water Balance Maps of Eastern North America", Resources for the Future, Inc., November, 1958.

376. University of Texas, "The Geology of Texas", The University of Texas Bulletin 3232, 1932.

377. Underwood, L. B., "Classification and Identification of Shales", ASCE Water Resources Engineering Conference Preprint 354, Denver, Colorado, May, 1966.

378. United States Department of Agriculture, County Soil Survey Series.

379. United States Department of Agriculture "Soils of the United States", Atlas of American Agriculture, Part III.

380. United States Department of Agriculture, "Soils and Men", Yearbook of Agriculture - 1938.

381. United States Army Corps of Engineers, Missouri River Division, "Report of Investigation of Expansive Characteristics of Shale and Weak Rocks", Civil Works Investigation No. 465, May, 1954.

382. United States Department of the Interior, Bureau of Reclamation, "Stabilzation of Expansive Clay Soils with Hydrated Lime and With Portland Cement, Friant-Kern Canal Lower Cost Canal Lining Program - Central Valley Project", Earth Lab. Rep. EM-500, June, 1957.

383. United States Department of the Interior - Bureau of Reclamation, "Design of Small Dams", U. S. Government Printing Office, Washington, D. C., 1960.

384. United States Geological Survey, "Geological Map of North America", North American Map Committee, 1965.

385. Vanderford, C. F., "The Soils of Tennessee", Tennessee Agriculture Experiment Station Bulletin 10, 1897.

386. Vanderford, H. B., "Soils of Mississippi", Mississippi State University Agriculture Experiment Station, February, 1962.

387. Ventskevitch, G. Z., "Agrometeorclogy", <u>Translation from Russian USDA and National Science Foundation</u>, Washington, D. C., 1963.

388. Visher, S. S., "Climatic Atlas of the United States", Harvard University Press, Cambridge, 1954.

389. Washington State University, "Soils of the Western United States", Washington State University, 1964.

390. Woods, K. B., Lovell, C. W. Jr., "Distribution of Soils in North America", Section 9, <u>Highway Engineering Handbook</u>, McGraw - Hill, New York, 1960.

391. Wooltorton, F. L. D., "The Scientific Basis of Road Design", Arnold Press, London, 1954.

392. Yong, R. N., Warkentin, B. P., "Introduction to Soil Behavior", Macmillan Co., New York, 1966.

393. Rangmathan, B. V., Satyanarayana, B., "A Rational Method of Predicting Swelling Potential for Compacted Expansive Clays", <u>Proceedings, 6th International Conference of Soil Mechanics and Foundation Engineering, Vol. 1</u>, Canada, 1965.

APPENDIX A

SAMPLE NCHRP MATERIALS QUESTIONNAIRE

APPENDIX A

Sample NCHRP Materials Questionnaire

Re: NCHRP Project 1-3(1) Part II
Subject: Materials Questionnaire

I. Enclosure 1 shows an abbreviated listing of probable aggregate materials: compiled from a literature search, indicating materials being produced in your state. Enclosure 2 is a list identifying the abbreviated materials. Check the material listing of Enclosure 1 for completeness. If a material type is not shown on the list but is used as a highway aggregate source, enter the abbreviated form under Others.

II. Enclosure 3 is a map of your state showing coded areas (location code). Indicate the occurrence of each material type shown in Column 1, Enclosure 1 within these areas by placing the location code/codes in Column 2. Place only one location type code in each row within a given material type.

III. Below is a list of general aggregate problems and a severity description. Place the problem code and associated severity code for that particular problem in Column 3 for each entry in Column 2. If multiple entries are necessary, place all entries in the row corresponding to the referenced location code entry of Column 2. A format example of an entry for Column 3 would be (CSu-I1).

Problem Code	Problem
Concrete Pavement Aggregate	
CAb	Abrasion Loss
CD	Durability
	Chemical Reaction
CSu	Sulphate
CAl	Alkali
CCb	Carbonate
CDe	Deleterious Substances*

*includes presence of organic silt and clay, coal lignite, soft particles, clay lumps or chert particles.

Problem Code	Problem
Bituminous Pavement Aggregate	
BAb	Abrasion Loss
BD	Durability
BAd	Adhesion (Stripping)
BSk	Skid (polishing)

Severity Code	Severity
Ll	Limited Local
Wg	Widespread General

IV. Indicate the general functional use or uses of each respective entry of Column 2 by placing the appropriate function code (shown below) in Column 4. Note that <u>more than</u> one function code may be placed in each row.

Function Code	Function
B	Bituminous Pavement** Aggregate
C	Concrete Pavement*** Aggregate
BS	Base/Subbase Aggregate
NS	Not Suitable for above uses

**Material above base course

***Material above subbase course

V. Indicate on Enclosure 3 approximate general boundaries of areas you feel lack suitable aggregate sources for normal highway use. If no such areas exist, check below.

None__________________

VI. Does the availabilty (non-availability) of suitable aggregate sources within a geographic area act as a major factor in the selection of a specific pavement type (Concrete or Bituminous)?

Yes

If yes, state the location code of the area/areas affected.

Location Code ____13b______

____20f______

____11i______

____

VII. Does the availability (non-availability) of a given cementing material (Portland cement or Bituminous material) within a geographic area act as a <u>major factor</u> in the selection of a specific pavement type (Concrete or Bituminous)?

Yes____________ No____X______

If yes, state the location code of the area/areas affected.

Location Code _____________

____

____

____

MISSOURI

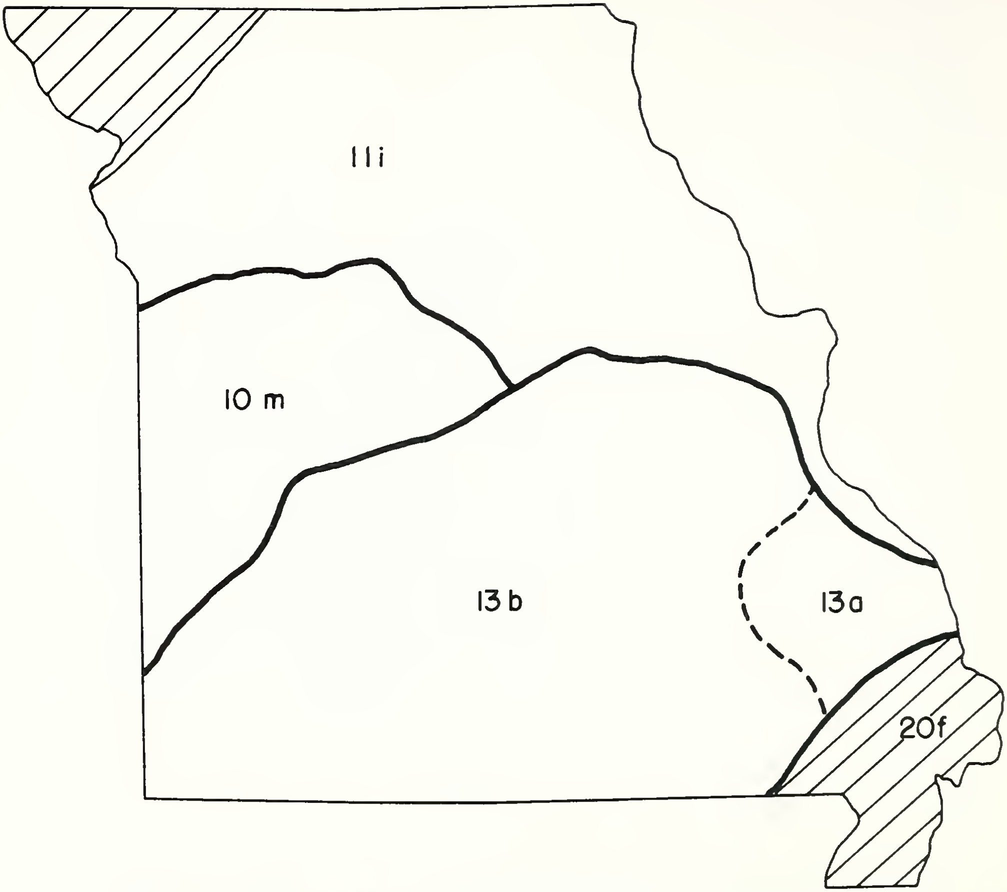
Enclosure 1 Re: NCHRP Project 1-3(1) Part II

Col (1)	Col (2)	Col (3)	Col (4)
Material Type	Location Code	Problem-Severity Code	Function Code
Ls	10m	CD-Wg;CDe-Wg;BSK-Wg	B;C;BS
	11i	CAb-Ll;CD-Wg;CDe-Wg;BAb-Ll;BSK-Wg	B;C;BS
	13a		B;C;BS
	13b	CAb-Ll;CDe-Wg;BAb-Ll;BSK-Wg	B;C;BS
Ss	10m	CAb-Wg;CDe-Wg;BAb-Wg;BD-Wg	NS
	11i	CAb-Wg;CDe-Wg;BAb-Wg;BD-Wg	NS
	13a	CAb-Wg;CDe-Wg;BAb-Wg;BD-Wg	NS
	13b	CAb-Wg;CDe-Wg;BAb-Wg;BD-Wg	NS
Do	10m	CD-Wg;BSK-Wg	B;BS
	11i	CD-Wg;BSK-Wg	B;BS
	13a	CD-Wg;BSK-Wg	C;B;BS
	13b	CD-Wg;BSK-Wg	B;BS
Gr	11i	CD-Ll;BAd-Ll	C;B;BS
	10m	CD-Wg;BAd-Ll	B;BS
	13a	CD-Wg;BAd-Ll	B;BS
	13b	CD-Wg;BAd-Ll	B;BS
	20f	CD-Wg;BAb-Ll	B;BS
S	10m		C;BS
	11i		C;BS
	13a		C;BS
	13b		C;BS
	20f		C;BS
Gn	13a		B
Ma			
Sg			

Enclosure 2 Re: NCHRP Project 1-3(1) Part II

Material Abbreviations

Material	Abbreviation
Andesite	An
Amphilbolite	Am
Basalt	Ba
Clam/Oyster Shell	Cs
Coquina	Co
Diabase	Db
Diorite	Dr
Dolomite	Do
Gabbro	Ga
Gneiss	Gs
Granite	Gn
Gravel	Gr
Limestone	Ls
Marble	Ma
Peridotite	Pe
Quartzite	Qz
Rhyolite	Rh
Sand	S
Sand/Gravel	Sg
Sandstone	Ss
Schist	Sc
Slag	Sl
Syenite	Sy



NOTE: 1. ALPHA-NUMERIC CODE REPRESENTS PHYSIOGRAPHIC UNIT CODE

2. CROSS HATCHED AREAS INDICATE GENERAL BOUNDARIES THAT LACK SUITABLE AGGREGATE SOURCES FOR NORMAL HIGHWAY USE

FIGURE 52 COMPLETED SAMPLE NCHRP MATERIALS QUESTIONNAIRE DIAGRAM ENCLOSURE FOR MISSOURI

APPENDIX B

DESCRIPTION OF BASIC UNIT BOUNDARIES

APPENDIX B

DESCRIPTION OF BASIC UNIT BOUNDARIES

General

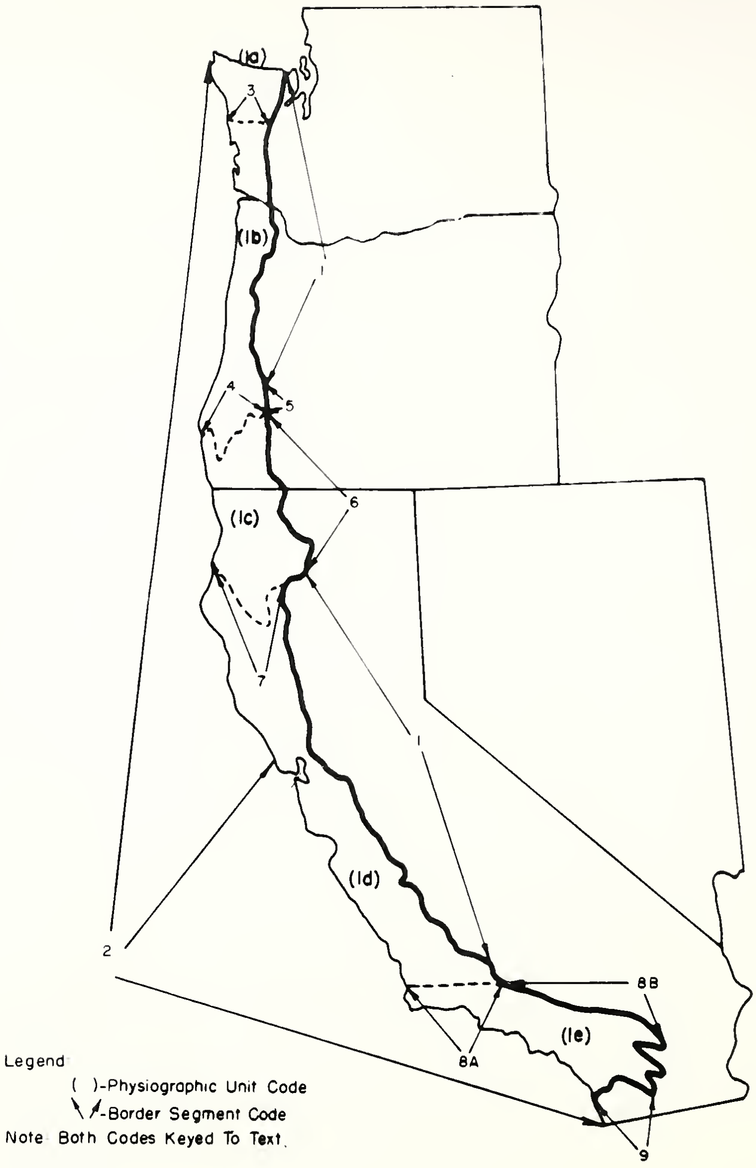
This appendix summarizes available information concerning the description of the basic unit boundaries. Figures 53 to 70 are individual Province/Section diagrams for the units discussed in the report. Each unit is identified by the unit code noted in Table 4. Diagrams containing boundary descriptions have coded border segments shown on each diagram. These segments are keyed to the descriptions, for a particular Province/Section, contained in the ensuing paragraphs. Liberal use has been made of information found in the writings of Thornbury (65), Fenneman (18, 19) and Lobeck (38).

Border Descriptions

Province I

Figure 53 shows the border portions used to describe the various Sections of the Province. They are:

1. See Pacific Troughs Province.
2. The Pacific Ocean (for highway engineering purposes) is taken as the entire weatern border of the Province.



FROM (31) (51) (61)

FIG. 53 WESTERN MOUNTAINS OF THE PACIFIC COAST RANGE PROVINCE / SECTION DIAGRAM

3. The Chehalis River is taken as the border. Although this is not precisely accurate it adequately serves to contrast the topographically and geologically different physiographic Sections.
4. This border is taken as the southern limit of Tertiary rocks common to the Oregon Coast Ranges. The Klamath Mountains are older, stronger and, in general, higher.
5. This border portion is common to the Cascade Section and is denoted primarily by differences in lithology between the two Sections. The Tertiary sedimentaries contrast with the volcanics common to the Cascades.
6. This border is determined by the western limit of Cenozoic volcanics of the Cascades which contrast with the older and differing rocks of the Klamath Mountains.
7. The northern boundary of the California Coast Range Section is taken as the South Fork Mountains which possess the characteristic topography of the Coast Ranges but, because its geology has more in common with the Klamath Mountains, it is placed in that Section. All rocks older than Jurassic have been included in the Klamath Section.
8. This border distinguishes differences in the

trends of the ranges common to the Transverse Range Subsection.

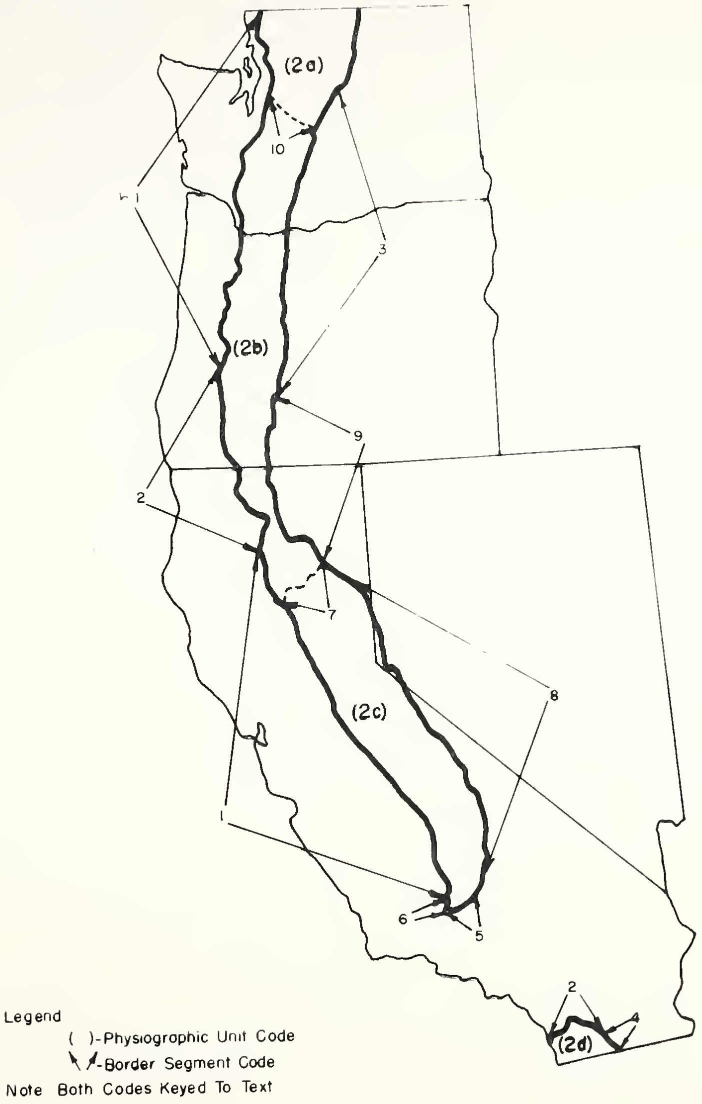
   a. This portion is the San Rafeal Mountains of the California Coast Ranges.
   b. The San Gabriel and San Bernadino Mountains comprise the major portion of this border.

9. This arbitrary border is taken as the southern limit of the Santa Ana and San Jacinto Mountains. These mountain ranges are parallel northwest southeast trending block mountains.

Province 2

Figure 54 shows the border segments utilized to distinguish the Sierra - Cascade Province. They are:

1. See Pacific Troughs Province.
2. See Western Mountains of the Pacific Coast Range Province.
3. See Columbia Plateau Province.
4. The east side of this Section presents a steep face due to a series of fault scarps that overlook the Salton Trough Section.
5. This border segment is terminated by the Garlock fault.
6. This border segment is terminated by the San Andreas fault.
7. This border notes a definite geologic contrast



FROM (31) (51) (61)

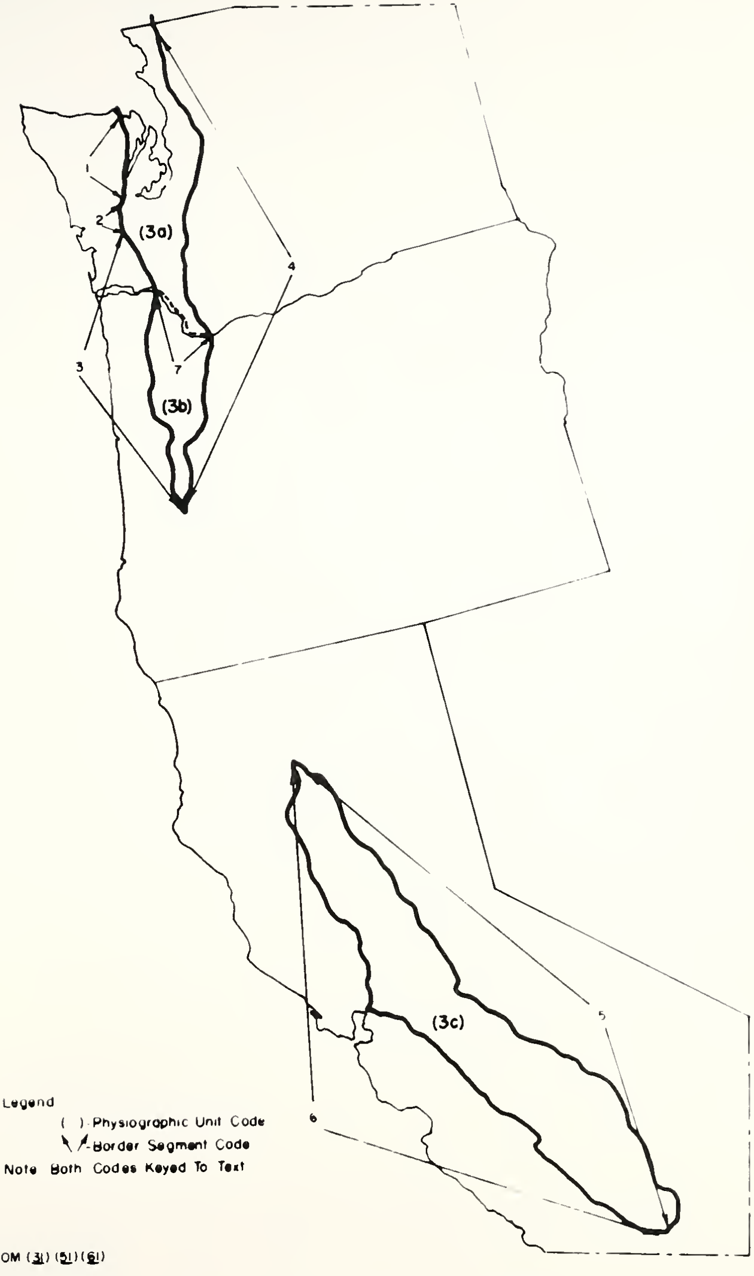
FIG. 54 SIERRA CASCADE PROVINCE / SECTION DIAGRAM where the bedrock of the Sierra Neveda disappears under the Cenozoic volcanic cover of the Southern Cascade Range.

8. This border is generally very topographically conspicous as a series of fault scarps of the Sierra Neveda overlook the Basin - Range Area.
9. This border segment can only be generally defined by topographic differences. The bedrock type (Cenozoic volcanics) is contiguous between the Cascade Range portion and the adjacent Basin and Range area (in California known as the Modoc Plateau). This border is quite similar to the southwest border of the Columbia Plateau Province.
10. This border distinguishes the volcanic materials of the Southern Cascade Section from the older metamorphosed and intruded granitic areas of the Northern Cascade Section.

Province 3

Figure 55 shows the border portions used to describe the Pacific Troughs Province. With few exceptions, the delineation of borders is fairly definite from a topographic viewpoint due to contrast with the surrounding mountainous uplands. The border portions are:

1. This border expresses a fairly distinct topagraphic contrast with the Olympic Mountains.
2. The topographic contrast is broken by the Chehalis



FROM (31) (51) (61)

FIG. 55 PACIFIC TROUGH PROVINCE / SECTION DIAGRAM

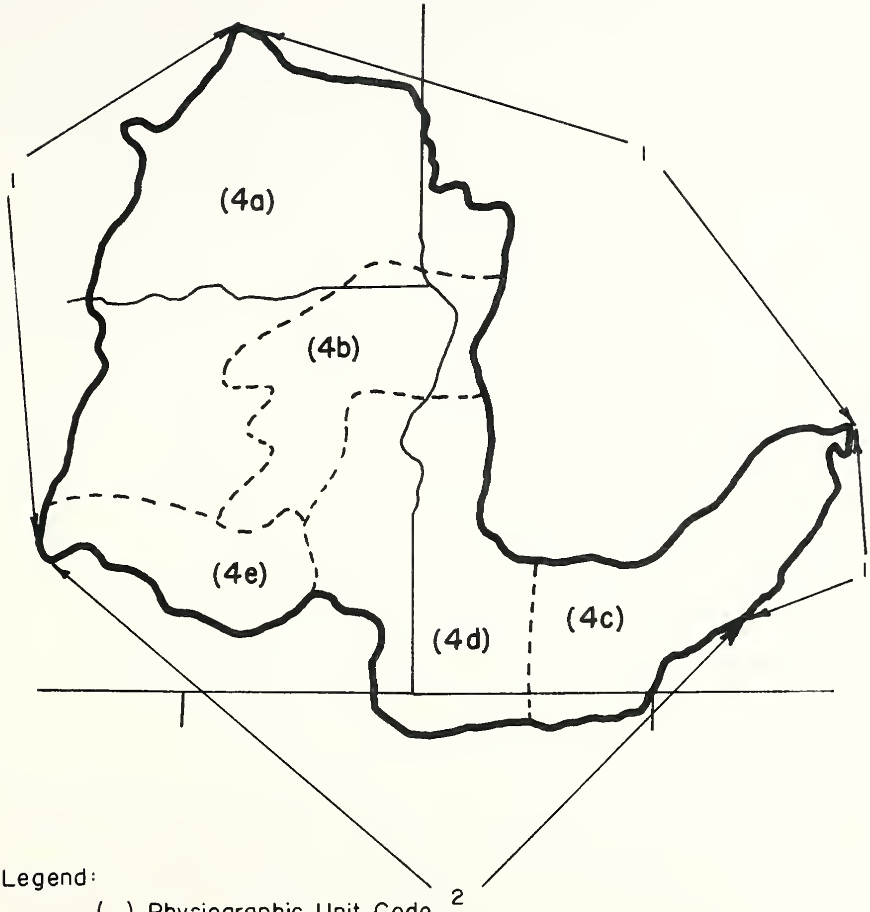
River Valley which traverses the Coast Range to the Pacific Ocean.

3. This border is similar to #1, except that the Oregon Coast Ranges do not provide as definite a contrast.
4. This border portion presents, for the most part, a fairly definite topographic contrast with the Cascade Range.
5. This border portion is a notable topographic contrast. It occurs with the Sierra Neveda and Cascade Mountains.
6. This border portion is quite similar in many respects with #1. This segment separates the California Coast Ranges from the Valley Section.
7. This border is the Lower Columbia River Valley, which is located in the Puget Sound Section.

Province 4

Figure 56 describes only a few major border features of this Province. For the most part, the borders; as denoted by Fenneman, are fairly ill defined. Some general facts regarding the two border portions shown are:

1. This border segment is, in general, topographically definite as it contrasts with surrounding mountainous uplands.
2. The southern border of the Province is generally very indefinite as it is a transistional zone,



Legend:

( )-Physiographic Unit Code

↖ ↗-Border Segment Code

Note: Both Codes Keyed To Text

FROM(65)(73)

FIG.56 COLUMBIA PLATEAU PROVINCE / SECTION DIAGRAM with much of its length being the drainage divide between the Snake River and undrained basins of the Basin and Range Province.

Province 5

Figure 57 illustrates the general location of the Sections comprising the Basin and Range Province. No descriptions of borders have been noted within the diagram.

Province 6

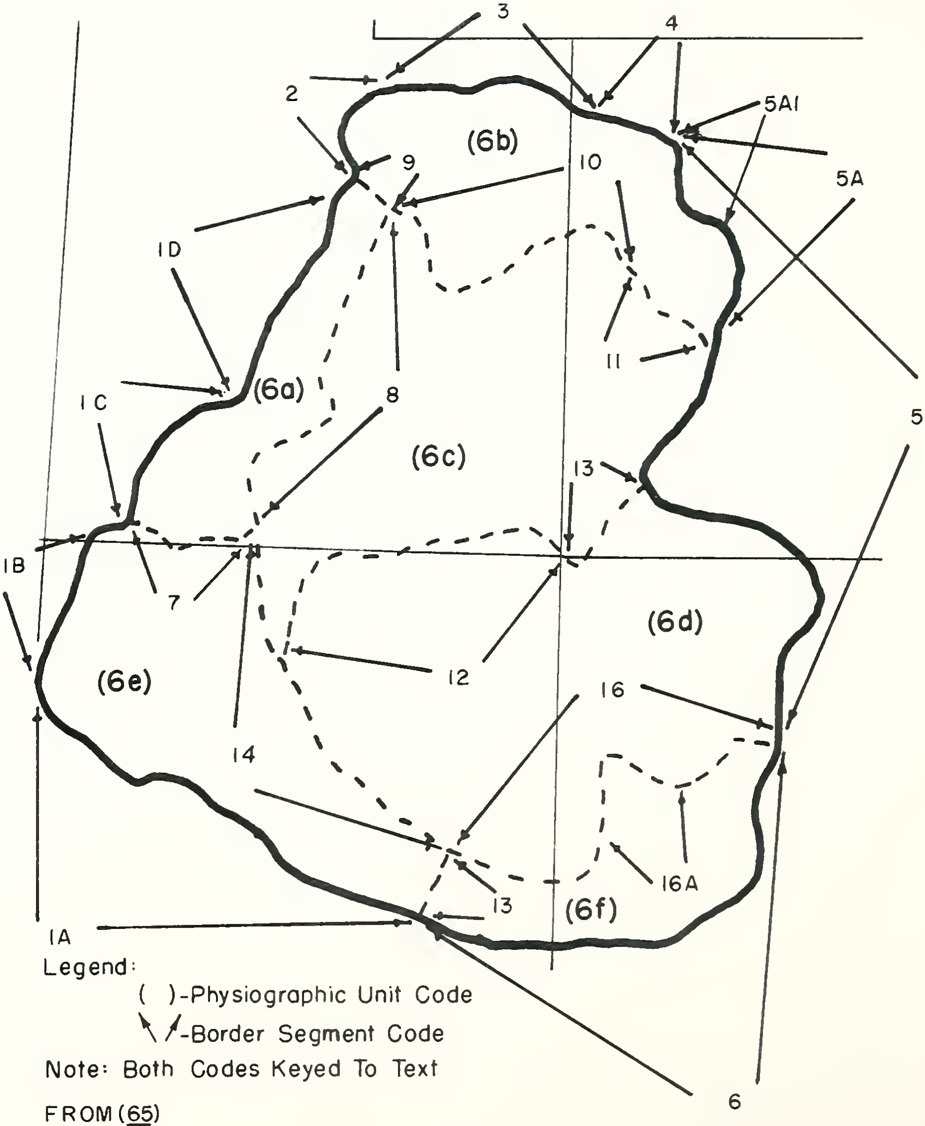
Figure 58 shows the various border portions used to describe the Colorado Plateau Province. The border portions are:

1. This border is generally controlled by massive scarps overlooking the topographically lower Basin and Range Province.
    - a. Called Mogollon Rim
    - b. Called Grand Wash Cliffs (Fault)
    - c. Called Hurricane Fault
    - d. Called Sevier Fault
2. This border is a fairly definite topographic contrast caused by the higher Wasatch Range overlooking the area. This range ends in the vicinity of Mt. Nebo.
3. This border is similar to #2 and is overlooked by the Uinta Mountains.
4. This border portion is fairly indefinite topographically and geologically. Topographically

Legend:
( )-Physiographic Unit Code Keyed To Text

FROM (83)

FIG.57 BASIN AND RANGE PROVINCE / SECTION DIAGRAM



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( )-Physiographic Unit Code

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Note: Both Codes Keyed To Text

FROM (<u>65</u>)

FIG.58 COLORADO PLATEAU PROVINCE / SECTION DIAGRAM the area gradually merges into the Wyoming Basin Section.

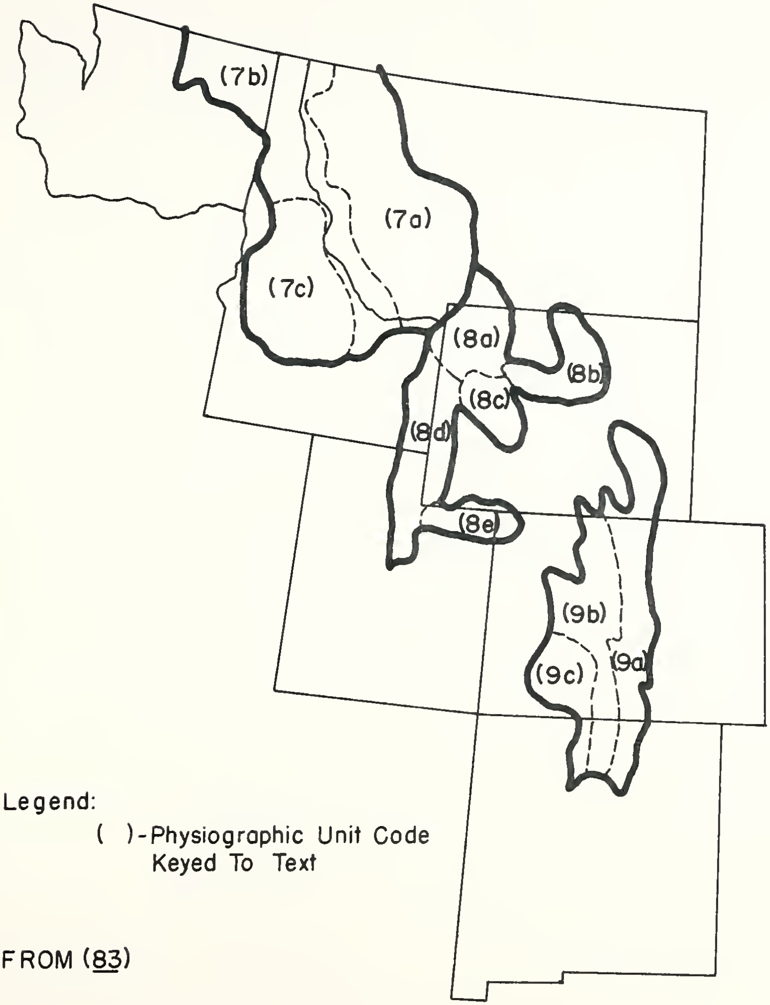
5. This border portion is, in general, topographically definite with the Southern Rocky Mountain Province.
    a. The Steeply dipping Dakota formation forms hogback ridges as the border between the Uinta Basin and the Rockies.
        1. This segment is overlooked by the White River Plateau.
6. The boundary with the Rio Grande Depression of the Mexican Highland Section is marked by the westernmost fault of the Rio Grande Depression (very generalized especially on the southern portion of the border).
7. An escarpment (Vermillion Cliffs) formed by the Jurassic Windgate sandstone overlooks the Grand Canyon Section and represents the boundary in this area.
8. This portion is a great escarpment overlooking the Canyon Land Section.
9. This border is arbitrarily limited by a 1000 to 2000 foot transverse valley in the vicinity of the Old Denver and Rio Grande Railroad.
10. This border is the south facing escarpment (Book and Roan Cliffs) developed by the dipping strata which comprise the Tavaputs Plateau within the

Uinta Basin.

11. This border is the southern edge of the Grande Mesa.
12. This border, although geographically precise, is fairly geomorphically indefinite. The major distinguishing modal characteristics of the adjacent Sections are based upon differences in dissection. The border is generally taken as the San Juan and Colorado Rivers.
13. No information obtained.
14. This border separates Carboniferous age formations from younger strata in the adjacent Sections (Triassic in the Navajo Section and Jurassic in the Canyon Lands Section). It essentially follows the Little Colorado River.
15. This border is the eastern edge of Carboniferous surficial rocks within the Grand Canyon Section.
16. This border is defined rather arbitrarily by the Puerco River.
    a. This border segment is the northern portion of the Zuni Uplift area occurring in the Datil Section.

Provinces 7-8-9

Figure 59 illustrates the generalized location of the Rocky Mountain Provinces and Sections within the United States.



Legend:
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FROM (83)

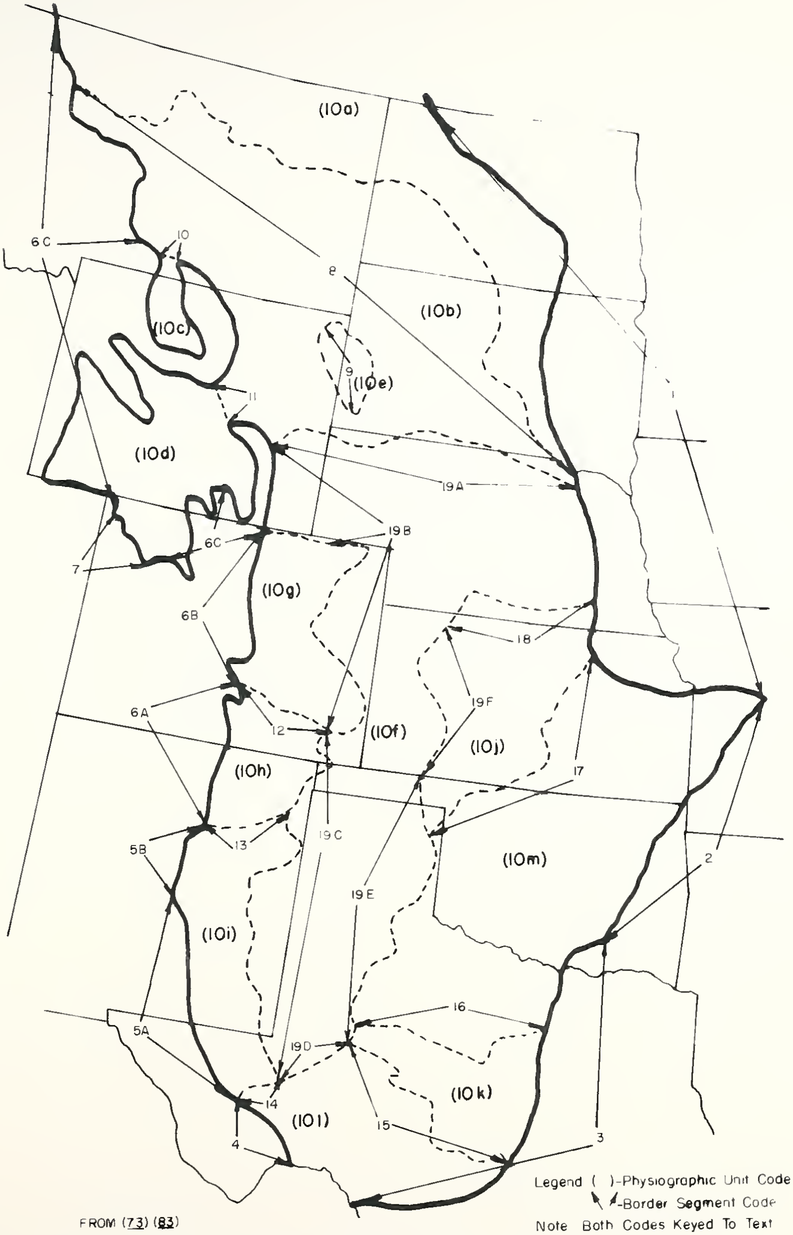
FIG. 59 ROCKY MOUNTAIN SYSTEM DIAGRAM

Although no specific border information is presented; many of the outer Province segments are described within the discussions of the adjacent Provinces.

Province 10

Figure 60 shows the various segments of the borders contained within and adjacent to the Great Plains Province. They are:

1. See Central Lowland Province
2. See Ozark and Cuachita Province
3. See Altantic and Gulf Coastal Plain Province
4. The western portion of the Stockton (Edwards) Plateau terminates against the mountains of the Great Bend Highland Section.
5. This border separates the Pecos Valley Section from the Sacramento Highland Section.
    a. This portion is taken as the eastern edge of the Guadalupe and Sacramento Mountains. They exhibit a fairly definite topographic contrast.
    b. This portion does not afford any gross topographic boundary to distinguish the two Sections and as a consequence is very indefinite.
6. This border delineates the Rocky Mountain System from the Great Plains areas.
    a. This portion, as noted by Thornbury,



FROM (73) (83)

FIG 60 GREAT PLAINS PROVINCE/ SECTION DIAGRAM presents a problem as to whether the border should be based on topography or geology. Similar bedrock types, age, and structure appear both in the Rocky Mountains portion and Great Plains Section. The border is, however, based on topographic differences.

   b. The typical and distinctive western border of the Colorado Piedmont Section is the hogback ridges produced by the titled Dakota sandstone formation.

   c. This border is generally, although not always, fairly definite in that it provides a strong topographic contrast.

7. See Colorado Plateau Province.
8. This border is taken as the southern limit of glacial deposits.
9. The border of this Section is taken as the outer rim of Triassic rocks (Spearfish formation) that comprise the Red Valley portion of the Black Hills. This border is contiguous and surrounded almost in its entirety by the Dakota formation which topographically overlooks the valley as a cuesta scarp on the west and as a hogback ridge on the east.
10. No apparent definite boundary has been established.
11. This border is taken as the Oil Mountain Anticline

which connects the elbow of the Bighorn Range with the end of the Laramie Range. This anticline causes older Paleozoic rocks to outcrop in the form of monoclinal ridges for most of the border length.

12. No sharp line separates the adjacent Sections.
13. This border is the Canadian Escarpment (southern edge of Cretaceous rocks in the Raton Upland Section).
14. This border is a ragged escarpment, more than 1000 feet high, rising to the Stockton (Edwards) Plateau. The escarpment overlooks the Toyah Basin in Texas.
15. This border is an escarpment marking the edge of where the horizontal limestone strata of the Edwards Plateau overlook the weaker, eroded, rocks of the Central Texas Section.
16. In the author's viewpoint, the description of this border from available references, appears to be quite vague and difficult to ascertain from topographic, geologic or soils maps. Fenneman describes it as an infacing (to Osage Plains Section) limestone excarpment. However, this east-west border buts across the northeast-southwest grain of Cretaceous, Permian and Pennsylvanian outcrops found continuous in both Sections across the border line.

17. This is a very arbitrary border and much difference of opinion exists as to which of the several cuesta scarps best serve as the boundary of the Section. Fenneman utilizes the east side of the Smoky and Red Hill areas.

18. This border portion, mainly in Nebraska, is very indefinite as the erosion and dissection common to the Plains Border is veneered with loessial deposits somewhat obscurring the edge of the east facing escarpments of the Plains Border Section.

19. This border is primarily concerned with various modifications to the Tertiary alluvial mantle diagnostic to the High Plains Section.

    a. This portion is the north facing Pine Ridge Escarpment capped by Tertiary (Arikaree formation) outwash. The escarpment locally attains heights of 1000 feet.

    b. This boundary is generally taken as the outer (approximate) limits of the Tertiary alluvium (outwash) still existent in this area.

    c. This portion is capped by the resistant Ogallala formation that forms the Mescalero (Caprock) Escarpment.

    d. The Tertiary alluvium in this portion is thin and discontinuous, offering no significant topographic difference.

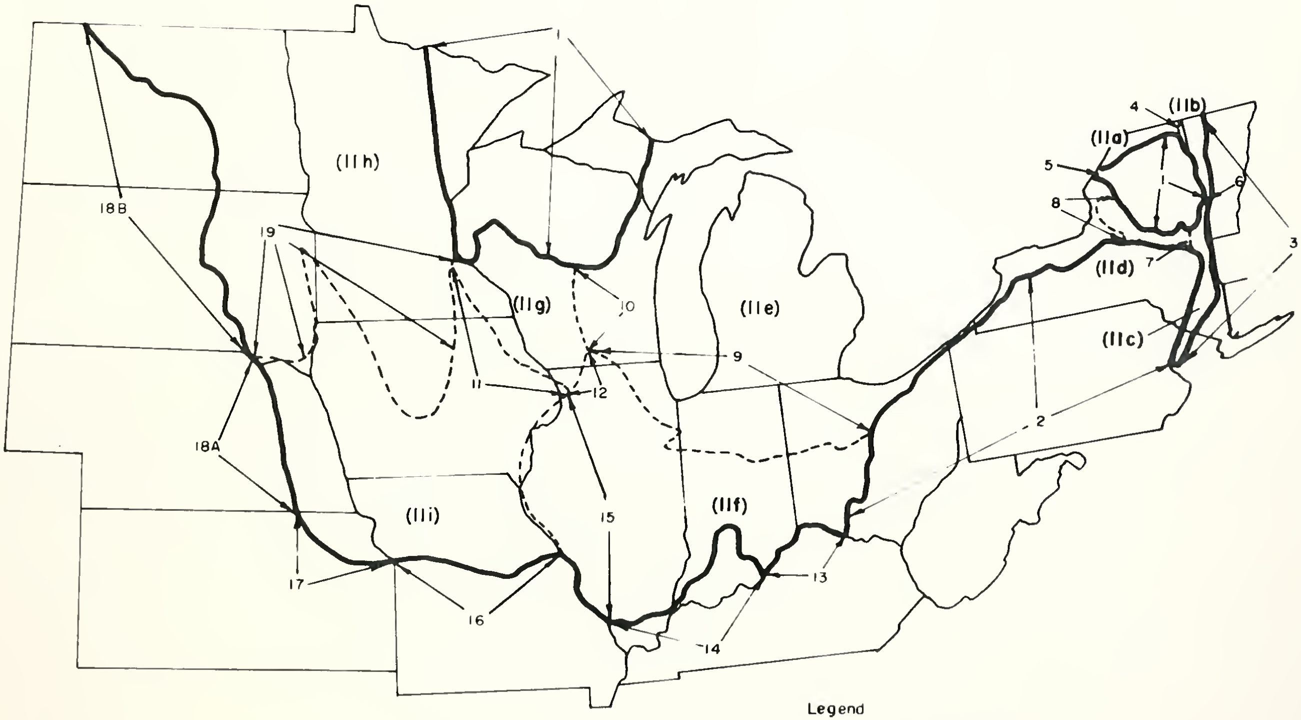
e. This portion is similar in description to #19c. The escarpment is termed the "Break of the Plains" or Caprock.

f. This portion is a continuance of the Break of the Plains Escarpment noted in #19e. However, because of climatic differences as one proceeds northward, the escarpment loses its topographic prominance. Consequently, approximately north of Texas and in Kansas, this border is not very definite.

Province 11

As noted in Figure 61 there are 19 boundary portions utilized to describe the border system of the Central Lowland Province. They are:

1. See Laurentian Upland Province.
2. See Appalachian Plateau Province.
3. See New England Maritime Province.
4. This border is taken as the west side of Lake Champlain.
5. This border, for purposes of describing physiography within the United States only, is a extension of Canadian Shield rocks that, in essence, connect the Adirondacks with the Southern Canadian



Legend

( )-Physiographic Unit Code

↖ ↗-Border Segment Code

Note Both Codes Keyed To Text

FROM (18) (65) (83) (84)

FIG. 61 CENTRAL LOWLAND PROVINCE / SECTION DIAGRAM

Uplands Section of the Laurentian Upland Province. The border is actually an area occurring at Thousand Islands.

6. The border is a relatively low moraine separating the Hudson and Champlain Valleys.
7. This border is a small east facing escarpment passing northward near Schnectady, New York.
8. The border does not follow any one sedimentary outcrop, however, it does follow a fairly definite west foot of the high cuesta that slopes away from the Adirondacks (ie...Tug Hill Cuesta).
9. This border is taken, as suggested by Thornbury, to essentially follow the Cary-Tazewell drift contact.
10. This border is marked by a fairly well defined topographic contrast by the edge of a late Wisconsin terminal moraine. Small areas of outwash are included <u>within</u> the Driftless Section.
11. This border is the western edge of surficial Kansan drift. This strip of Kansan drift consequently lies <u>within</u> the Driftless Section.
12. This border is taken as the edge of Illinoian drift. However, the topographic contrast is not great between the glaciated and non-glaciated sections as the drift is fairly thin and considerably eroded.
13. This border is taken as the Ohio River between

Louisville, Kentucky and Cincinnati, Ohio. South of this area, minor known glacial deposits of Kansan drift have been recorded, but for general analysis this area has been included within the Interior Low Plateau Province. Note that this is a major exception to the border.

14. This border is the southern limits of Illinoian drift.
15. This border is the western edge of Illinois drift. For practical purposes, the drift approximates the western boundary of the state of Illinois (Mississippi River).
16. This border is taken as the Missouri River within the state of Missouri. The exact border actually should be defined by the farthest southern extant of Aeolian deposits within the Dissected Loessial and Till Plains Section. For most of its length, the Loessial boundary is slightly to the south of the Missouri River.
17. This border is the southern and western limits of Kansan drift that appears as surficial deposits in the northeast portion of the State of Kansas.
18. This border is the east facing Missouri Escarpment.
    a. Within Nebraska, this escarpment is, in general, completely lacking. As a result,

in North Dakota, the escarpment is very prominant and attains a height of 300 to 400 feet.

19. This border is placed at the Cary drift boundary of the Des Moines - Dakota ice lobes.

Province 12

Figure 62 illustrates the border portions that are used to describe the boundaries of the Laurentian Upland Province. They are:

1. This border is quite apparent from a topographic, geologic age, and bedrock type difference. In essence,the Adirondacks can be noted by the outer extent of old Igneous and Metamorphic rocks which contrast with Sedimentary rocks present in the adjacent lowlands.
2. This border agrees quite well with dividing the Pre Cambrian rocks of the Superior Upland from the Sedimentary rocks of the Central Lowland Province. In the Upper peninsula of Michigan, topographic contrast of the Superior Upland Section (relief and altitude) is quite different from the adjacent area.
3. This border is quite indefinite in that Cambrian rocks common to the Driftless Section are placed within the Superior Upland Section because they are covered by thick drift.

FROM (18)

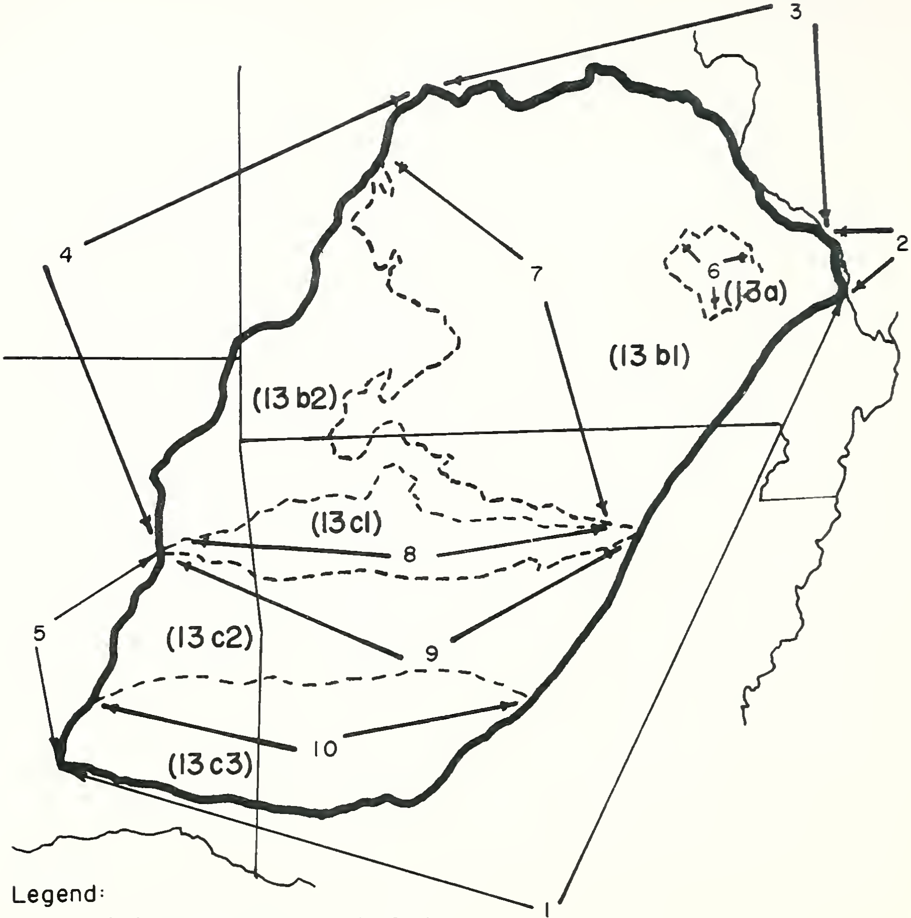
FIG 62 LAURENTIAN UPLAND PROVINCE / SECTION DIAGRAM

4. This border is very arbitrary. It is taken as a line drawn northward from a location near St. Paul, Minnesota along the 93rd meridian.

Province 13

As shown on Figure 63, 10 segments are utilized to describe the borders of the Ozark and Ouachita Province. They are:

1. See Atlantic and Gulf Coastal Plain Province.
2. See Interior Low Plateau Province.
3. See Central and Eastern Lowland Province.
4. This border has very little topographic contrast. The boundary is best located by geologic age difference between Mississippian age rocks of the Springfield Plateau and the Pennsylvanian (Cherokee) clay and shale of the Osage Plains Section.
5. This border is recognizable by contrast between the east-west trending ridges of 13c2 and 13c3 with the north-south trending cuestas of the Osage Plains Section. There is <u>no</u> outstanding contrast nor difference in rock type and age between the two adjacent areas. Both areas are predominantly Pennsylvanian sandstone and shales.
6. This border is highly indefinite due to the partial exhumation of the Paleozoic Sedimentary rocks that are also found in the Springfield-Salem Plateau Section. It appears that an attempt is



Legend:

( )-Physiographic Unit Code

↖ ↗-Border Segment Code

Note: Both Codes Keyed To Text

FROM (75)

FIG. 63 OZARK AND OUACHITA PROVINCE / SECTION DIAGRAM made to enclose the outer limits of the PreCambrian Igneous rocks that have been exhumed. As a consequence, Paleozoic Sedimentary rocks that appear between the Igneous outcrops may form a contiguous border with the Paleozoic rocks common to the Salem Plateau.

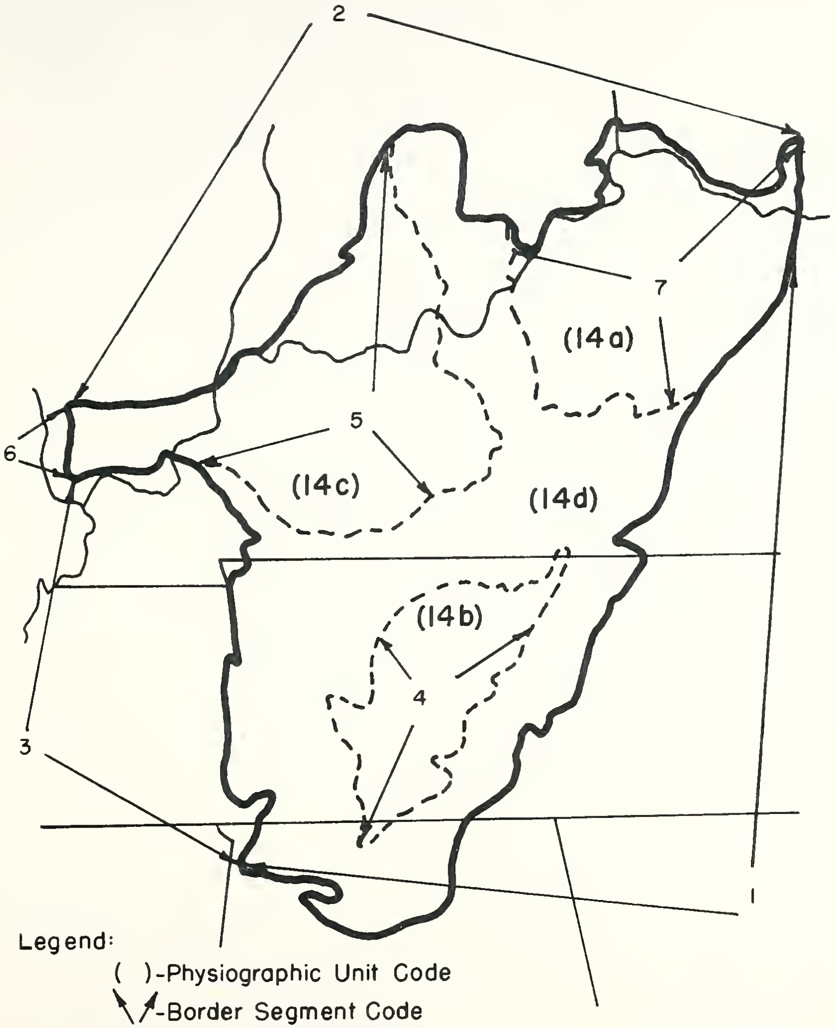
7. This border appears to have considerable difference in location particularly for that portion in Missouri close to the Missouri River. The border itself is the Eureka Springs Escarpment, which is the retreating edge of the Mississippian strata found characteristically in the Springfield Plateau. The escarpment is quite prominant in southwest Missouri but decreases gradually as one goes north until its dissappearance as a pronounced topographic expression occurs near the Osage River Valley.
8. The boundary is the Boston Mountain Escarpment. Geologic age as well as difference in lithology can also be used to determine this border.
9. This border, as described by Fenneman, occurs where the "mountainous upland of the Boston Mountains merges with the hills of the Arkansas Valley Section. At places the topographic break is abrupt, mainly where the boundary is against a local southdipping monocline, but at places the break in topography follows a fault".

10. The western portion of this border is the Chocktaw Fault that separates north dipping beds of the Arkansas Valley with the south dipping beds within the Ouachita Mountain area. In Arkansas, the border is described as following parts of the Petit Jean Creek, Dutch Creek and Poteau River.

Province 14

Figure 64 shows the border portions utilized to describe the Interior Low Plateaus Province. In general, the borders can be fairly definitely located by either marked topographic features or by differences in geology except for the northern and western boundaries. All the remaining borders are noted by escarpments which are directly due to the structure of the bedrock with the area and surrounding Provinces. The border portions are as follows:

1. See Appalachian Plateau Province.
2. See Central and Eastern Lowland Province.
3. See Atlantic and Gulf Coastal Plain Province.
4. This border is an in facing escarpment (towards the Nashville Basin) known as the Highland Rim Escarpment. It essentially separates the Ordovician (minor Silurian - Devonian) limestone area of the basin from the younger (Mississippian) Fort Payne Chert of the Highland Rim. The escarpment is several hundred feet high.
5. This border is determined by an escarpment overlooking the Highland Rim Section. In Indiana it



Legend:

( )-Physiographic Unit Code

↖↗-Border Segment Code

Note: Both Codes Keyed To Text

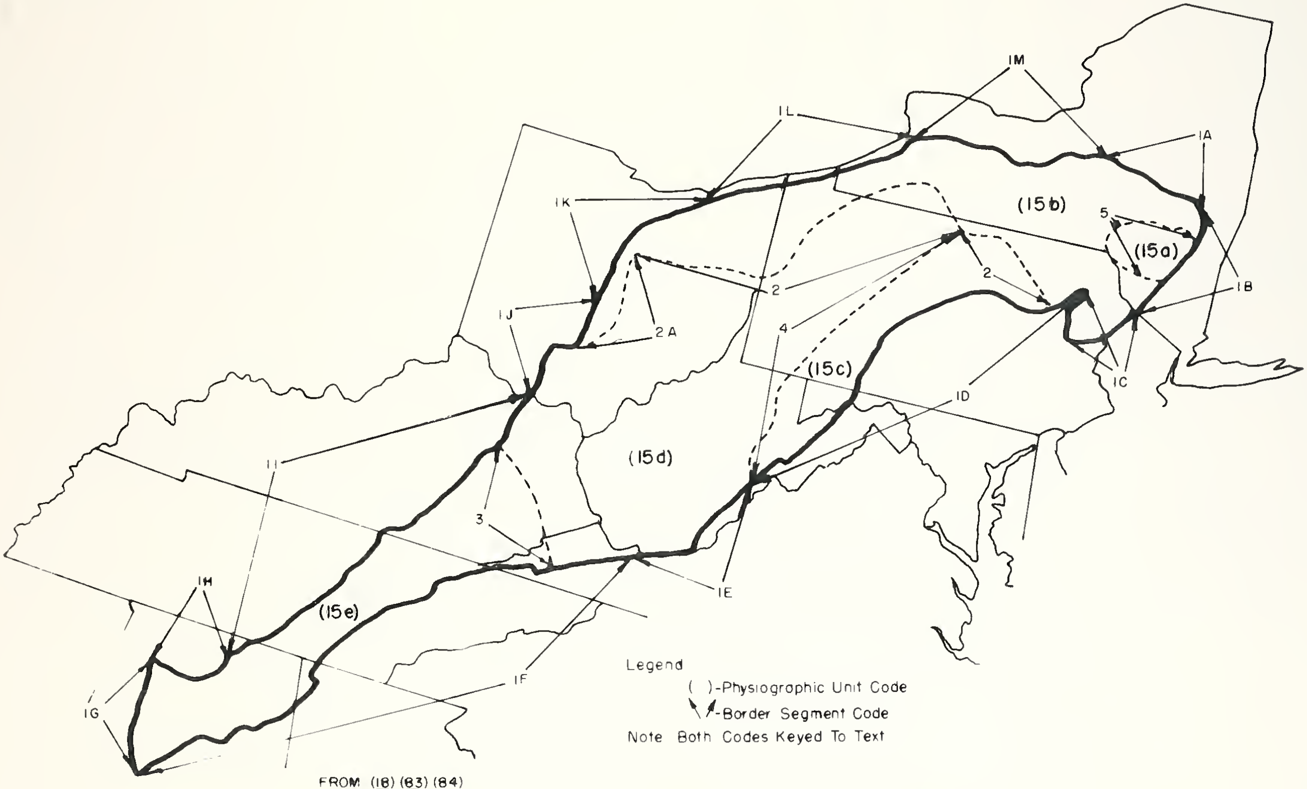
FROM (75)

FIG.64 INTERIOR LOW PLATEAUS PROVINCE / SECTION DIAGRAM is called the Chester Escarpment while in Kentucky it is called the Dripping Springs Escarpment.

6. Topographic contrast of this border is quite indefinite for, surficially, the area is veneered by unconsolidated aeolian and alluvial materials that gradually merge with adjacent Sections. In general, the border follows the western limit of Mississippian rocks within the Shawnee Section and differs from the adjacent Pennsylvanian rocks underlying the extreme southern tip of Illinois.
7. This escarpment is similar in geologic respects to border #4 in that it occurs on Mississippian rocks and overlooks the Bluegrass Section. In Kentucky the escarpment is called Muldraugh's Hills; while, in Indiana, it is termed the Knobstone Escarpment. In Southern Indiana this escarpment proceeds northward under the glacial drift where it is still topographically conspicuous for some distance.

Province 15

The border portions utilized to describe the Appalachian Plateau Province are shown on Figure 65. In general, the borders that describe the outer margin of the Province are very distinct from a topographic viewpoint, while all other interior portions become quite indefinite and in some cases arbitrary. The border portions are:



FROM (18) (83) (84)

FIG. 65 APPALACHIAN PLATEAU PROVINCE / SECTION DIAGRAM

1. The outer margin of the Plateau Province is set off by marked outfacing scarps or dissected mountain fronts. The scarps in the east are generally higher and more clearly defined than the lower and more jagged scarps on the west.
    - a. This scarp is called the Helderberg Escarpment.
    - b. This scarp is called the Catskill Escarpment.
    - c. This border portion is contiguous with the Pocono Plateau.
    - d. This scarp is called the Allegheny Front.
    - e. In central West Virginia, the mountains of the Plateaus have the same altitude as those within the Ridge and Valley Province. However, the dendritic pattern within the Plateau Province contrasts with the linear ridge-valley pattern of the Ridge and Valley Province.
    - f. This border portion is called the Cumberland Front.
    - g. This border offers no marked topographic contrast with the Coastal Plain Province. Hills of the Plateau are often capped by remnants of the coastal plain sediments and merge. (Also see geologic border discussion for Province 20).

h. Within Alabama the scarp portion is generally lacking. A generalized border separates the Pennsylvanian rocks of the Plateau from the Mississippian rocks in the Interior Low Plateau.

i. This border portion gives a fairly good topographic contrast due to the scarp which appears in southern Tennessee. The scarp approaches some 1000 feet in height. Geologic differences are similar to border #1h.

j. The border is noted by the west facing scarp of Mississippian rocks within the Appalachian Plateau.

k. From Columbus, Ohio (slightly east) to Cleveland, Ohio; the west facing escarpment is lost but the contact of the till plain topography with the hilly terrain of the Plateau is recognizable.

l. From Cleveland, Ohio to an area south of Buffalo, New York; the scarp appears but does not follow any geologic boundary.

m. From Buffalo, New York to near Utica, New York, the scarp is at the edge of the Portage sandstone and Tully, Onandago, and Helderberg limestones.

2. This border is taken as the southern most limit

of Wisconsin glaciation. (note: older drift extends beyond this limit but is not topographically prominant).

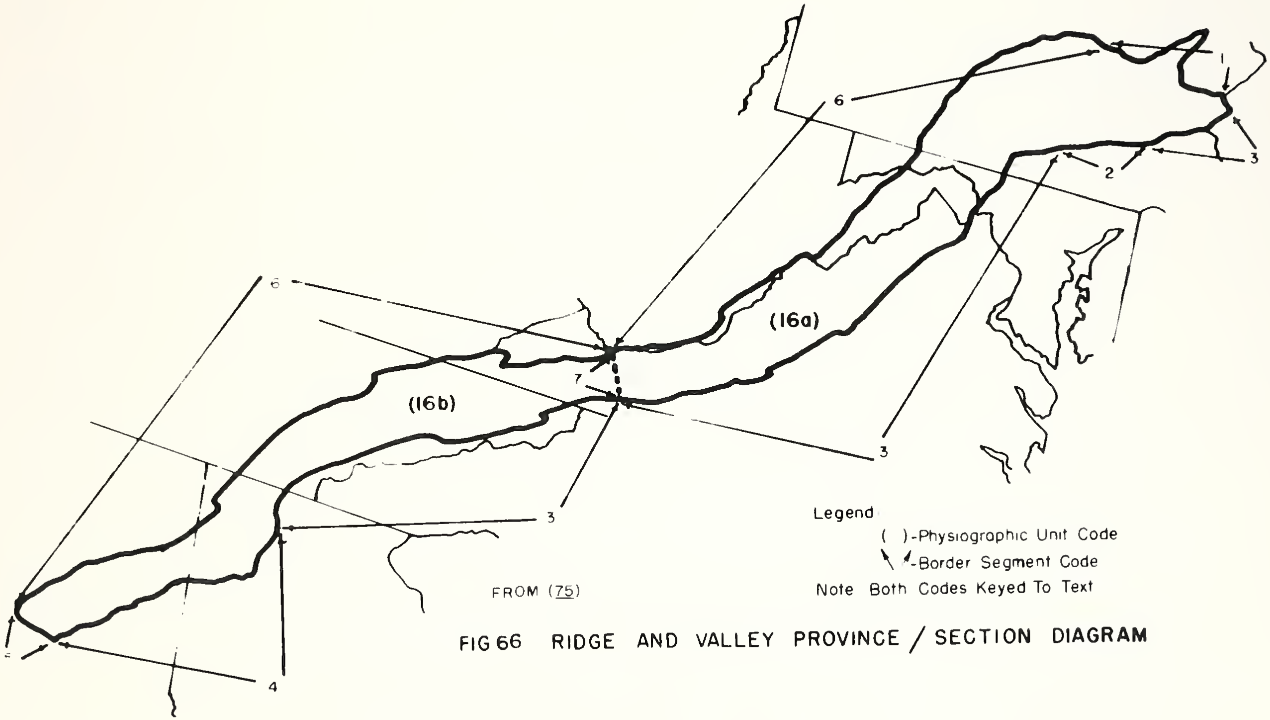
    a. This border portion encloses an area not shown in Fenneman's diagrams. However, recent information indicates the presence of Wisconsin drift in this area.

3. This border is very arbitrary as it attemps to separate degrees of dissection between the adjacent Kanawha and Cumberland Plateau Sections.
4. In general the Allegheny Mountain Section stands topographically higher and is dissected greater than the surrounding Kanawha Section. In West Virginia the altitude of both Sections is about the same and is very difficult to denote.
5. This border may be thought of as arbitrary due to the facies change in resistant stratum that protects and characterizes the Catskill Plateau Section. These stratum generally loose their resistance and character to the west and south and thus gradually merge with the New York Section.

Province 16

As noted in Figure 66 the border portions that describe the Ridge and Valley Province are as follows:

1. This border is based upon the southern limits of Wisconsin glacial drift.



FROM (75)

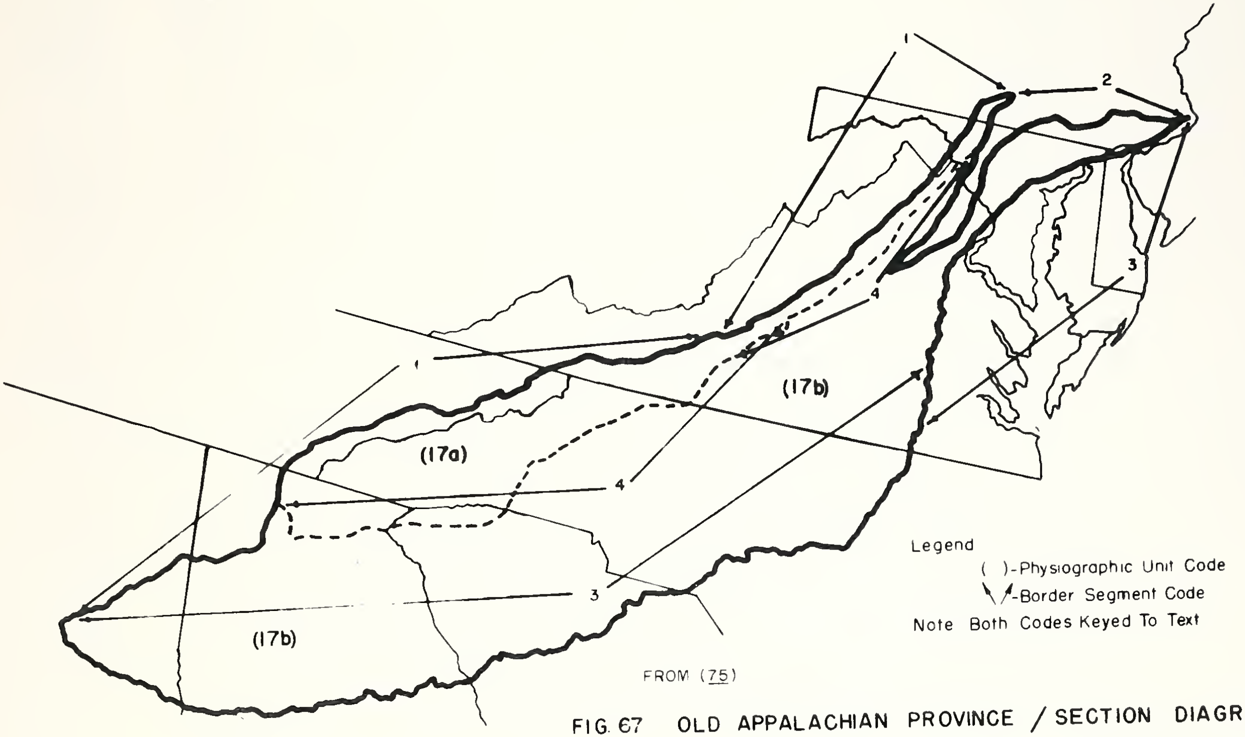
FIG 66 RIDGE AND VALLEY PROVINCE / SECTION DIAGRAM

2. See Triassic Lowland Province.
3. This border is generally rather apparent from a topographic viewpoint. The mountainous upland terrain of the Blue Ridge and Reading Prong contrasts with the series of bordering lowland valleys developed on limestone within the Ridge and Valley.
4. This border has as a mutual Province the Piedmont Section of the Old Appalachians. The topographic difference between the two areas is not as pronounced as the border of #3. Difference in rock type exists between the areas.
5. See Atlantic and Gulf Coastal Plain Province.
6. The border is the prominant topographic escarpment of the Appalachian Plateau Province (Alleghany Front). Within central West Virginia, ridges of the Ridge and Valley Province are at approximately the same elevation of the plateau areas of the Appalachian Province.
7. This border is arbitrarily taken as the drainage divide between the New and Tennessee Rivers.

Province 17

Figure 67 contains the legend of the border areas described below for the Old Appalachian Province. They are:

1. See Ridge and Valley Province.
2. See Triassic Lowland Province.
3. See Atlantic and Gulf Coastal Plain Province.



FROM (75)

FIG. 67 OLD APPALACHIAN PROVINCE / SECTION DIAGRAM

4. This border is generally based upon topographic differences of elevation and relief between the two Sections. The border is termed the Blue Ridge Escarpment and is quite variable in its clarity toward creating a definite border. In many cases, particularly in the southern portion of the boundary, the high relief of the Blue Ridge is gradational to the Piedmont. As a consequence, numerous Blue Ridge outliers are found in the Piedmont Section making border placement quite difficult and indefinite.

Province 18

As noted in Figure 68, there are 4 boundary portions utilized to describe the border system of the Triassic Lowland. They are:

1. This border is distinguished by geologic age difference between the Triassic rocks and the older (Pre-Cambiran to Early Paleozoic) crystalline rocks. Topographically, the Triassic areas are lower than the crystalline areas which generally form the uplands.
2. The border is taken as the Crdovician limestone areas. Topographically they are also lower than the crystalline uplands.
3. This boundary is distinguished by geologic age difference between the Triassic rocks and the

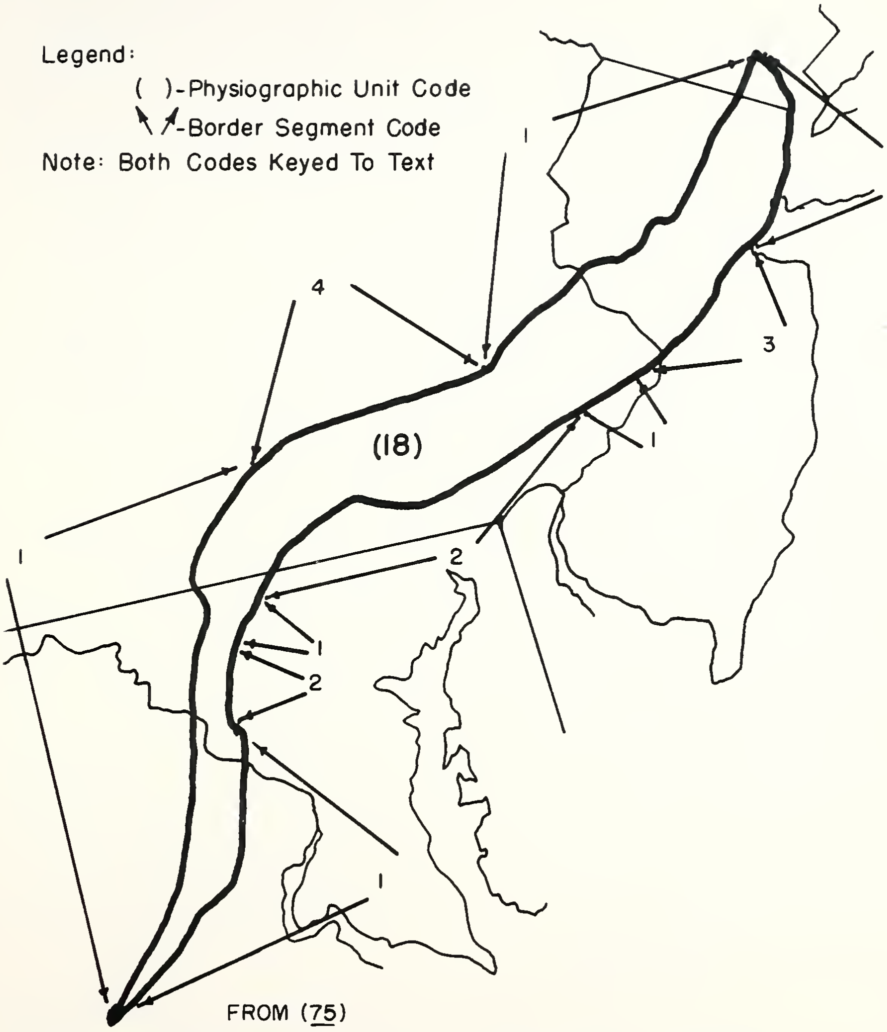


FIG.68 TRIASSIC LOWLAND PROVINCE DIAGRAM

Cretaceous coastal sediments. Topographic contrast in much of the area is lacking.

4. This border is similar to border #3 in that the Triassic "Lowland" area becomes an upland area when contrasted to the topographically lower Great Valley system of the Ridge and Valley Province. The border can be distinguished by the geologic age difference between the Ordovician limestone valley and the Triassic sediments.

Province 19

As shown in Figure 69, eleven (11) border portions have been utilized to describe the borders of the New England Maritime Province. They are:

1. This border can only be generally defined and therefore it is quite indefinite. It attemps to separate areas within which mountainous terrain is sufficiently abundant to dominate the landscape in a general view. However, plateau surfaces, diagnostic of the New England Upland Section invades the margin of the area and is elsewhere surrounded by monadnocks. The border has been arbitrarily defined as the 1500 foot contour by Fenneman.
2. This border tends to separate the lower, smoother topography of the Seaboard Lowland Section from the higher, less smoother topography of the New England Upland Section. Fenneman defined this

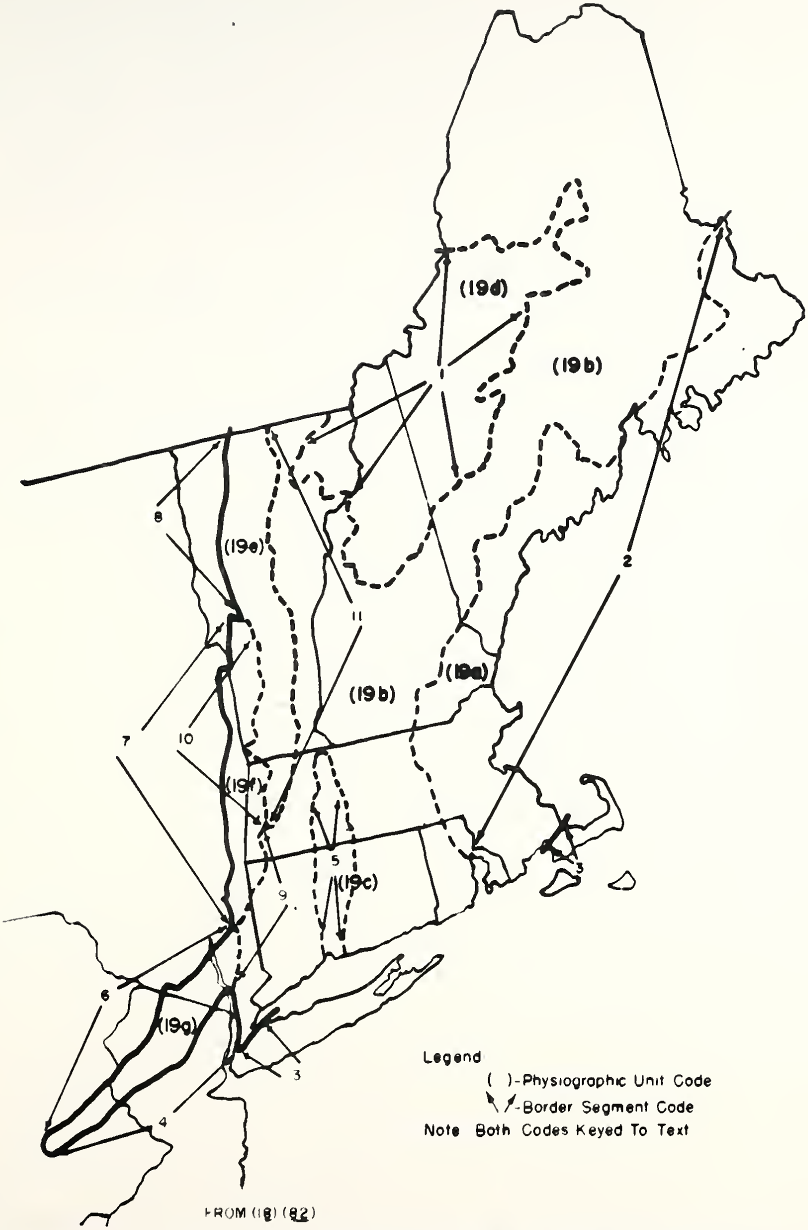


FIG 69 NEW ENGLAND MARITIME PROVINCE / SECTION DIAGRAM

change (ie...border) in topography occurring between the 400 and 500 foot contour intervals. Differences in geologic rock types or ages cannot be utilized to obtain the boundary and; consequently, this border is similar in nature to border #1.

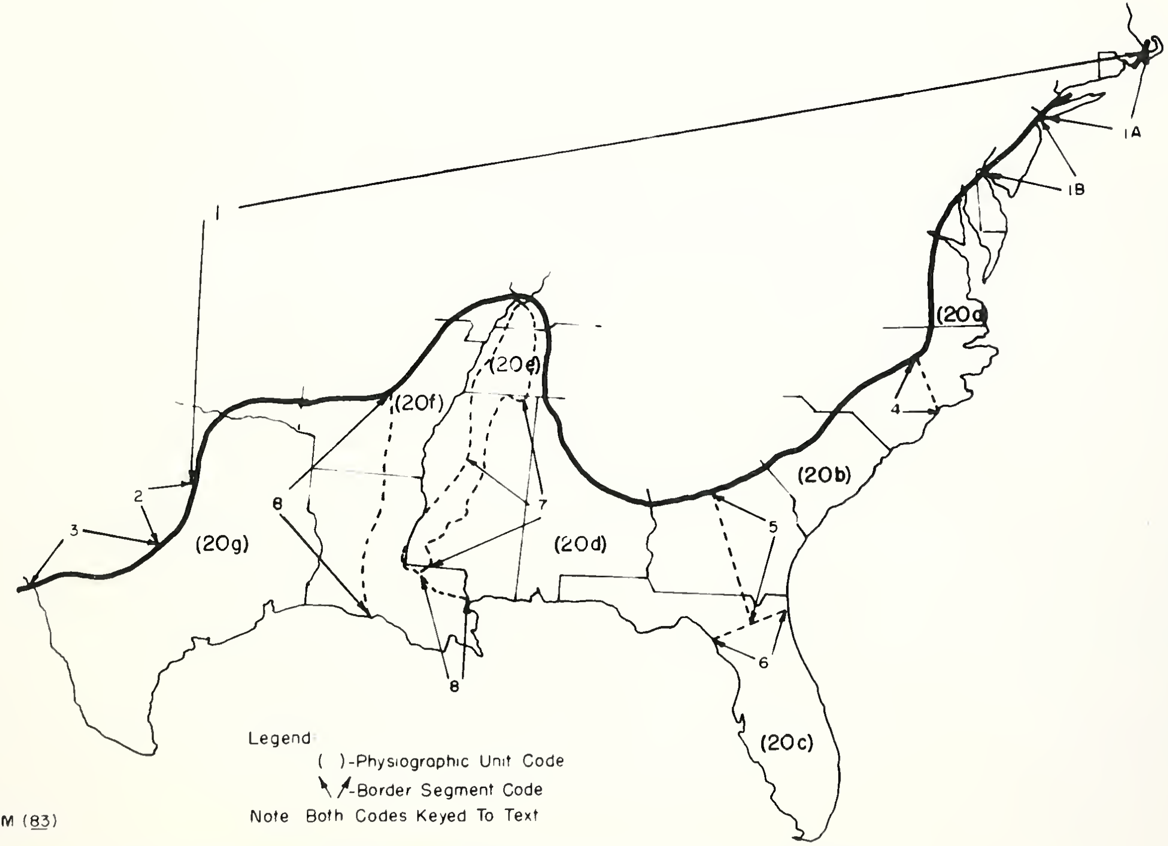
3. See Atlantic and Gulf Coastal Plain Province.
4. See Triassic Lowland Province.
5. This border is fairly definite from both a topographic and geologic standpoint. The lowland area developed on relatively weak Triassic rocks contrasts with the older schists and granites of the uplands to either side (east-west).
6. This border is fairly definite from both a topographic and geologic standpoint. The crystalline PreCambrian rocks of the Reading Prong topographically overlook the Paleozoic Sedimentary rocks of the Hudson Lowland Section. (note: the northern portion of this border ends approximately 20 miles north of where the Hudson River enters the Highlands (Reading Prong) near Poughkeepsie, New York).
7. This border is based primarily on differences in rock type attributed to the change of degree in metamorphism. The schists of the Taconics stand above and in a fairly definite linear trend compared to the slates of the Hudson Lowland.

8. The southern half of this border portion is quite definite from a topographic viewpoint as it appears as a nearly straight wall up to 500 feet high. The northern portion becomes quite indistinct and a unique line separating adjacent Sections is difficult to draw.
9. This border portion is quite ill defined within the literature available. It appears to be quite difficult to determine particularly in the northern portion as a gradual topographic merger between Sections occurs.
10. This border is separated by a series of valleys developed on carbonate rocks that are physiographically treated within the Taconic Section.
11. This border portion is not well defined due to the gradual change from the plateau-like topography of the New England Upland to the mountainous topography of the Green Mountain Section. The northern portion of the border is perhaps slightly more noticeable than the southern portion as a terracing effect occurs in the North (due east of the Green Mountains).

Province 20

As shown in Figure 70, there are 8 boundary portions to describe the various borders of the Atlantic and Gulf Coastal Plain. They are:

1. This boundary occurs from Cape Cod, Massachusetts



FROM (83)

FIG. 70 ATLANTIC AND GULF COASTAL PLAIN PROVINCE / SECTION DIAGRAM to Waco, Texas. The boundary is easily described as Cretaceous and younger sediments bordering the older consolidated materials of the uplands.

   a. Long Island and Cape Cod have both been glaciated. As a result, the border must be based on the northern limit of cretaceous rocks that underlie Pleistocene glacial sediments.
   b. In this area, topography is not significantly different where the coastal sediments border soft Triassic age sedimentary rocks.

2. This border is generally the contact between lower and Upper Cretaceous rocks. Lower Cretaceous rocks have been assigned to the Central Texas Mineral Section of the Great Plains Province due to the fact that the dissected topography upon the Lower Cretaceous rocks is more in common with the Section of the Great Plains rather than the Coastal Plains Province.
3. This border occurs approximately from Austin, Texas to the Mexico border.. The border is fairly definite, being recognized by the Balcones Escarpment which divides Lower and Upper Cretaceous rocks.
4. The border is very indefinite as it is primarily based upon topographic differences of the coast line (ie...separates embayed areas of Section 20a from sea islands characteristic of Section 20b).

5. This border is similar to #4 as it is of the indefinite type. Topographic changes occur a little west of the Georgia - South Carolina border.
6. The border is similar to #4 and #5 in that each Section (20b, 20c and 20d) each have major differing modal characteristics. However, the location of the border dividing these characteristics is very indefinite.
7. This boundary is based on the limits of surficial aeolian deposits. The eastern boundary, in many cases, is of a gradational variety.
8. This boundary is based upon the border that separates the Mississippi alluvial deposits from the coastal sediments. The boundary can be easily located from either geologic, pedologic or soil origin maps of the area.

APPENDIX C

STATE AGGREGATE PRODUCTION DATA

Table 41

Summary of Aggregate Production Rankings by State

				Ranking[1]				
				Sand Gravel		Crushed Stone		Ratio
State	No.	Population	Area	(tonnage)	(ton. per Pop.-Area)	(tonnage)	(ton. per Pop.-Area)	(SG/CS)
Alabama	(1)	3,267,000	52,000	41	44	23	25	37-39
Arizona	(2)	1,302,000	114,000	14	25	39	43	8
Arkansas	(3)	1,786,000	53,000	26	23-24	24	13	31
California	(4)	15,717,000	159,000	1	40	16	38	17
Colorado	(5)	1,754,000	104,000	12	26-27	34-36	37	12
Connecticut	(6)	2,535,000	5,000	32	5	27	2	28
Delaware	(7)	446,000	2,000	48	3	44-48	44-48	1-5
Florida	(8)	4,952,000	59,000	38	46	3	10	45-46
Georgia	(9)	3,943,000	59,000	45	47	18-19	23	48
Idaho	(10)	667,000	84,000	13	15	34-36	29	16
Illinois	(11)	10,081,000	56,000	6	35	1	15	36
Indiana	(12)	4,662,000	36,000	10	19	14	11	32
Iowa	(13)	2,757,000	56,000	21-22	29	5	5	40-42
Kansas	(14)	2,179,000	82,000	25	33	18-19	19	34
Kentucky	(15)	3,038,000	40,000	40	36	12	7	45-46
Louisiana	(16)	3,257,000	49,000	23	30	26	26	23-24
Maine	(17)	969,000	33,000	24	10	42	41	7
Maryland	(18)	3,101,000	11,000	18	9	25	4	25-26
Massachusetts	(19)	5,149,000	8,000	11	6	28	8	20
Michigan	(20)	7,823,000	58,000	2	26-27	21	31-32	19
Minnesota	(21)	3,414,000	84,000	5	23-24	30	34	15
Mississippi	(22)	2,178,000	48,000	37	32	44-48	44-48	1-5
Missouri	(23)	4,320,000	70,000	27	43	7	16	43-44
Montana	(24)	675,000	147,000	17	17	37	36	11
Nebraska	(25)	1,411,000	77,000	19	20	33	31-32	18
Nevada	(26)	285,000	111,000	20	8	40	39	9
New Hampshire	(27)	607,000	9,000	34-35	2	44-48	44-48	1-5
New Jersey	(28)	6,667,000	8,000	15	11	20	3	29-30
New Mexico	(29)	951,000	122,000	34-35	31	32	30	21-22
New York	(30)	16,782,000	50,000	3	39	6	27	29-30
North Carolina	(31)	4,556,000	53,000	28	41	10	14	40-42
North Dakota	(32)	632,000	71,000	30	13	44-48	44-48	1-5
Ohio	(33)	9,706,000	41,000	4	4	8	1	27
Oklahoma	(34)	2,328,000	70,000	39	42	17	12	43-44
Oregon	(35)	1,769,000	97,000	13	28	11	9	35
Pennsylvania	(36)	11,319,000	45,000	16	45	4	22	40-42
Rhode Island	(37)	859,000	1,000	47	1	43	40	6
South Carolina	(38)	2,383,000	31,000	44	34	29	20	33
South Dakota	(39)	680,000	77,000	20-21	12	34-36	28	14
Tennessee	(40)	3,567,000	42,000	36	38	9	6	47
Texas	(41)	9,596,000	267,000	19	48	2	33	37-39
Utah	(42)	891,000	85,000	31	22	41	42	10
Vermont	(43)	390,000	10,000	46	7	44-48	44-48	1-5
Virginia	(44)	4,967,000	41,000	29	37	15	17	37-39
Washington	(45)	2,853,000	68,000	8	16	22	24	21-22
West Virginia	(46)	1,860,000	24,000	43	21	31	21	23-24
Wisconsin	(47)	3,952,000	56,000	7	18	13	18	25-26
Wyoming	(48)	330,000	98,000	42	14	38	35	13

Notes:
1. Ranking Number 1 is largest production factor; #48 is lowest production ranking.
2. Information concerning sand gravel obtained from reference (175) for 1964.
3. Information concerning crushed stone obtained from reference (189) for 1958.

Table 42

Summary of State Aggregate Production Factors

By Increasing Magnitude

Sand Gravel Data		Crushed Stone Data		Ratio
Tonnage	Density	Tonnage	Density	
$(\text{Tons}\times 10^{6})$	$\left(\frac{\text{Tons}}{\text{Pop.-Area}}\times 10^{-6}\right)$	$(\text{Tons}\times 10^{6})$	$\left(\frac{\text{Tons}}{\text{Pop.-Area}}\times 10^{-6}\right)$	$\left(\frac{\text{SG Tonnage}}{\text{CS Tonnage}}\right)$
1.2 (7)	11.3 (41)	0 (7)	0 (7)	0.5 (9)
1.6 (37)	17.2 (9)	0 (22)	0 (22)	0.6 (40)
1.8 (43)	24.0 (8)	0 (27)	0 (27)	0.7 (8)
4.2 (9)	31.3 (36)	0 (32)	0 (32)	0.7 (15)
4.6 (38)	34.2 (1)	0 (43)	0 (43)	0.8 (23)
5.5 (46)	36.4 (23)	.002 (37)	0.7 (2)	0.8 (34)
5.6 (48)	42.7 (34)	.04 (17)	1.1 (42)	0.9 (13)
5.8 (1)	45.4 (31)	.08 (42)	1.3 (17)	0.9 (31)
6.6 (15)	45.7 (4)	.09 (26)	2.0 (37)	0.9 (36)
6.8 (34)	46.5 (30)	0.1 (2)	2.8 (26)	1.2 (1)
7.4 (8)	53.2 (40)	0.3 (48)	3.7 (4)	1.2 (41)
7.8 (22)	53.9 (44)	0.6 (24)	4.4 (5)	1.2 (44)
8.0 (40)	57.0 (15)	0.8 (5)	6.0 (24)	1.3 (11)
8.8 (27)	62.0 (11)	0.8 (10)	7.8 (48)	1.5 (35)
8.8 (29)	67.5 (38)	0.8 (34)	8.7 (21)	1.6 (14)
9.6 (10)	73.0 (14)	1.5 (25)	9.3 (41)	1.7 (38)
10.1 (6)	76.2 (22)	1.6 (29)	13.7 (20)	2.4 (12)
10.2 (42)	77.5 (29)	1.7 (46)	13.7 (25)	2.5 (3)
10.5 (32)	88.0 (16)	2.5 (21)	13.8 (29)	2.6 (28)
10.6 (44)	91.0 (13)	2.9 (38)	14.2 (10)	2.6 (30)
11.2 (31)	105 (35)	3.3 (19)	15.3 (39)	2.8 (6)
11.4 (23)	115 (5)	3.6 (6)	18.3 (30)	2.9 (33)
11.7 (3)	115 (20)	4.0 (16)	25.1 (16)	3.4 (47)
13.0 (14)	121 (2)	4.4 (18)	28.0 (1)	3.4 (18)
13.5 (17)	126 (3)	4.8 (3)	29.5 (45)	3.5 (16)
13.6 (16)	126 (21)	4.9 (1)	34.0 (9)	3.5 (46)
13.8 (39)	131 (42)	5.7 (45)	36.2 (36)	5.6 (29)
13.8 (13)	133 (46)	6.2 (20)	37.8 (46)	5.6 (45)
14.1 (26)	137 (25)	7.0 (28)	39.2 (38)	6.4 (19)
14.6 (25)	143 (12)	7.9 (9)	44.0 (14)	8.4 (20)
15.1 (18)	154 (47)	7.9 (14)	45.2 (47)	10.0 (25)
16.0 (24)	160 (24)	8.7 (34)	45.6 (44)	12.3 (4)
16.2 (36)	165 (45)	9.2 (4)	46.0 (23)	12.5 (10)
17.7 (28)	178 (10)	9.3 (44)	46.5 (11)	14.4 (21)
18.1 (2)	187 (48)	9.9 (12)	48.8 (31)	17.5 (39)
18.3 (35)	244 (32)	10.0 (47)	50.5 (3)	24.0 (48)
20.7 (5)	269 (39)	10.4 (15)	53.3 (34)	26.3 (5)
21.3 (19)	368 (28)	11.7 (35)	59.2 (12)	26.7 (24)
24.4 (12)	437 (17)	11.8 (31)	67.7 (8)	125 (42)
29.2 (41)	441 (18)	13.2 (40)	68.5 (35)	167 (26)
31.9 (45)	468 (26)	13.3 (33)	80.5 (19)	180 (2)
34.3 (47)	500 (43)	13.9 (23)	85.0 (15)	350 (17)
34.8 (11)	512 (19)	15.3 (30)	88.0 (40)	1000 (37)
35.8 (21)	555 (6)	15.6 (13)	101 (13)	∞ (7)
37.7 (33)	950 (33)	18.5 (36)	129 (18)	∞ (22)
39.3 (30)	1000 (7)	19.8 (8)	143 (28)	∞ (27)
51.9 (20)	1800 (27)	23.8 (41)	200 (6)	∞ (32)
112.9 (4)	2000 (37)	26.3 (11)	333 (33)	∞ (43)

Notes:
1. Number in parenthesis refers to state description number in Table 41
2. Information concerning sand gravel obtained from reference (<u>175</u>) for 1964
3. Information concerning crushed stone obtained from reference (<u>189</u>) for 1958