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THE ROLE OF ENGINEERING-GEOLOGIC FACTORS IN THE EARLY SETTLEMENT AND EXPANSION OF THE CONTERMINOUS UNITED STATES

ROLE DES FACTEURS GÉOLOGIQUES ET GÉOTECHNIQUES LORS DE L'ÉTABLISSEMENT DES PREMIÈRES COLONIES PUIS AU COURS DE L'EXPANSION DES ETATS-UNIS.

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Abstract

Geologic factors that are favorable or unfavorable for land use and construction strongly influenced the early history and expansion of the United States. Many Indian settlements in the American west were built on natural plateaus, near the rims of canyons, or in recesses in canyon walls where they could be defended easily. After 1492, European settlers built communities along the seacoasts, where there were natural harbors, or along lakes and rivers that were transportation routes. Many of these places were low and swampy, so that construction difficulties were common when the early settlements began to expand. Early roads and canals were laid out and built with little or no benefit of geologic knowledge.

The Appalachians were a barrier to westward expansion until the first part of the 19th century, when settlers began moving into the interior. In the 1850's the War Department engineers made exploratory surveys to determine the best routes for railroads that were to cross the country from the Mississippi to the Pacific Coast. Most of their geologic reports described the fossils, topography, lithology, and the natural resources of the country they explored, but dealt very little with the geological problems that might be encountered during construction of the railroads. In 1868 the burgeoning town of San Francisco was damaged by an earthquake, but the scientific report that was prepared after the disaster was never published.

During the late 1800's four great geological exploratory surveys examined the natural resources of the west, and in 1879 the U.S. Geological Survey was established as a government agency. At first the work of the Geological Survey emphasized mining geology, but the scope of their studies gradually broadened. In 1890 they published an account of the earthquake at Charleston, South Carolina. In 1894 the application of geologic information to construction was discussed in a Geological Survey publication dealing with roads of the United States. A similar report was published by the New York Geological Survey in 1897. However, it was not until the end of the 19th century and the beginning of the 20th, that the clear relationship between geology and civil engineering was well established, and the location of roads and structures was influenced by studies of the geologic conditions of the routes or sites.

Résumé

Les facteurs géologiques, qu'ils soient favorables ou non, ont fortement influencé l'histoire des Etats-Unis. Beaucoup de villages indiens de l'Ouest étaient établis sur des plateaux naturels, au bord de canyons ou dans des renfoncements dans les parois de canyons, tous lieux faciles à défendre. Après 1492, les colons européens construisirent leurs premiers villages le long des cotes, là où existaient des ports naturels, où au bord de lacs et de rivières utilisables pour le transport des marchandises.

Beaucoup de ces emplacements étaient à basse altitude, souvent marécageux, et les difficultés rencontrées lors de la construction, très fréquentes. Les premières routes et les premiers canaux furent mis en place et construits sans guère d'intervention des connaissances géologiques.

Les Appalaches ont été un obstacle à l'expansion vers l'Ouest jusqu'à la première moitié du XIXe siècle, quand des colons commencèrent à pénétrer vers l'intérieur du pays. Dans les années 1850 les ingénieurs des Armées firent des reconnaissances pour choisir les meilleurs itinéraires pour les chemins de fer destinés à traverser le pays depuis le Mississipi jusqu'à la côte du Pacifique. La plupart de leurs rapports géologiques contiennent une description des fossiles, de la topographie, de la lithologie et des ressources naturelles des régions traversées, mais ils prenaient très peu en compte les problèmes géologiques qu'allait soulever la construction des voies de chemin de fer. En 1868, la ville de San Francisco en plein développement, fut endommagée par un tremblement de terre, mais le rapport scientifique préparé après le désastre ne fut jamais publié.

A la fin du XIXe siècle, quatre grandes études géologiques furent lancées sur les ressources de l'Ouest, et en 1879 le "U.S. Geological Survey" fut mis en place en tant que Service de l'Etat. A l'origine, le travail du Geological Survey porta surtout sur la géologie minière, mais peu à peu le champ des activités s'agrandit. En 1890, ils publièrent un compte-rendu du tremblement de terre de Charleston, en Caroline du Sud. En 1894, une publication du Geological Survey prit en compte les données géologiques pour le choix des tracés routiers. Un rapport similaire fut publié par le "New York Geological Survey" en 1897. Cependant ce n'est que tout à fait à la fin du XIXe siècle et au début du XXe qu'une relation claire fut établie entre la géologie et le Génie Civil et que le choix des tracés et des structures fut réellement influencé par l'étude des conditions géologiques des sites.

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Introduction

The application of geology to the planning, design, construction, and maintenance of structures has been formally recognized as the specialized field of engineering geology for only the last 75 years or so, but geological materials have been used in construction and geologic conditions have directly or indirectly determined the location and form of man-made structures for thousands of years. Geologic factors have strongly influenced all aspects of mankind's building activities throughout the world ever since settled communities with permanent structures were first established.

In North America the American Indians were the first settlers. They remained the only permanent human occupants of the region for many millenia, until the influx of Europeans in the 16th century.

Those who settled on the East Coast sought well-watered land and fertile soil on which to establish farms. Rumors of gold in Indian cities motivated the expeditions of early Spanish explorers, who landed in Florida in the early 16th century and later marched northward from Mexico into what is now the southwestern part of the United States. Only a little more than 130 years ago, the discovery of gold in California spurred the overland migration from the eastern and central parts of the country to the west.

After the early settlers and the gold-seekers, came the engineers, who first built canals and roads along the eastern seaboard to link the early British colonies and infant states and later constructed railroads across the country to connect the two seacoasts. Roads fanned out across the land. More towns sprang up along the routes of transportation, many of them expanding to become the metropolitan centers of today. The location of all these routes and settlements was to some extent controlled by the geologic conditions of the land. For example, the position of the lakes and rivers that determined the eventual location of the city of Chicago was established by drainage patterns initiated during the last glacial period. Geologic factors established the form and location of such great harbors as Boston Harbor (Kaye, 1976) and San Francisco Bay.

The science of geology was still in its infancy when the building of roads and canals began along the East Coast. At first, the problems of foundation conditions and sources of construction materials were handled

Fig. 1a : Index map of the United States.

largely by engineers. It was not until the late 19th century that geologists in the United States began deliberate consideration of the geologic problems related to construction. Not until the 20th century did engineering geology become a full-fledged speciality within the field of geology in the United States, as more and more engineering problems that were related to geologic conditions and processes began to trouble the fast-growing nation. Concern about the effect of large-scale engineering projects on the environment as against the effect of geologic conditions on the engineering structures caused an expansion of the field of geology to include studies of environmental geology.

Prehistory

The first people to establish settlements in North America were the American Indians, who may have reached the continent about 30,000 years ago. They were predominantly hunters, and most of them remained nomadic, but in the arid west-central part of the continent they established permanent villages, with stone and mud buildings, in the region that is now Arizona, New Mexico, Colorado, and Utah (fig. 1a).

Many of the earliest dwellings were on the tops of mesas or on plateaus near the rims of canyons. The steep-sided mesas were particularly safe places to build, for the villages on their flat tops could be defended easily. The plateaus and mesas owe their origin to geologic factors that are characteristic of the southwestern United States. Alternating strata of hard and soft rocks, from Precambrian to Tertiary in age, cover much of the area. These rocks have been warped into broad uplifts, basins, and monoclines, which have been deeply eroded so that broad plateaus rise above wide valleys. Steep-sided canyons cut the plateaus, and in places the plateaus have been reduced by erosion to a series of flat-topped, freestanding mesas where remnants of resistant sandstone or volcanic rock overlie softer materials. The erosion was facilitated by regional and local joint systems that provided channels for rainwater; the rocks broke along joints into blocks that separated from the edges of canyons and mesas to slide and fall down their steep sides.

One of the most famous early Indian settlements that was established on the top of an isolated, steep-sided mesa is in New Mexico-Ácoma, The Sky City, a stone and adobe pueblo which has been occupied for at least 700 years and perhaps as long as 2000 years (Minge, 1976). The builders of Ácoma utilized the local rock for building material; they approached the city by a steep trail, now a road, which followed the joints that cut the mesa. Those joints are clearly visible on Fig 1, an aerial photograph of Ácoma.

In other places, the early inhabitants of the southwest built clusters of rock houses in arched recesses in steep canyon walls, easily defended positions where they were protected from elements by overhanging rock. There were other advantages to these sites, many of which faced the south. Stone buildings in a south-facing recess embody many of the principles of passive solar design in use today. The village was warmed by the winter sun and was shaded in summer. The thick masonry walls of the buildings were cool in summer, and in winter they retained and radiated the sun's heat.

Geologic factors were paramount in the formation of these natural building sites. The recesses are caused by the disintegration of vertical rock plates that were formed by stress-release fractures parallel to the canyon walls (Radbruch-Hall, 1977). Plates parallel to the cliffs may be so weakened by lateral stream erosion or by seeps along flat-lying bedding planes that the lower part of the plate disintegrates and collapses as a rockfall. As this process extends upward and inwards, a large recess is formed, generally with an arched roof. The same seepage that causes undercutting was often utilized by the inhabitants of the recesses as a water supply.

Mesa Verde, in southwestern Colorado, is one of the most picturesque of these ancient rock pueblos built in a recess. Archaeologists estimate that it was occupied between approximately 1200 and 1300 A.D. (Editors of Sunset Books, 1970). The vertical joints and plates, and the rockfalls from the roof of the recess, are clearly visible in Fig. 2. Some of the stone dwellings are built on top of masses of rock that fell from the ceiling before the houses were constructed. Many of the mesas in the southwestern United States are rimmed with rockfalls and masses of landslide debris.

There is much scholarly disagreement about the date when people from Europe or other lands to the west first came to North America. Certain peculiarities of native American Indian languages and a number of inscribed stones have been interpreted to indicate the presence of Celts, Phoenicians, Egyptians, or other peoples who (various scholars claim) may have found the New World nearly 3000 years ago but mingled with the native population and left little trace (Fell, 1978). There is little doubt that adventurous Norsemen landed on the northern part of the continent, Perhaps as early as 800 A.D. (Fell, 1978), but their colonies were transitory.

European colonization and early history (1492-1783)

Large-scale migrations of peoples from Europe to the Americas began after Christopher Coloumbus' first voyage of discovery in 1492. The Spanish conquistadores entered South America soon after 1492, and in the spring of 1513 Ponce de Leon landed in Florida near the present site of Saint Augustine. During the first half of the 16th century, the Spanish adventurers continued to explore southeastern North America and began to probe what is now the southwestern part of the United States. In 1540, Francisco Vasquez de Coronado made a foray northward from Mexico in search of the Seven Cities of Cibola, whose streets were rumored to be paved with gold. He and his soldiers marched up the Gulf of California into Arizona and New Mexico, on to Texas and up into Kansas and Nebraska. They returned to the Rio Grande, then moved back down along the Gulf of California, and so again to Mexico City. They found none of the fabled gold of Cibola

Fig. 1b : Aerial photograph of Acoma. Note prominent joint system.

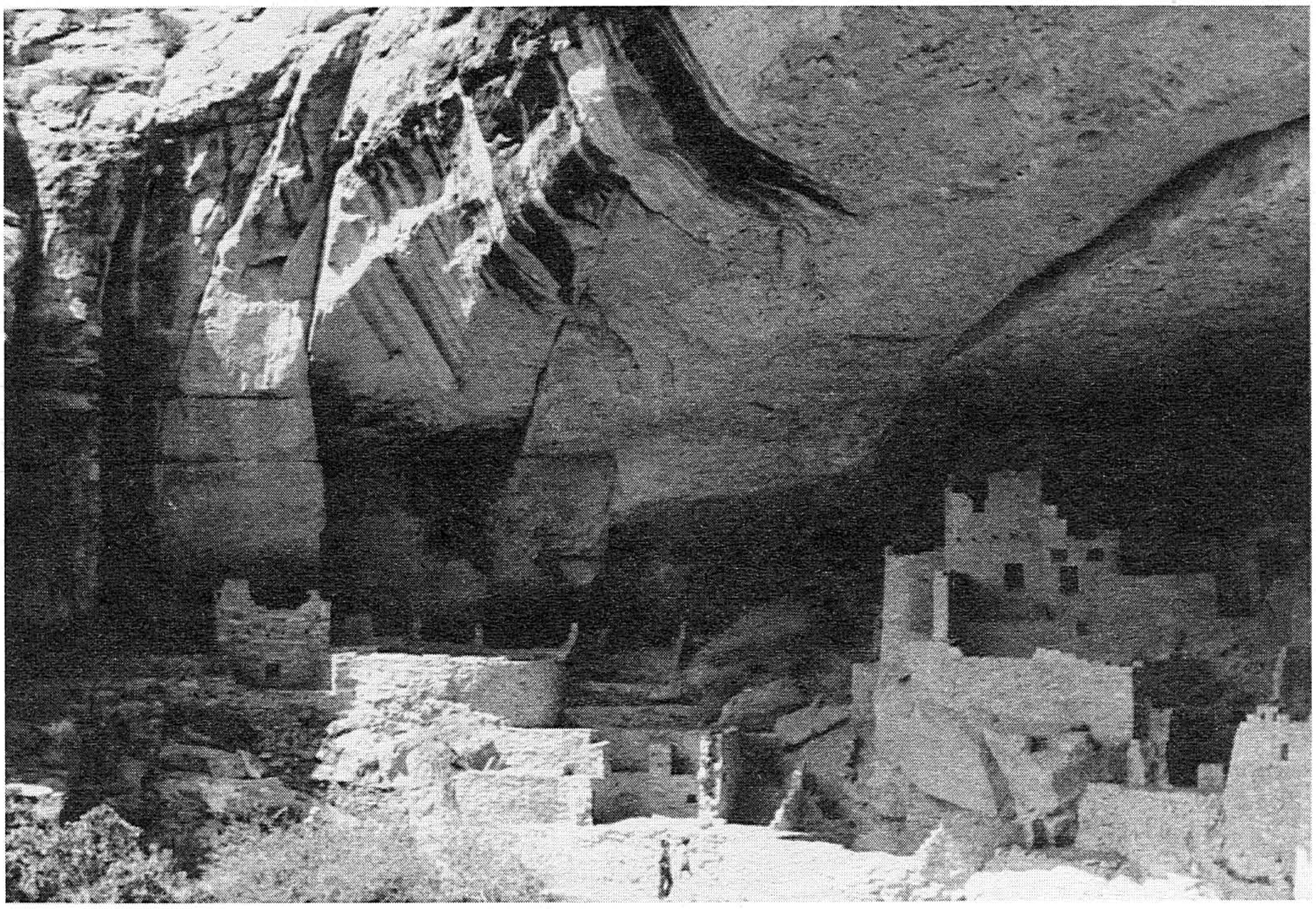


Fig. 2 : Cliff Palace, Mesa Verde, Colo. Prominent joints visible in walls of recess are parallel to valley wall. Note blocks of rock that have fallen from roof of recess. Scale indicated by human figures in foreground.

(Cooke, 1977), but a party of Coronado's soldiers headed by Captain Hernando de Alvarado passed by Ácoma pueblo, which they described as one of the "strongest ever seen, because the city was built on a high rock" (Minge, 1976).

In 1565 the first Spanish fort was built in Florida, at Saint Augustine. It was the first of a line of forts, extending northward, that was established to protect the Spanish ships from pirates (Cooke, 1977) and to secure Florida against the French (Rose, 1976), who had tried to found a colony there (Cooke, 1977; Bannon, 1963).

The geologic conditions of Florida are quite different from those of the canyon and mesa land of the southwestern United States. Florida is a low, flat peninsula that is underlain primarily by limestone. The fort at Saint Augustine was built on a flat plain bordering the harbor. If we can believe some of the old maps (Fig. 3), the fort was in or near a marshy area.

The Saint Augustine fort was built of coquina from the Anastasia Formation, of Pleistocene age, which accumulated in shallow seas during several interglacial periods when sea level was higher than it is now. The coquina consists of whole or broken shells more or less firmly cemented; the harder parts make a durable building stone (Cooke, 1945). The name of the formation comes from Anastasia Island, opposite Saint Augustine. It is from this island that the Spanish obtained the rock for their early fort (Fig. 4). The Island is pockmarked with pits from which the coquina has been quarried.

The French were not far behind the Spanish in the rush to exploit the riches of the New World. Only twelve years after Columbus' first voyage, Breton fishermen began to harvest the seas near Nova Scotia. The French soon went up the St. Lawrence River, where they began a profitable fur trade, trapping far into the interior and trading with the Indians. They made their first permanent settlement at Quebec in 1608, a year after the first English colony was established in Virginia. Quebec, like the pueblos of the southwest, was built on a rocky point (fig. 5) that could be easily defended. When Col. Benedict Armold laid seige to it in 1775 and 1776, it proved a formidable fortress.

In 1682, the French explorer La Salle went from the south end of Lake Michigan down the Illinois River and so to the Mississippi, finally reaching its mouth. There he planted the flag of France and claimed in the name of King Louis all the country he had traversed, calling this huge tract of land Louisiana in honor of his monarch (Cooke, 1977).

In 1718, French settlers founded New Orleans on the delta of the Mississippi River (see fig. 1a). It was the southernmost of the ports on the river where goods could be transferred to and from the river boats that served the entire Mississippi Valley. The settlers built most of the town on the river's natural levees, which provided relatively firm foundations for structures. Many of the early buildings rested on timber grillage and masonry footings (fig 6).

Throughout most of the 18th century, events in Europe rather than in America still determined which European countries would dominate various areas of North America. By the middle of the century, the British colonies that were soon to become an independent nation stretched along the Atlantic coast from Maine

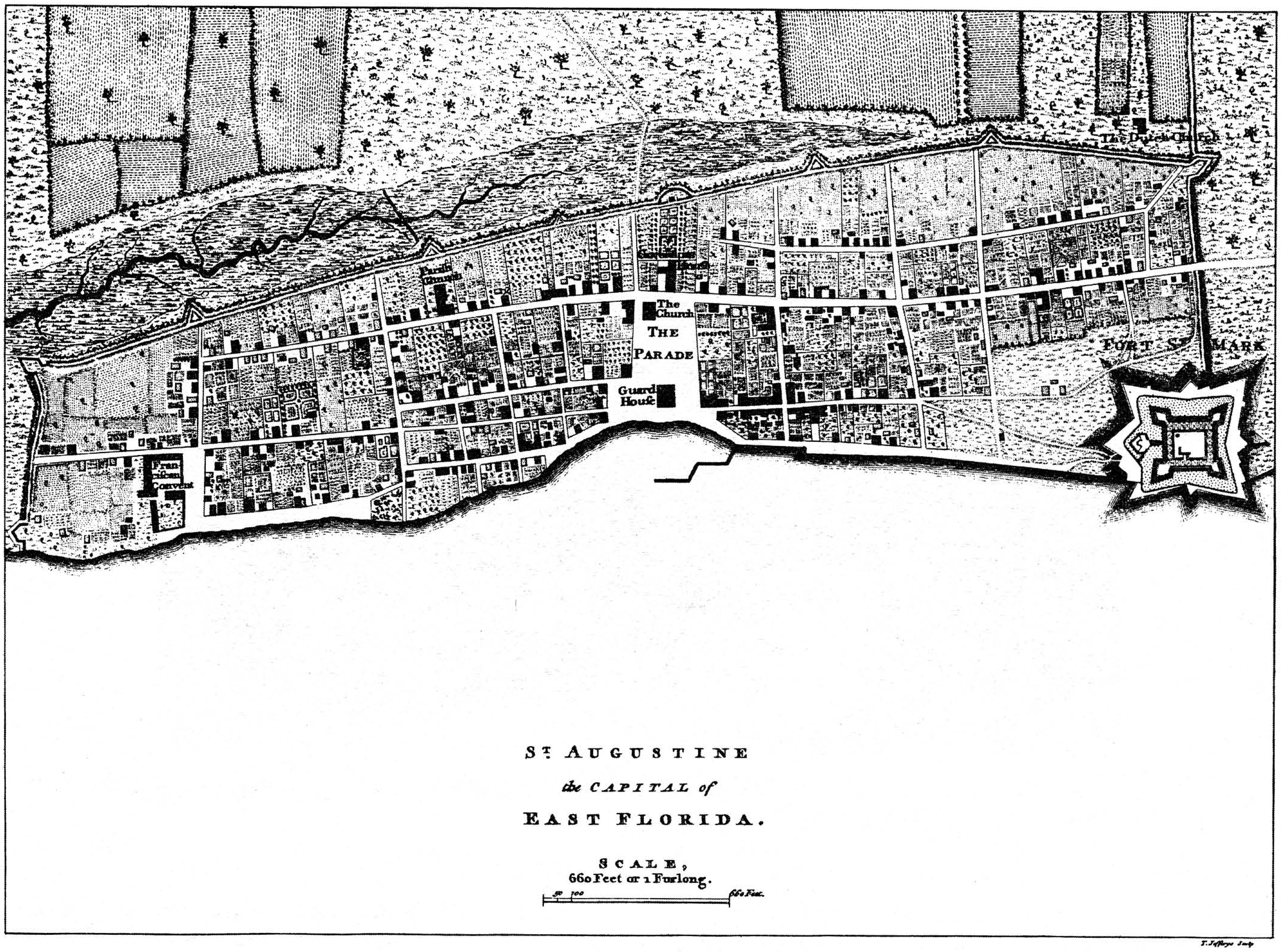
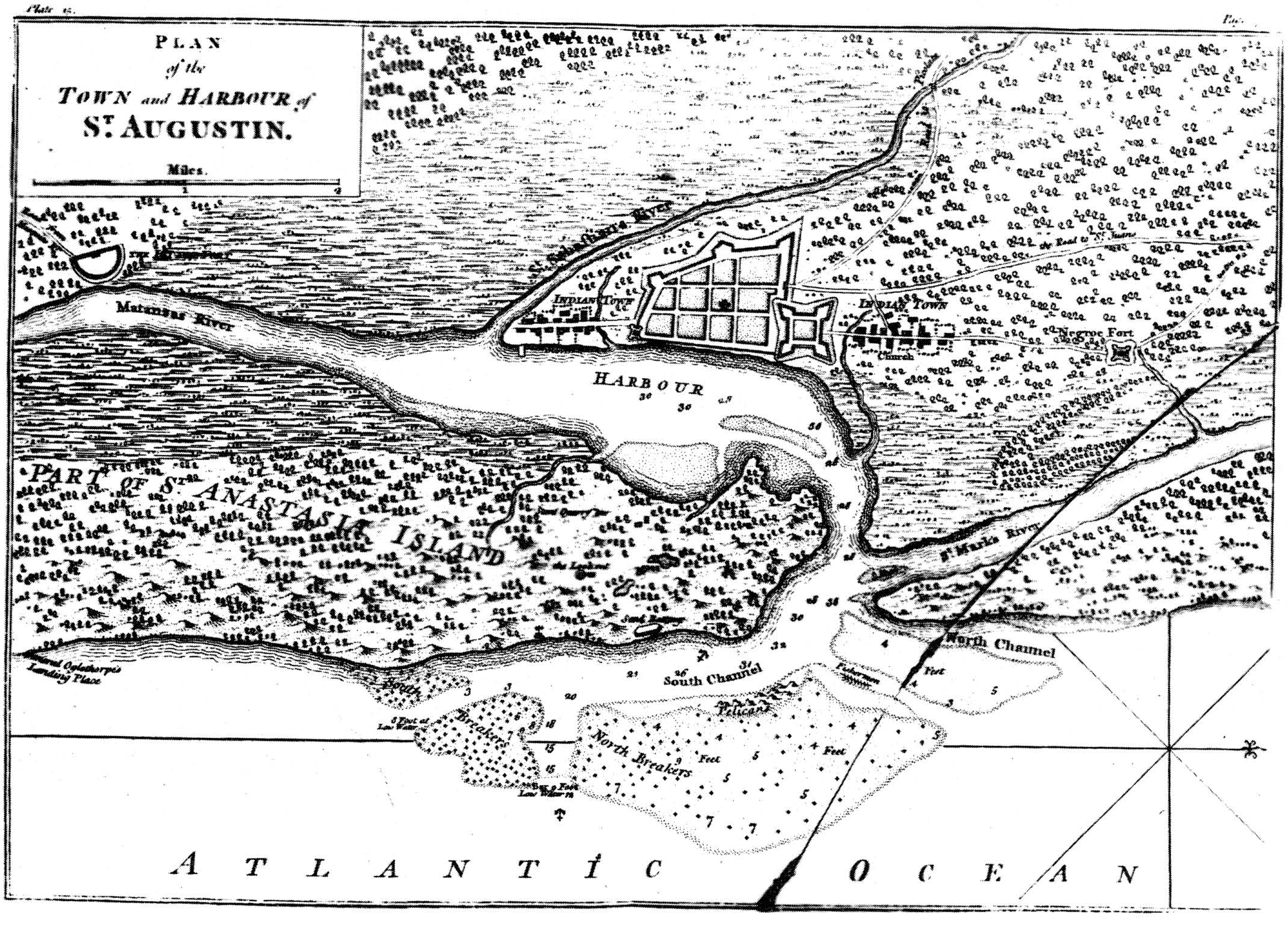


Fig. 3. : Saint Augustine, 1763. Courtesy Historic Urban Plans. Note swampy ground behind town.

Fig. 4. : Saint Augustine and Anastasia Island, 1762. U.S. National Archives, Drawer 72, sheet 28-4, Record Group 77. Note Stone Quarry on Anastasia Island.



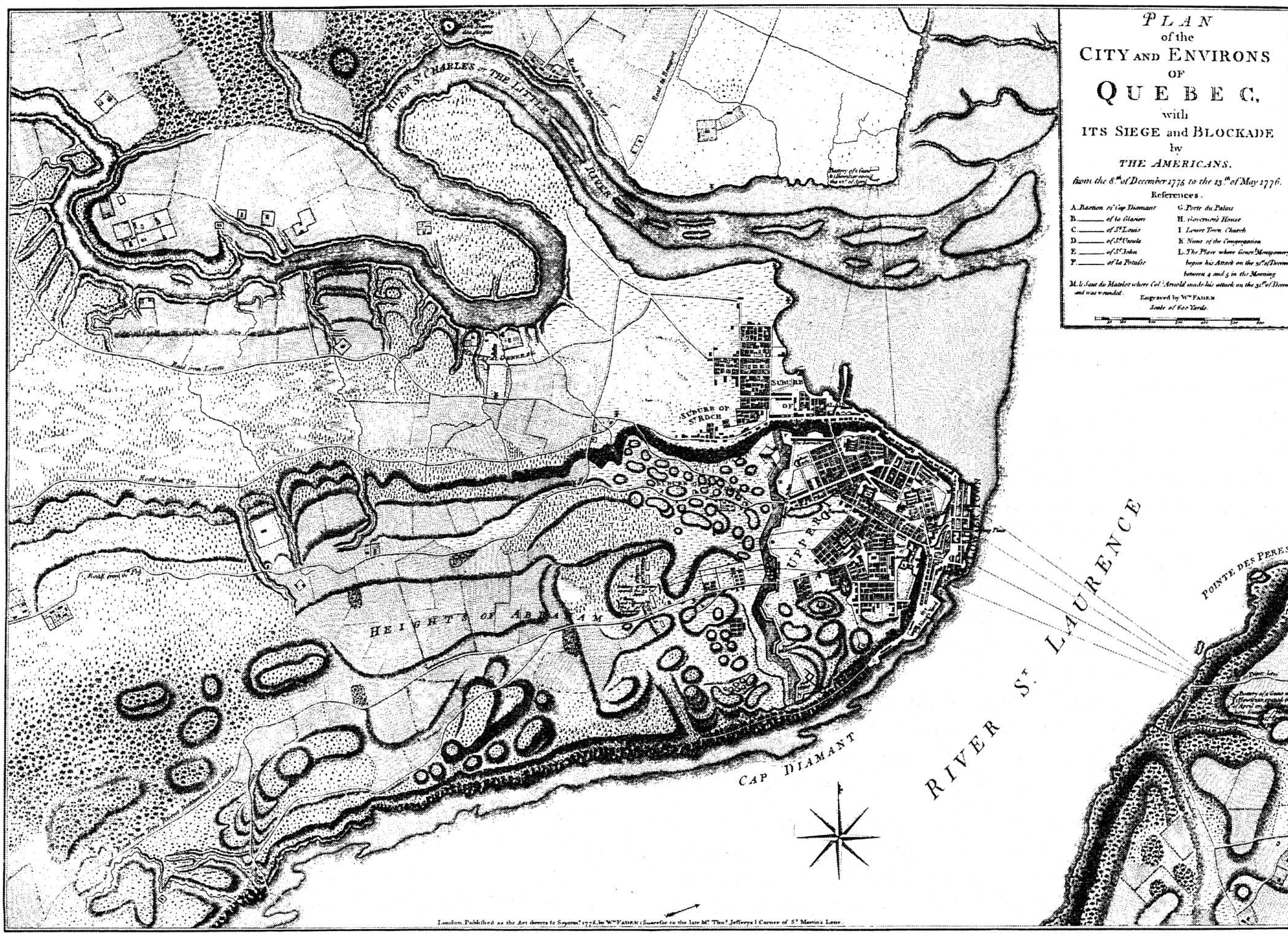
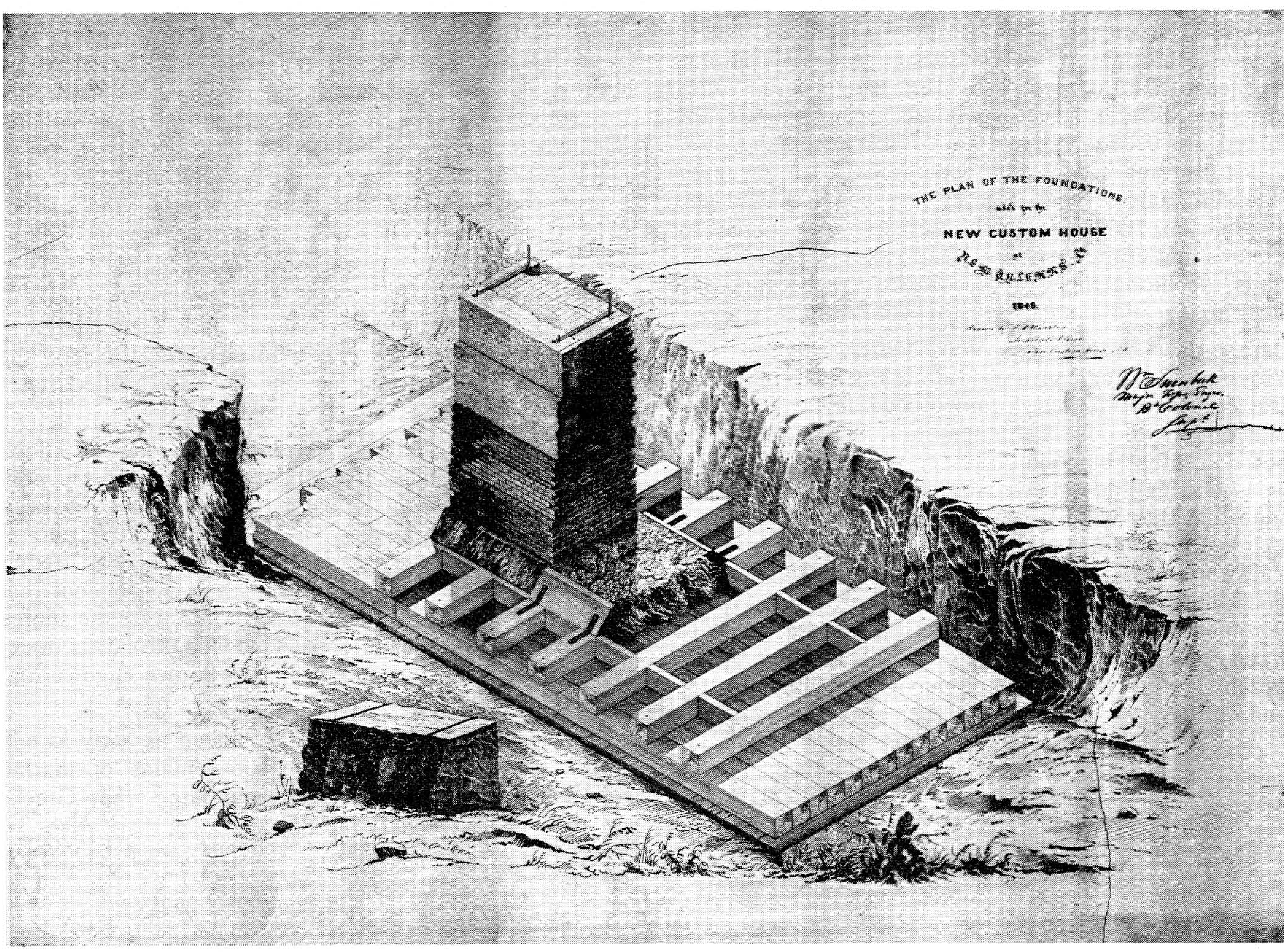


Fig. 5 : Quebec, 1776. Map courtesy of Historic Urban Plans.

Fig. 6 : New Orleans, plan of foundation for New custom House, 1849. From National Archives, Record group 77, Civil Works Map File.



to Georgia. In 1763, the Treaty of Paris stripped France of Canada and the land east of the Mississippi, which became part of the British possessions. The British colonies between Canada and Florida became independent of England after the Revolutionary War that began in 1775 and ended with the signing of a treaty in 1783, but control of the Mississippi by the fledgling United States was not complete until the Louisiana Purchase of 1803, which also made New Orleans a part of the United States (Duke, 1978; Lewis, 1976; Morison, 1965).

With the French to the north and along the Mississippi to the west, and with the Spanish to the south, the cluster of British colonies along the Atlantic coast, later the infant nation, was at first restrained from expansion. Travel between the coastal colonies was largely by sea along the coast or by primitive roads near the coastline. The Appalachians were a barrier to westward movement, although local east-west travel was feasible along rivers and smaller streams and a few gaps in the mountains provided limited access to the interior. The Appalachians, though not as high as the mountains in the western part of the continent, had steep slopes and rough terrain. They also were heavily covered with forests made almost impenetrable by underbrush.

The geological conditions of the Appalachians and the plain between the mountains and the ocean greatly influenced the movement of people, the construction problems they encountered, and the kind of contruction that was undertaken in the early history of the United States. The northeast-trending Appalachian mountain chain consists of several parts : the steep-sided Blue Ridge and the Piedmont Plateau west of the coastal plain; the adjacent Ridge and Valley province to the west; and the westernmost part, the Allegheny Plateau. These mountains were formed by lateral pressure that deformed the rocks into great parallel northeast-trending folds. In the Ridge and Valley province differential erosion and weathering of the folded and fractured hard rocks produced long, northeast-trending ridges and valleys, with a few gaps extending across them from east to west (Cleaves and Stephenson, 1949). Most of these gaps were created by streams that eroded narrow, steep valleys. Early Indian trails ran along the valleys close to the streams, and early roads and canals used the same routes.

Before the Revolutionary War, a dirt road ran from Virginia and Pennsylvania through the Cumberland Gap, north to Pittsburgh and thence northwest to the falls of the Ohio. It was then no more than a horse trail, but even after the Revolutionary War and still as late as 1794, this and other roads were in such a terrible state that they were barely passable by wagons (Rose, 1976). Even before the war, the need for improved transportation, both by road and by canal, was so great that George Washington urged the improvement of the Potomac River for navigation, as it was the shortest water route between the Atlantic Coast and Pittsburgh, which lay at the head of navigation beyond the mountains.

Construction after the Revolutionary War

Canal construction in the eastern states began soon after the treaty ending the Revolutionary War was signed in 1783. In 1785, George Washington's dream of improving the Potomac River began to take shape with the formal organization of the Potomac Company, which was to build several short canals skirting the falls along the Potomac (Hahn, 1976). Construction methods used for the canal were relatively primitive, although a great deal of finely cut stone was employed in the locks and canal walls. In some places hard rock was excavated by blasting with black powder. Holes for the powder were laboriously drilled by hand.

The canals along the Potomac were built to skirt waterfalls that are characteristic of the "fall line" that extends from the west end of Long Island to Florida along the east side of the Appalachians (Merrill, 1964). This line or zone marks the boundary between the hard metamorphosed sedimentary and volcanic rocks of the Piedmont Plateau to the west and the soft, easily eroded sand, gravel, and clay of Cretaceous and Tertiary age that underlie the coastal plain. It is the line along which falls and rapids are first encountered when one ascends the major rivers. These falls define the upper limit of navigation; for this reason, and because the waterfalls provided power for mills of all kinds, many of the early settlements in the middle eastern states were established along this zone.

The Great Falls of the Potomac, which were a major obstacle to navigation on the river, lie somewhat west of the regional fall line. The river at Great Falls flows over a series of thick layers of metamorphosed sandstone that is particularly resistant to erosion. These hard layers slowed the process of valley cutting so that the river came to drop over ledges into the gorge that was cut in the less resistant rocks that lie below the falls. The fall line was first recognized as a physiographic feature of the American continent by Johann David Schopf, who came to America as a surgeon to the Hessian troops during the Revolutionary War and after the treaty of 1883 made a tour of the eastern United States as far south as Florida (Merrill, 1906).

At the time work began on the early canals, very little was known about the geology of the Appalachians. In considering the use of geology in early construction in the new little nation, it is helpful to recall briefly the status of the science at the time when the Untied States was founded.

The Egyptians and Romans had much practical knowledge about the use of earth materials in construction. The oldest known geologic map was made in Egypt in about 1300 B.C. (Ball, 1942). The best-known part of that map shows the location of gold mines (Fig 7a), but of more interest for our purposes is a fragment that deals with the location of quarries that were the source of much Egyptian building stone (Fig. 7b). This document might be considered the first known engineering-geologic map.

Some Greek intellectuals had realized as early as 600 B.C. that fossil shells were the remains of marine organisms (von Zittel, 1962), and later other Greeks

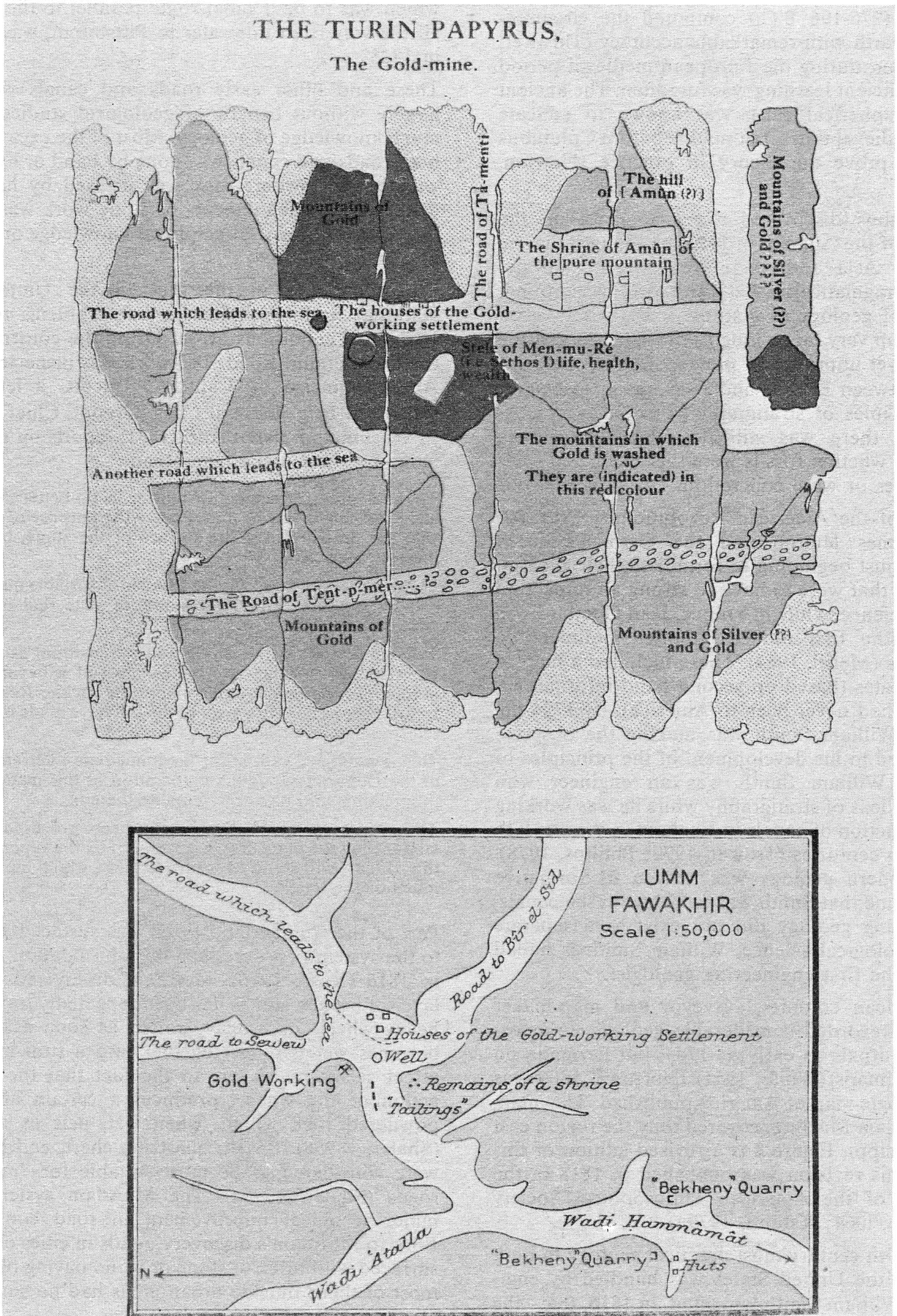


Fig. 7. : The Turin papyrus, the gold mine and the quarries, approximately 1300 B.C. From Ball, 1942.

proved theoretically that the earth was a sphere (Adams, 1938).

Eratosthenes (276-196 B.C.) computed the circumference of the earth with remarkable accuracy (Thrower, 1972). However, during the European medieval period much of the ancient learning was forgotten. The ancient theory of a spherical earth was known to educate persons in medieval times, but no one before Columbus had tried to prove the theory in practice (Newton, 1968).

When Columbus discovered the land mass on the western side of the Atlantic in 1492, he thought that he had come to Asia and, therefore, that he had demonstrated pragmatically that the world was round. The science of geology as a study of the whole earth did not develop very far so long as the sphericity of the earth was as yet unproved in practice, the existence of continents between Europe and Asia was unsuspected, and the principles of stratigraphy were unknown. As late as 1700 there was still no agreement among scholars as to whether fossils were the remains of once living creatures or were concretions (Adams, 1938).

At the time of the American Revolutionary War, the Scotsman James Hutton and the German Gustav Werner were just beginning to formulate their geological principles that were to have so strong an impact on the modern science, while in France, Jean Guettard was constructing the first modern, though rudimentary, geologic maps (Merill, 1964). These included a map of the United States (based on second-hand information, for Guettard had never been to America). By 1794 the Englishman William Smith was making the observations which led to his development of the principles of stratigraphy. William Smith was an engineer who acquired his ideas of stratigraphy while he was working on the construction of canals in England in the late 18th and early 19th centuries (Trower, 1972; Phillips, 1978). Although modern geology was still in its formative stage at the time that Smith was working on the canals, and engineering geology did not exist as a separate branch of geological science, William Smith is hailed by many as the first engineering geologist.

In the American colonies, surveyor and map-maker Lewis Evans recorded considerable geologic information in his journals as early as 1743, but he made no true geologic maps (White, 1951). Not until 1809 was the first geologic map of America published. This map, made by William Maclure, covered only the region east of the Mississippi. Figure 8 is a revised edition of this early map; this revision was published in 1818 in the Transactions of the American Philosophical Society (Merrill, 1906, 1064; Rabbitt, 1979a).

In the early 19th century most practical geology in both England and the United States was handled by engineers. Even William Smith lamented, in 1816, that "the theory of geology was in the possession of one class of men, the practise (sic) in another" (Adams, 1938). It was in this setting that construction was begun on several transportation routes running westward from the Atlantic Coast. The Erie Canal, across the northern part of the Appalachians, was begun in 1817 and finished in 1825; the Cumberland Road, along the valley of the Potomac, was started in 1802 (Waggoner, 1958; Rose, 1976). The Chesapeake and Ohio Canal, which was to be a canal route parallel to the Potomac all the way from tidewater to Pittsburgh, was initiated in 1825.

These and other early roads and canals were built largely without benefit of geological studies or even much knowledge of geology. Most of the excavation for both roads and canals was done by hand or by blasting with black powder; rock was dressed by hand; and material for embankments or stone work was selected largely on the basis of empirical knowledge or availability, or both.

Correspondence in the files of the United States National Archives indicates that problems related to geological conditions arose during the construction of the Cumberland Road. The work was inspected for the Army engineers by Capt. A. Talcott; a letter from Talcott to Brig. General Chas. Gratiot, Chief Engineer in Washington, dated April 1831, reports on the use of stone on the Cumberland Road :

"What is used for cement or mortar, is no better than if they had used clay or earth; it may serve the purpose of equalising (sic) the pressure over the surface of the stone, but cement them, it never will.

The material prepared for the Road is of variable quality, from a first rate Lime and Flint stone, to slate that is perfectly worthless.

The Lime Stone passes, by gradual transition, as you travel west from Zanesville, into Slate : most of it beyond the 11th mile is not worth the labor of putting on the Road, though some of the contractors west of the 11th have made much better selections than others.

This is a subject, calling for the immediate interfereance (sic) of the Department, as the preparation of this material is still progressing, and payments making thereon,...

The sandstone which could have been procured with less labour than the Slate, has been refused by the superintendent; this at least will stand exposure to frost, which has destroyed much of the slate".

Part of the Cumberland Road was surfaced according to the system first described by John Loudon McAdam in 1816 (Rose, 1976). McAdam discovered that if a layer of broken stones has been repeatedly traversed by heavy wheels or a heavy roller, as soon as the layer becomes wet it binds together into a firm mass. The effect seems to be due to the fact that the grinding action of the wheels produces a certain amount of powdered rock which, when wet, acts as a cement (Shaler, 1895a). Basalt, quartzite, chert, and limestone were considered to be most suitable for "macadam" roads (Shaler, 1895a). The McAdam system was a major technical improvement in road construction. Prior to McAdam's discovery, roads in cities often were surfaced with brick or stone or wood paving blocks, but most of those outside urban areas had no surfacing at all.

The routes for the various parts of the Chesapeake and Ohio Canal were laid out by engineers, who determined grades and on some of their preliminary maps indicated cliffs and existing quarries. The famous Seneca quarry, source of the Seneca sandstone so widely used in building the canal, is indicated on some of these

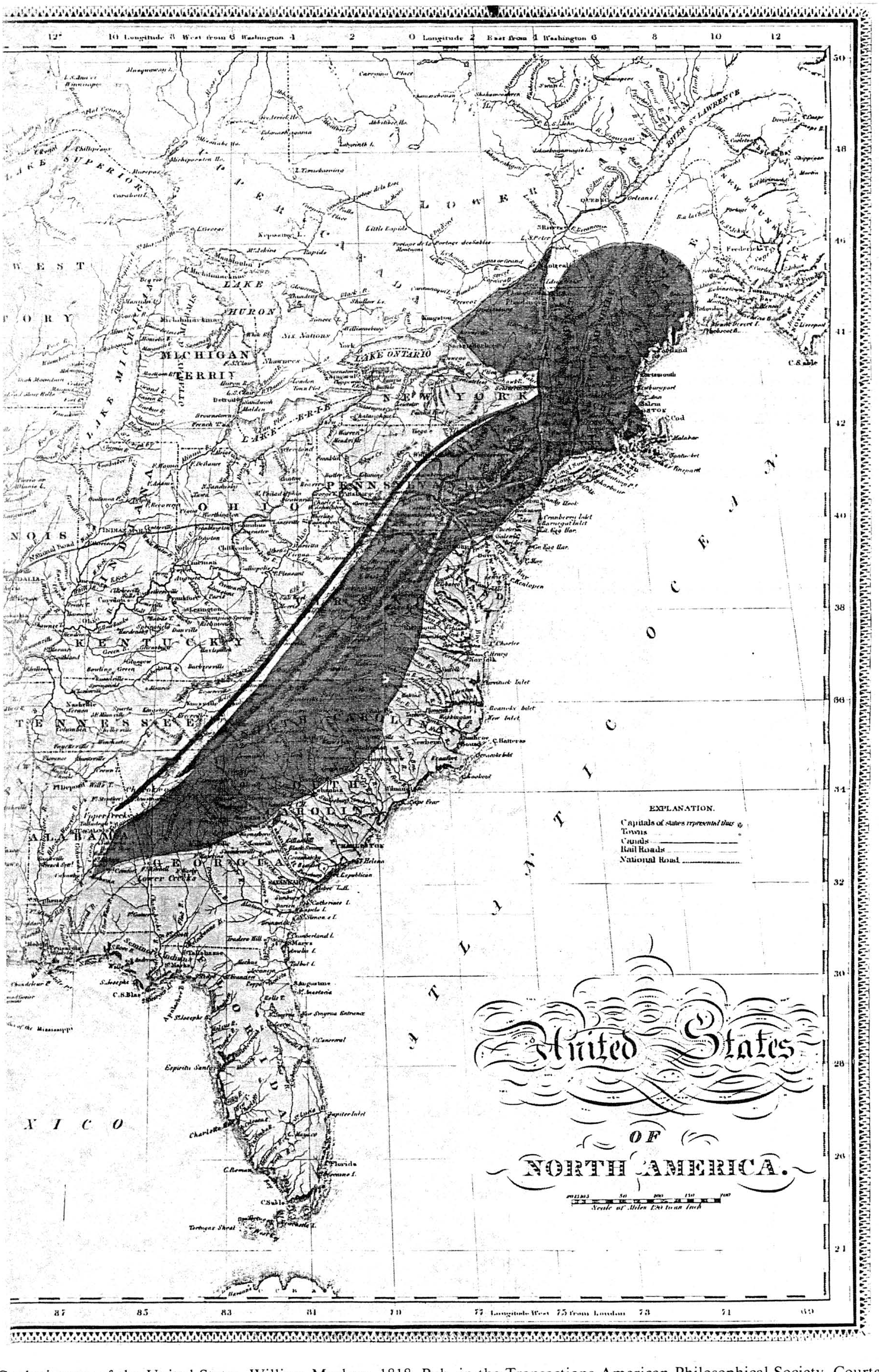


Fig. 8. : Geologic map of the United States, William Maclure, 1818. Pub- in the Transactions American Philosophical Society. Courtesy Library of Congress.

early maps simply as "quarry" (Folio RG77, Records of the Office of the Chief of Engineers Headquarters, Map file canals 70, Cartographic Branch, National Archives). Stone used in parts of the Chesapeake and Ohio canal is discussed in several publications (e.g., Davies, 1970; Hahn, 1974).

One of the earliest detailed geological studies of a large proposed engineering project in the United States was made by Michael Tuomey, who in 1851 examined a portion of the proposed Kanawha Canal and Reservoirs of the James River in the Allegheny Mountains (Tuomey, 1851). His stated objective was unusually direct for the time :

"I shall attempt no geological generalizations in this brief report, but confine myself strictly to the statement of the facts observed in relation to the mineral composition and geological structure of the rocks forming the basins to be occupied as reservoirs, and of the portions of the line of canal examined; these being, as I conceive, the only considerations bearing directly upon the problem to be solved".

This concise report is illustrated with numerous cross sections and sketches, and the text describes the depth of disintegration of granite, suitability of rocks for building materials.

In 1790, at about the same time as canal construction began, a tract of land along the Potomac River was selected to be the seat of government of the United States. The general area chosen, which was on the fall line, included the existing river ports of Georgetown, Maryland, and Alexandria, Virginia. In 1791, George Washington selected the site within this tract on which the capital city would be built.

The early inhabitants of the United States placed a great many of their settlements on or near swampy ground, probably because the towns were established on harbors or on rivers that had become major arteries of travel before improved roads were constructed. The nation's capital was one of these. The city was traversed by several streams with marshy borders, and included areas of tidal flats (Fig. 9). Tiber Creek (called "Goose Creek" or "Tyber Creek"), which drained much of the District of Columbia, was a sluggish stream that repeatedly overflowed, so that the land between the "President's House" and the Potomac River was generally a great swamp. The area was appropriately nicknamed "Foggy Bottom" (Carr, 1950). In 1870, a corduroy road was laid across the swamp. Eventually the Tiber was converted into a canal, and finally was

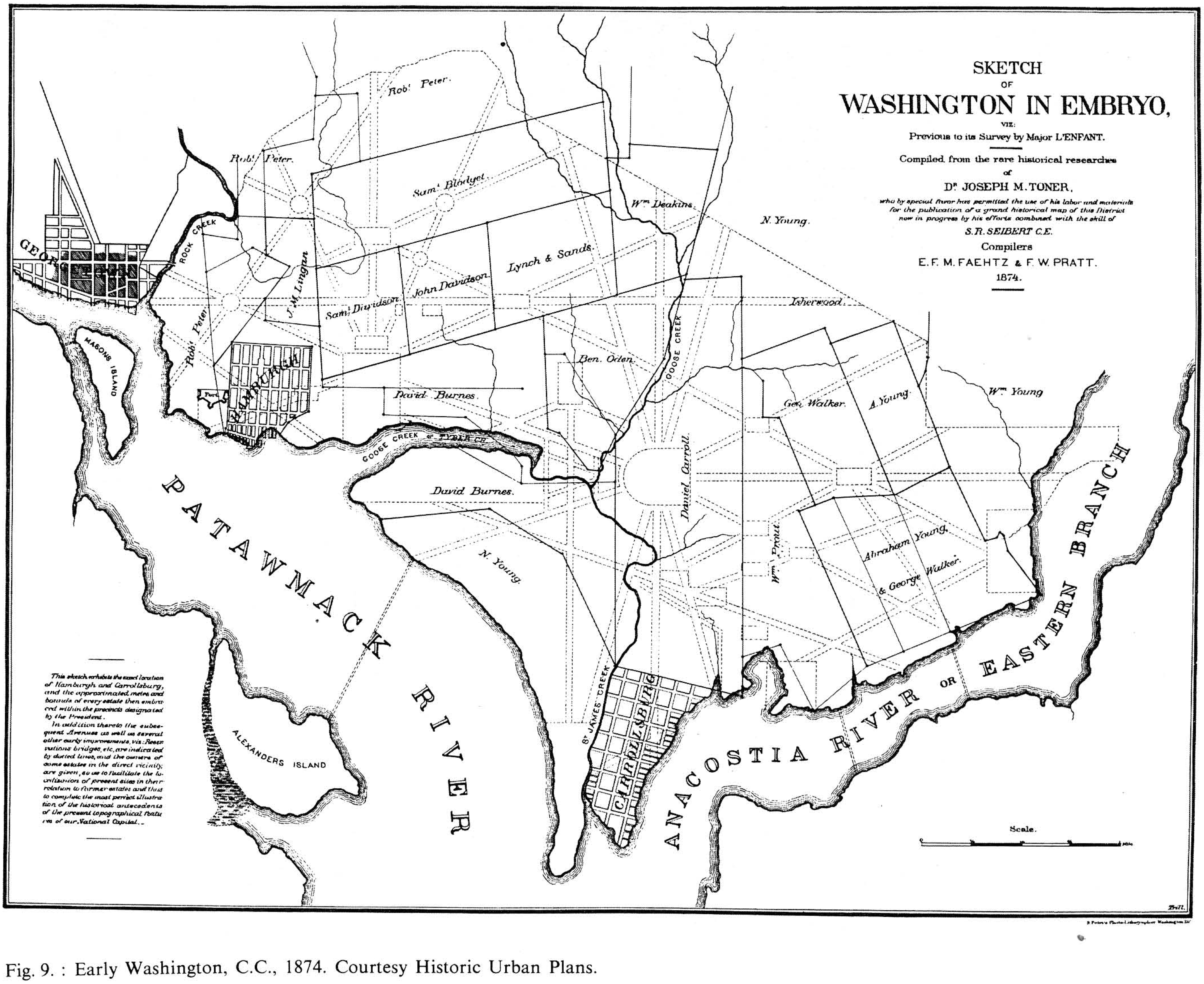


Fig. 9. : Early Washington, C.C., 1874. Courtesy Historic Urban Plans.

covered over. Even today, pumps operate under the National Archives Building to protect the foundations from waters of the swampy area along the old Tiber Creek (Federal Writers Project, 1937).

In addition, both the Piedmont province, west of the fall line, and the coastal plain, east of it, presented foundation problems in the District. Within the Piedmont province, most buildings now have firm foundations on solid crystalline rocks. However, even there foundation conditions are troublesome in places where the rocks are decomposed. The bearing strength of the unconsolidated deposits of the coastal plain is very low in many places, so that most of the massive buildings must be supported on piers of piles, many of which extend to bedrock (Carr, 1950). Isolated buried muck and peat beds of Pleistocene age add to the difficulties (Wentworth, 1924).

The foundation problems posed by coastal plain sediments are perhaps best illustrated by the construction history of the Washington Monument. In 1783 the Continental Congress first considered a monument to George Washington, but it was not until 1848 that the first cornerstone of that monument was laid.

The Civil War put a stop to the building of the obelisk; then in 1878, when construction was resumed, the engineers found that the original base would not support the proposed structure. A new slab was poured beneath the old foundation, and the whole was enclosed by a concrete buttress (Ereidel and Aikman, 1973). In 1901, a Senate commission recommended an elaborate landscaping project that would have involved the moving of much earth around the monument. Fortunately, the landscaping was delayed. Borings made by the Army Engineers in 1930, before the project was finally to be started, revealed that the monument would be endangered by large-scale earth moving. The borings showed that the foundation of the obelisk was on sand, clay, and gravel overlying soft blue clay that rests on bedrock. Such soft clay is compressible under a heavy load, so that the removal of earth around the sides of the monument might have allowed some squeezing out of the soft clay from under the monument, thus seriously endangering its stability. The clay was deposited by the Potomac River when its course was different from the present one, and the mud was subsequently covered by deposits of sands and gravels. In view of the conditions revealed by the borings, the landscaping project was prudently abandoned (Hoover, 1934).

While transportation was being improved in the east and post-Civil War construction in the capital proceeded apace, settlement of the interior was just beginning. In order to protect the settlers who were migrating westward to the new land opened up the Louisiana Purchase and the treaty ending the War of 1812, the U.S. Army began to build forts and roads in the interior.

In 1816 a contingent of the U. S. Army went to Green Bay, that thumb on the mitten of Lake Michigan, (Fig. 1a) to establish Fort Howard (Biddle, 1854; Kellogg, 1934). Once again, marshy land was selected for the site. A letter of early but undetermined date from Lt. James Dean to Capt. James H. Hook in Washington gives Lt. Dean's opinion of the location :

> "I am confident that a more ineligible site on which to have erected a permanent military work could not have been selected in this country, than that of Fort Howard is. Its front resting on a barren waste of sand, which is subject to agitation, at almost every breath of wind, its rear immersed into a sinking swamp, and the whole overlooked by a neighbouring height — such is the position, which the engineer selected for the performance of this duty — fixed upon for the site of Fort Howard".

Early maps show a cranberry bog at the west corner of the fort (Fig. 10).

The troops assigned to such forts spent more of their time constructing buildings, hunting and farming to supply themselves with food, and building roads through the swampy, forested wilderness, than they did in the soldierly duty of fighting Indians (Prucha, 1967). Shortly after the Army was established at Fort Howard, Army troops began construction on roads southward to Lake Winnebago, to Prairie du Chien, and eventually to Chicago, where other troops occupied Fort Dearborn.

Fort Howard was established the year after William Smith's geologic map of England was published and only 20 years after James Hutton's death. Construction practices of the army at that time differed little from the practices of the engineers who had accompanied the Roman army to England in 55 B.C. and 43 A.D. The geologic conditions with which the Roman army in England and the U. S. Army in Wisconsin had to contend were in many ways similar. Northern England and Wisconsin had both been covered with ice during the Pleistocene epoch. In both places the retreating ice left rolling, boulder-strewn fields and swampy areas in its wake. Blocks of ice partly buried in glacial debris had melted to leave hollows that eventually became swamps. Other depressions were an aspect of the irregular topography that had been formed when the glaciers melted during their retreat and so deposited their accumulated loads of rocks and soil on top of the bedrock in untidy heaps. In the wet northern climates the depressions accumulated water, became sinks for minor streams, and gradually filled with water-soaked organic debris.

Fort Howard was built on the edge of one such bog, and roads that were later constructed in the area had to cross extensive swamps in many places. To build across swampy ground or to construct small bridges across creeks, engineers of both the Roman Army and the U.S. Army resorted to logs laid crosswise over foundation timbers that were anchored into the ground with stakes or large forked branches (Figs 11 and 12). Roads made of these Figures 11 and 12 inserted here crosswise logs are called corduroy roads, for obvious reasons. A few back roads of this type are still in use in swampy, forested areas in northern parts of the United States.

Both the army and the early settlers soon needed a road between Fort Howard, at the mouth of the Fox River where it flows into Green Bay, and Fort Crawford, at Prairie du Chien, near the mouth of the Wisconsin

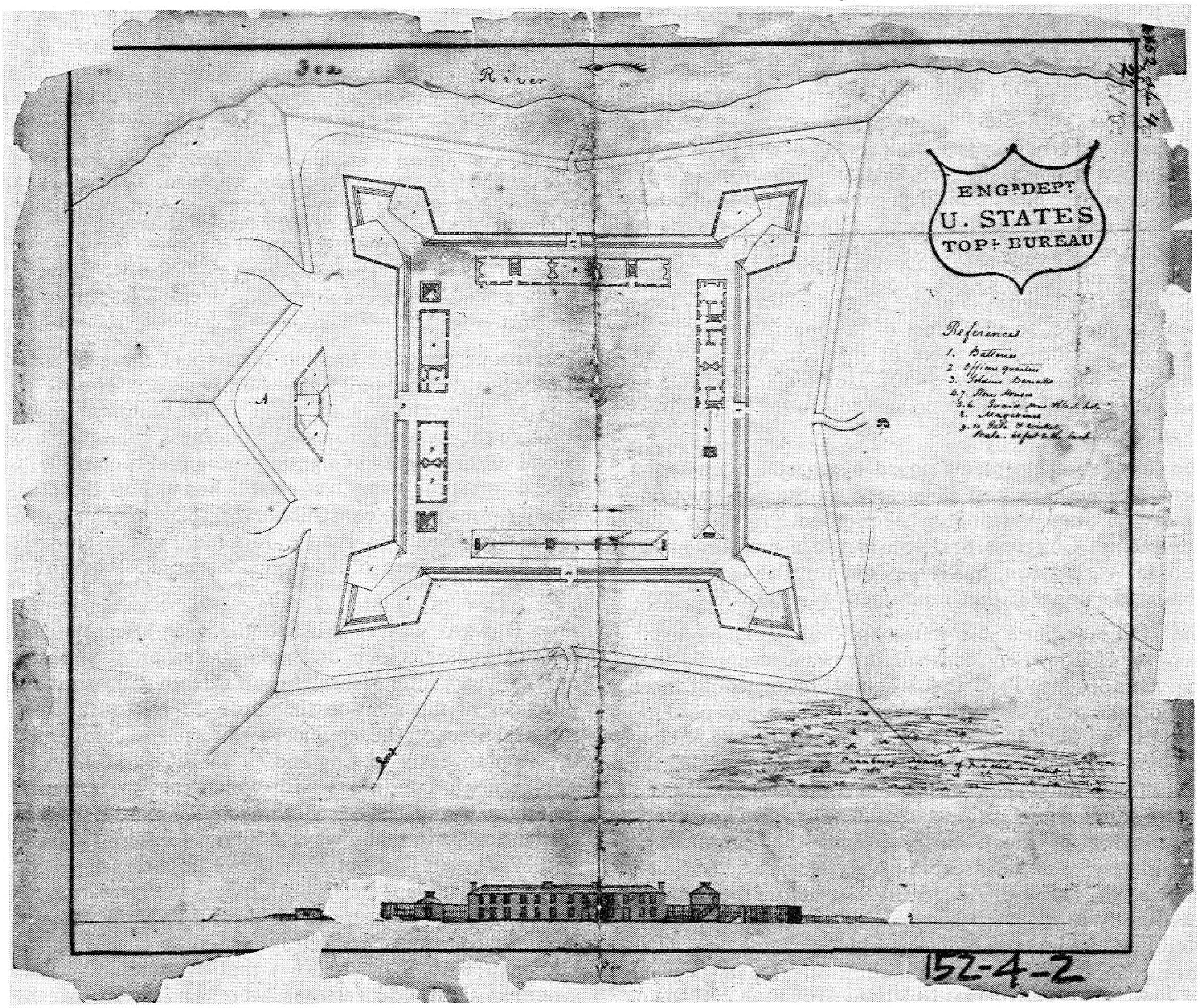


Fig. 10. : Ft. Howard, Wisconsin : date unknown, approximately 1818. From the National Archives, Record Group 77, Dr. 152, Sh. 4/2.

River where it discharges into the Mississippi (Prucha, 1967).

A letter written in 1833 by Lt. A. J. Center, Detroit, to Maj. General Jesup in Washington, D.C. describes the difficulties of road-building in northern Wisconsin at the time :

"From the examination I have already made of the country, I am clearly of the opinion, that the Mil. (sic) Road must pass by the southern extremity of Lake Winnebago, — this is likewise the opinion of J. D. Doty, Esqr. — the distance from Green Bay to the foot of Lake Winnebago (called Fond-du-Lac) is about 35 or 40 miles. The country immediately south of the settlements on the Fox River, and bordering upon Manitowok River is an impassible (sic) swamp; these swamps extend to the head waters of the Manitowok, within a few miles of Fond-du-Lac". (See fig. 13.) (National Archives, RG 92, Consol. Corresp. file, Box 925).

The route selected followed old Indian trails for much of the way (Cole, 1925).

Conditions in that part of the country are well illustrated by the difficulties of a troop movement that was undertaken in December of 1826. Troops were moved from Fort Dearborn to Fort Howard, although the move was protested by officers at Fort Dearborn on the ground of the extreme difficulty and expense involved at that time of year. The passage through uninhabited and trackless forest in the middle of winter was described in a letter dated February 11, 1837, from Capt. S. F. Jamison to his superior in Washington, D.C. :

"The march of the troops and the movement of so many columns of teams through a wild and untrodden wilderness, for more than 100 miles of which the journey was attended with uncommon difficulties, in the midst of deep snow and very cold weather, rendered the progress of the troops slow, tedious and even hazardous to life. So great indeed were the justly anticipated expenses and dangers of such an expedition at this inclement season of the year that it would seem nothing short of the most imminent necessity or danger at Fort Howard and vicinity from War and famine could justify it".

The road from Fort Howard to Prairie du Chien was not completed until 1837, and even then was a minimal trackway through the woods, unsurfaced, muddy and

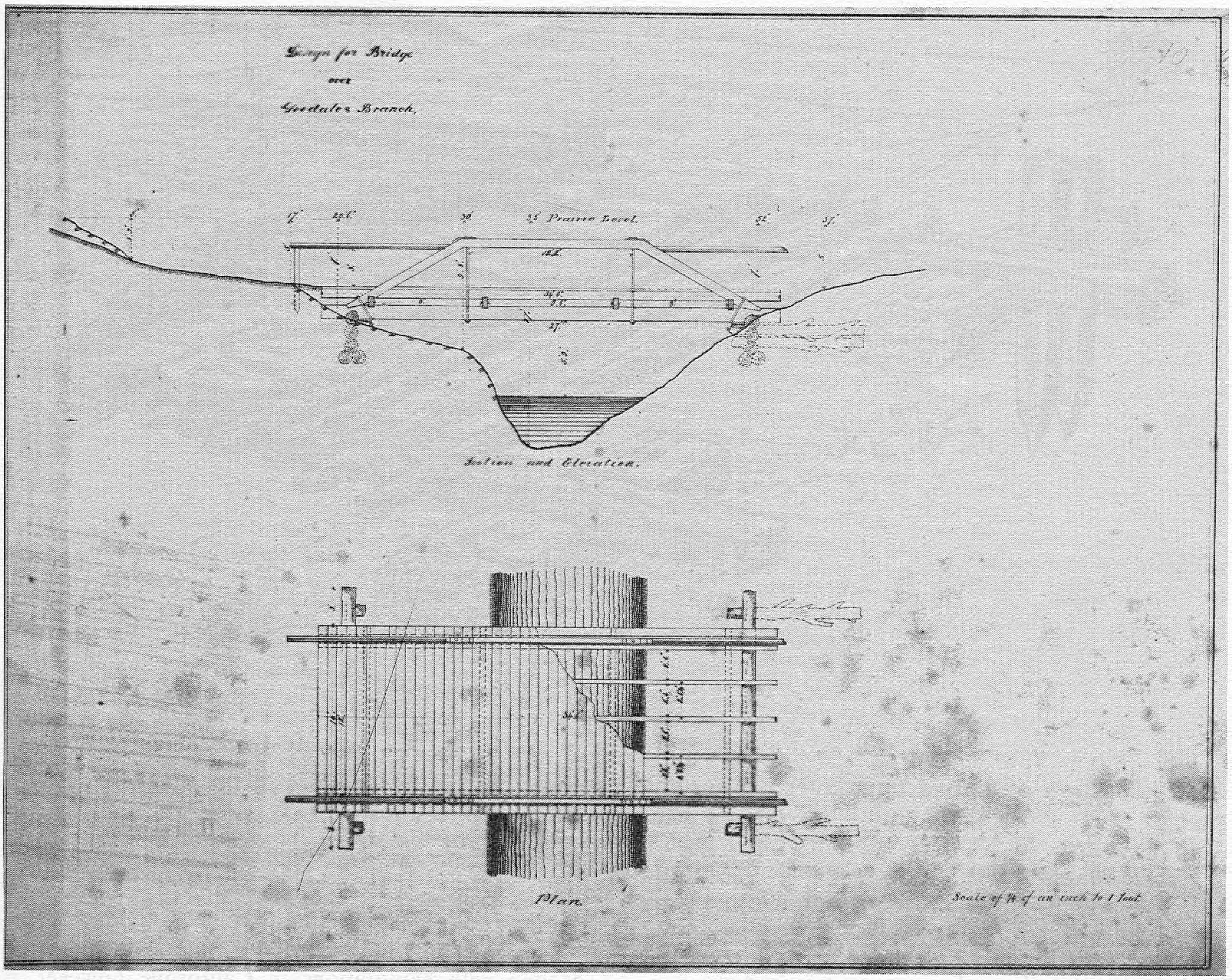


Fig. 11. : Early bridge built by army engineers about 50 miles southeast of Ft. Kearney (which is on the Platte River). From the National Archives, Record Group 77, Civil works Map File.

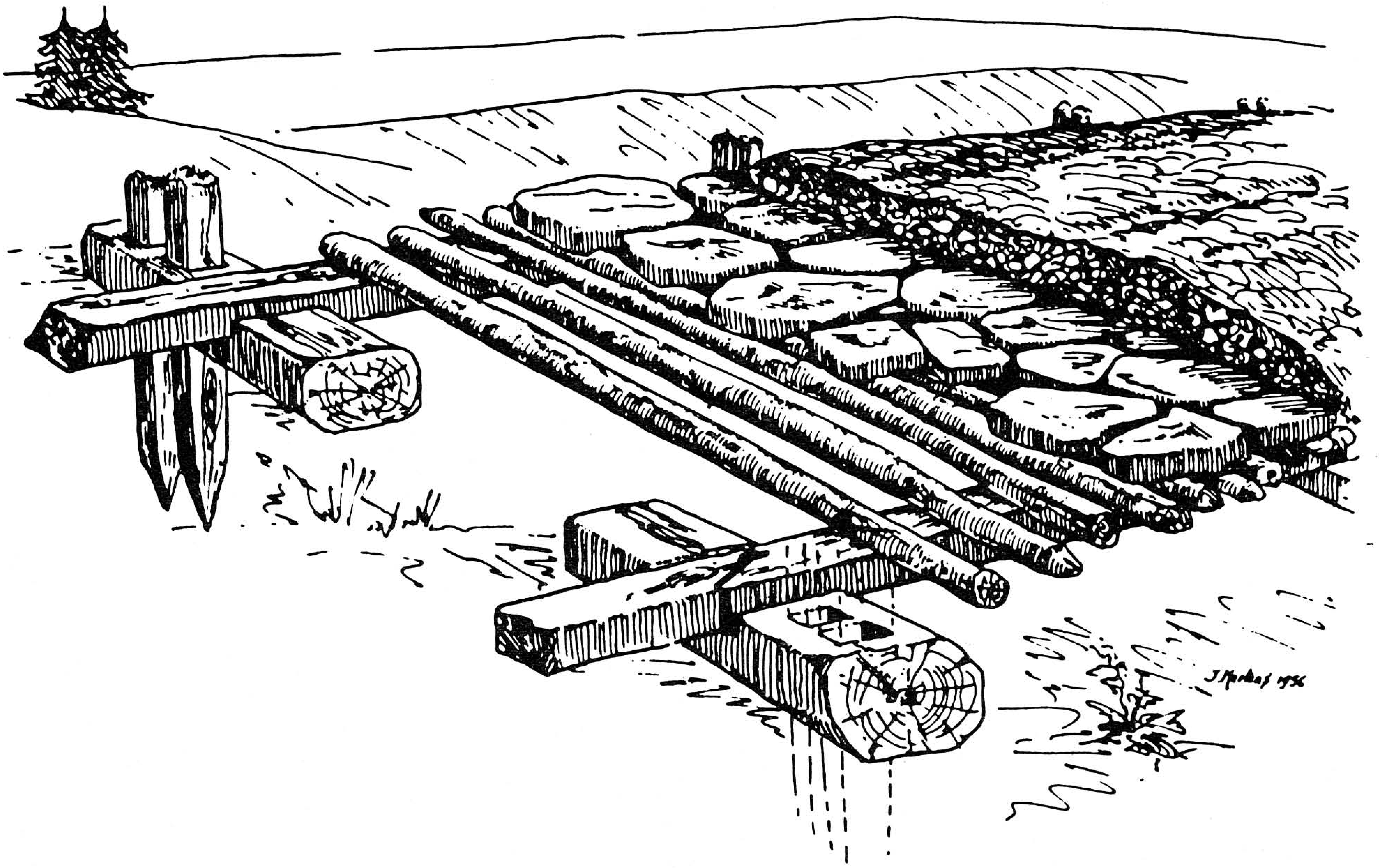
rough. But it served the ever-swelling tide of pioneers who streamed into the Northwest Territory and who then began to move even farther west.

While the pioneers moved westward, transportation in the east was being revolutionized by the development of the steam locomotive and its immediate use, on the Baltimore and Ohio Railroad in 1831 (Rose, 1976). The railroad gave tremendous competition to the canals and soon changed the entire pattern of transportation in the country.

Expansion to the Far West

The discovery of gold at Sutter's Mill in California in 1848 sparked a frenzied migration across the nearly trackless west that was without precedent in this country's early history. Pioneers in wagons drove their oxen westward across poorly defined trails over prairies, deserts, and mountains to reach the fabulous West Coast. Others went around Cape Horn, and a bustling town soon developed on the west side of San Francisco Bay, one of the best harbors on the West Coast (Fig. 1a). Here docked ships that were bearing goldseekers and their goods together with merchants anxious to serve them and supplies that the merchants would sell. Many of the immigrants settled on the mudflats and sloughs around the edge of San Francisco Bay, building an instant town of wooden structures on dirt tossed carelessly over the mud. No thought was given to the effect that the settling mud would have on the buildings. Nobody paid much attention to rumors of a damaging earthquake in 1836.

A number of geologic factors had shaped the magnificent harbor that is San Francisco Bay. A combination of warping and faulting produced a northwest-trending trough, which subsequently was nearly filled with sedimentary deposits during the Pleistocene. The combined Sacramento and San Joaquin Rivers cut a course westward from the Great Valley to create Carquinez canyon (now Carquinez Strait) on the east side of the trough and Golden Gate canyon on its west side. The Golden Gate, which is floored by bedrock, is the deepest part of the present bay. The rise of sea



Section of a road built over on unstable ground: the *via Mansuerisca* in the Hautes-Fagnes (after J. Mertens, op. cit., p. 39)

Fig. 12. : Structure of a Roman road in France built over unstable ground. From Chevallier, 1976.

level that resulted from the melting of the last ice sheets flooded the trough and canyons to produce San Francisco Bay, which ships from the Pacific Ocean now enter through the narrow channel of the Golden Gate. Fine muds deposited at the edge of the bay have formed a wide band of tidal flats along the shores (Louderback, 1951).

So rapid was the settlement of the West Coast that railways were proposed to cross the entire continent in order to serve the population on the coast as well as to make available for settlement the area between the Mississippi River and the Pacific Ocean. In 1855-54 the War Department engineers made extensive exploratory surveys to determine the best routes for the railroads. These survey parties, directed by U.S. Army officers, were accompanied by botanists, ethnologists, zoologists, and geologists, who made detailed studies of the plants, Indian tribes, animals, and geology along the various survey routes. They moved on horseback and on foot across new and unexplored terrain; their many volumes of reports are classics in the annals of the early exploration of the United States (U.S. War Department, 1855-60).

Most of their geological reports dealt mainly with fossils, physiography, soil, rock types and structure, and to some extent with natural resources including coal, water and building stone, but very little with the geological problems that might be encountered in the construction of the railways. The geologic report dealing with explorations in California, however, is exceptionally detailed; it discusses building stone, vegetation, ore deposits and mining methods, railroad grades, the possible obstruction of roads or railroads by sand, water supply, and the possibility of irrigation in the desert. It includes a number of sketches and small, generalized geologic maps in color (U.S. War Department, vol. V, 1856).

In general, however, it is the accounts written by the army engineers that give us most of the information about topographic difficulties along the proposed routes, sources of wood and coal to fuel the engines, grass for pack animals during railway construction, and water supplies for engine, man, and beast, timber and stone for construction together with an occasional remark on possible construction difficulties due to geologic conditions such as steep cliffs of hard rock, avalanches, or conditions affecting water supply. To a large extent, it was still true that "the theory of geology was in the possession of one class of men, the practise (sic) in another".

None of these reports describes the geology of the route that the main rail line ultimately took from Omaha to the Pacific Ocean. A geologic reconnaissance along the eastern part of this line was made by a geologist of the Union Pacific Company, David Van Lennep (1867, 1868), but even his reports were concer-

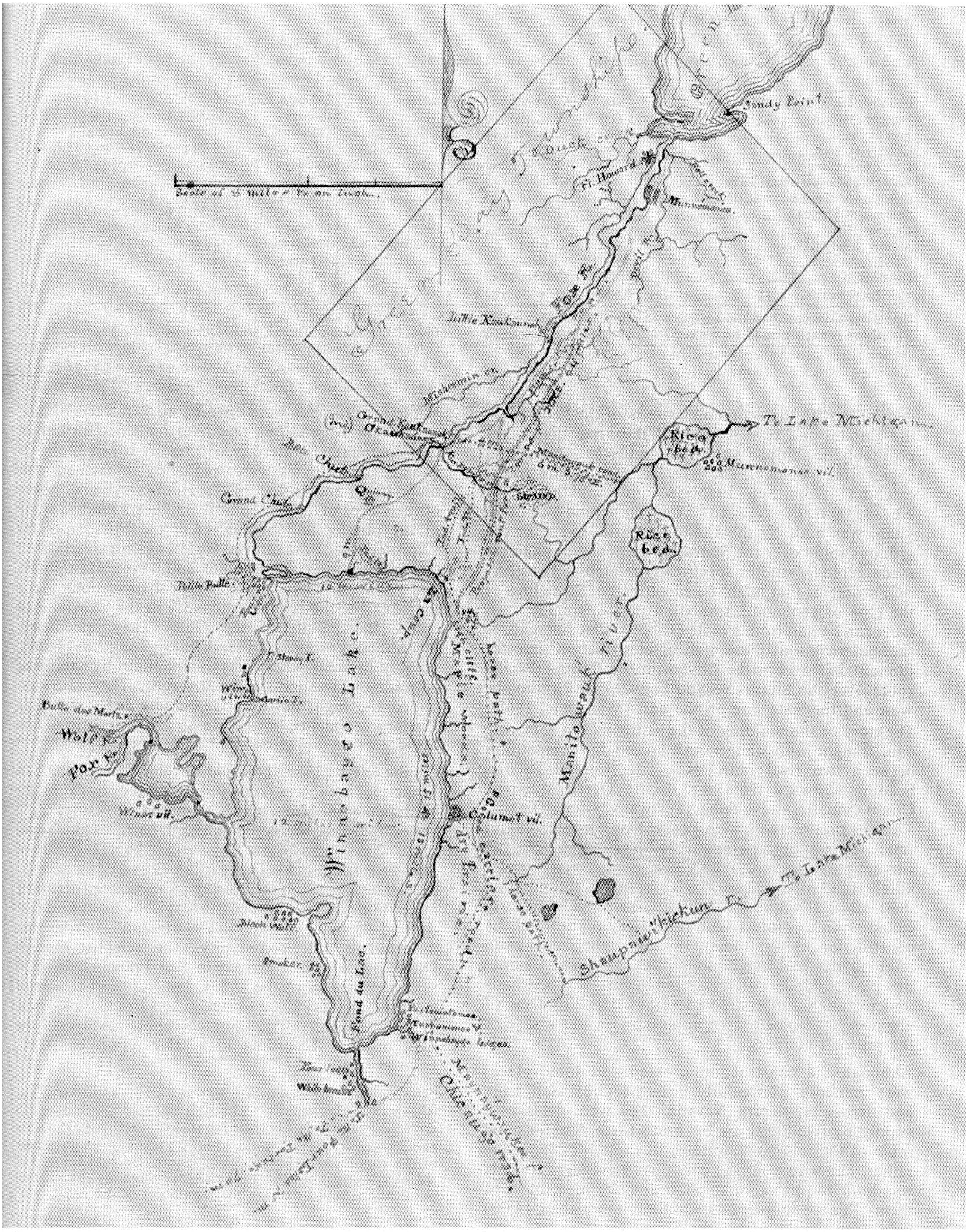


Fig. 13. : Sketch map of proposed road location, Green Bay to Fond du Lac, Wisconsin, 1829. From the National Archives, Record Group 92, consolidated correspondence file, Box 925.

Table 1 : List of tunnels on second and third divisions.

Locality in feet	Length	Material	Probable time required for construction	Remarks
Boulder Hill	200	Cement and Conglomerate	60 days	
Prospect Hill	400	Clay, slate & Cement	100 days	Will require lining
Fort Point	300	Clay, slate & Cement	75 days	Will require lining
Grizzly Hill	600	Conglomerate	150 days	A portion will require lining
Lost Camp Spur	300	Slate & Sandstone	100 days	
Red Hill, above Crystal Lake	300	Schist	120 days	
Opp. Jones' Station	200	Granite	100 days	
Summit of Sierras	1,700	Granite	19 months	Will be constructed
Cement Hill	400	Cement	120 days	for double track
Mouth Strong's Canon	180	Granite	90 days	" " "
Colsdtream	900	Cement	1 year	" " "
Devil's Grip	175	Cement	80 days	
Total feet	5,655			

Being less than one-third the aggregate length of tunneling contemplated by the original surveys.
The above tunnels can all be worked from both ends, and with the exception of the Summit Tunnel, will require no shafting.

ned more with the economic aspects of the geology — the amount and type of mineral resources that might profitably be shipped on the new railroad — than with engineering geology. The western part of the route, extending from San Francisco up over the Sierra Nevada, and then onward to join the Union Pacific in Utah, was built by the Central Pacific. Even for the arduous route over the Sierra, no geologist or engineer made geologic studies specifically related to construction problems that might be encountered. Some idea of the type of geologic information that was made available can be had from a table (Table 1) that summarizes the materials and the length of construction time for tunnels that were to be driven on the Central Pacific route over the Sierra Nevada between Colfax on the west and the state line on the east (Montague, 1865).

The story of the building of the railroads is a romantic one, fraught with danger and spiced by competition between two rival railroads — the Central Pacific, heading eastward from the Pacific Ocean, and the Union Pacific, advancing westward from Omaha. Construction on the Union Pacific was hampered in no small way by hostile Indians, who attacked both the survey party members and the construction crews, killed some of the surveyors and workmen, and stole their stock (Dodge, 1910). The army was frequently called upon to protect both the survey parties and the construction crews. Indians attacked the trains even after regular passenger service was established across the plains. Under these circumstances it is perhaps understandable that concerns other than problems of engineering geology were uppermost in the minds of the railroad builders.

Although the construction problems in some places were immense, particularly near the Great Salt Lake and across the Sierra Nevada, they were dealt with mainly by avoidance or by brute force. The original route of the railroad ran north of the Great Salt Lake rather than across it. The road over the Sierra Nevada was built by the labor of thousands of men, most of them Chinese immigrants. In 1867, more than 14,000 men were employed on the Sierra route at one time (Daggett, 1966; Central Pacific Railroad Co., 1865).

While the railroads were opening up vast tracts of land west of the Mississippi, that river remained an important commercial waterway with many towns along its banks. Those towns were frequently threatened with inundation, and in the 1850's Humphreys and Abbot of the Corps of Topographical Engineers made a study of the physics and hydraulics of the Mississippi for "...protection of the alluvial region against overflow..." (Humphreys and Abbot, 1861 and 1876). Humphreys and Abbot discussed the geological formations along the banks of the river, particularly in the alluvial area below the mouth of the Ohio. They specifically mentioned caving and landslides along the banks, notably in areas where clay is underlain by sand that is gradually washed out by the river. They also described the high bluffs of Quaternary loess overlying Tertiary sediments, which are so characteristic of the lower part of the Mississippi Valley.

On the West Coast, the rapid development of the San Francisco area was rudely interrupted by a major earthquake in 1868, which damaged structures in a wide area and nearly demolished parts of the small town of Haywards (now Hayward), on the east side of San Francisco Bay. The earthquake was caused by right-lateral movement along a northwest-trending major fault that ran directly through the town and that derived its name— "the Hayward fault"— from that unfortunate little community. The scientist George Davidson, who had arrived in San Francisco in 1850 as a party leader of the U.S. Coast Survey, was one of a committee appointed to study the earthquake (Lewis, 1954). However, the committee report never saw the light of day. According to a later report by A. C. Lawson (1908) :

"Shortly after the earthquake of 1868 a committee of scientific men undertook the collection of data concerning the effects of the shock, but their report was never published nor can any trace of it be found, although some of the members of the committee are still living. It is stated that the report was suppress (sic) by the authorities, through the fear that its publication would damage the reputation of the city".

In areas less prone to earthquakes, growing towns had other problems. In the Midwest, the burgeoning city of

Chicago was nearly destroyed in 1871 by a different kind of disaster —a raging fire (which tradition says was caused by Mrs. O'Leary's cow kicking over a lighted lantern into the hay of her barn)— but with characteristic pioneer exuberance the Chicagoans immediately rebuilt the town.

Like many another early settlement much of Chicago was built on low wet ground, in an area that was once covered by an ancient glacial lake. The Des Plaines River, on the west side of Chicago, was once an outlet for the old glacial lake. Gullies or sloughs draining into the Chicago River, in what is now the main business district, were filled with water (Peck, 1948).

Chicago grew up on the west shore of Lake Michigan where the Chicago River flows into the lake. The reason for its location there is that just west of the business district of the present metropolis there lay a little lake (Mud Lake or Portage Lake) whose west end drained into the des Plaines River, which could be followed via the Illinois River to the Mississippi, whereas the lake's east end came to within one and a half miles of the headwaters of the south branch of the Chicago River. Boats and goods could be moved by a short portage between the east end of the little lake and the headwaters of the river. This portage thus connected the Great Lakes-St. Lawrence River System and the Mississippi River System, two mighty waterways through the continent. The portage trail had been used by prehistoric man and by the Indians who were here when Europeans arrived; it was called by the French "Le Portage de Checagou". The great present-day city developed from a trading post established at this old Chicago Portage (Knight and Zeuch, 1928).

The central part of the city (the "Loop" area) was built on swampy, low ground, so that even before the great fire it had been found desirable to raise the ground level of the entire area. According to an account of 1855, "The grade established by the city... made it necessary to build stone walls around each block to retain the filling of the streets... Mr. James Brown... contracted with J.D. Jennings to raise his store on the northeast corner of Dearborn and Randolph Streets... An entire block of heavy buildings on the north side of Lake Street... was raised simultaneously". After the fire, the grades were raised once more, so that eventually about eight feet of artificial fill overlay six feet of compressible silt. Below that was a thin crust of desiccated clay underlain by soft clay, hard clay of variable thickness, and bedrock. The heavy post-fire buildings rested on shallow stone footings founded in the silt below the fill. Largely as a result of compression of the soft clay, the buildings settled unevenly, with consequent cracking and distortion.

As early as 1873 a Chicago architect, Frederick Baumann, made the first statement in the United States that elucidated principles for the scientific design of foundations; he emphasized the method of isolated piers. His two main principles to govern the design of footings were that the areas of the base must be in proportion to the load, and that "the centers of these areas of base must coincide with the axes of their loads". His principles were followed in Chicago and at other places with similar foundation conditions until these methods were eventually replaced by others more modern and more satisfactory (Peck, 1948).

A recognition of geology's relevance to engineering was developing slowly during the late 19th century. For example, plans and drawings made in 1870-71 for the

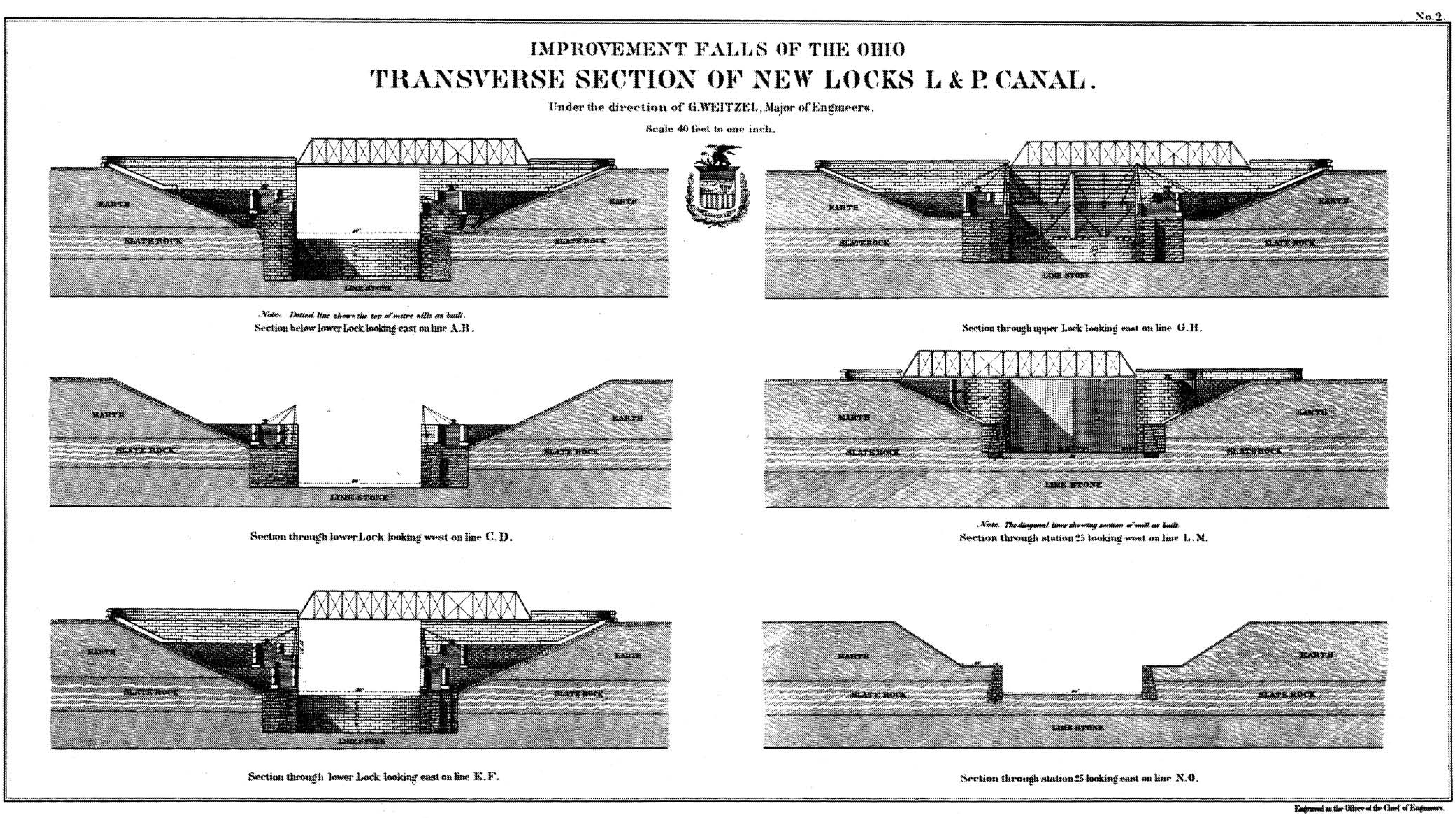


Fig. 14. : Transerve section of New Locks, Falls of the Ohio, 1870-71. From the National Archives, Record Group 77, Civil Works Map File.

improvement of the falls of the Ohio show the type of bedrock in great detail (Fig. 14). After the railroad surveys, and in part because of them, both government and industry became aware of the vast mineral potential of the western United States. This awareness led to the four great geological exploratory surveys of the western United States that preceded the establishment of the U.S. Geological Survey as a government agency in 1879. Mary C. Rabbitt (1979a) has described in great detail the work of these four surveys, as well as other early geological work, in volume l of "Minerals, Lands, and Geology for the Common Defence and General Welfare". She precisely summarizes them (Rabbitt, 1979b) as follows :

"The Geological Exploration of the Fortieth Parallel, the first of the four great surveys..., was authorized by congress on March 2, 1867. It was planned, organized, and directed by Clarence King, though administered by the Army Engineers. A survey of the natural resources of the new State of Nebraska, authorized on the same day under the Land Office and with Dr. F.V. Hayden in charge, increased in scope and size until it became the Geological and Geographic Survey of the Territories under the Department of Interior. Yet a third survey, at first under the Smithsonian Institution and later under Interior, grew out of the daring exploration of the Colorado River by John Wesley Powell in 1869. The Army resumed its major exploratory activities with reconnaissance surveys in 1869 and 187l and in 1872 initiated the Geographical Surveys West of the 100th Meridian, under Lt. George Wheeler".

The Geological Survey continued the work of the earlier surveys; initially the emphasis was on mining geology, but the scope of the agency's geologic studies gradually broadened. In 1890 the U.S. Geological Survey published an account of the disastrous earthquake at Charleston, South Carolina. The primary investigation was made by Capt. Clarence E. Dutton, geologist (1889), who was then of the U.S. Ordnance Corps, but his report was published by the Geological Survey. Theory and practice, long widely separated, were beginning to show some signs of drawing closer together. At that time there was no way to determine precisely the magnitude of an earthquake, but in the investigation of the Charleston earthquake it was clearly recognized that surface materials had some influence on the amount of damage. This influence was taken into account in the attempt to determine the location of the epicenter by evaluating the damage. The large number of sand boils in an area where quicksand lay close below the surface was particularly noted, as follows :

"These craterlets seemed to reach their greatest development, both in size and number, near Ten-mile Hill. Some of them were very large, one measuring 2l feet across (Pl.XX). Many acres of ground were overflowed with the sand, which was two feet or more in thickness near the orifices, thinning out towards the margins. These craterlets, however, depend for their size and number not alone upon the violence of the earthquake, but also upon the nature of the strata beneath. The water and sand thrown out came from a few feet only beneath the surface, and were originally contained in beds of quicksand thoroughly saturated with water. The earthquake opens a crack in the ground above, affording free communication with the surface. The overlying soil being of much greater specific gravity than the water, the water rises by virtue of the simple hydrostatic law, bringing the loose fine sand with it. Attempts to sink artesian wells at Ten-mile Hill have been defeated by a bed of water quicksand about twelve feet below the surface, which could not be kept open. The area thus underlain by quicksand is very large, but it is not universally distributed over the entire epicentral tract. Wherever it occurs near the surface the craterlets are abundant; but they are frequently absent or very scarce where the energy of the earthquake is known from other indications to have been very great".

In spite of these and other observations, the report contained no discussion that correlated the amount of damage with the type of earth material underlying damaged structures, nor any conclusion that areas such as the quicksand tract should be avoided in future construction.

In 1888 (Powell, 1890), the application of hydrogeology to irrigation in the arid west was systematically begun with the establishing of the United States Irrigation Survey within the U.S. Geological Survey. The short-lived Irrigation Survey became the separate Bureau of Reclamation shortly after 1900. In 1894, the direct application of geologic information to construction problems was discussed in a Geological Survey publication entitled "Common roads of the United States", by N. S. Shaler (1895a). This study, executed less than 100 years ago, was prepared at a time when automobiles, the use of petroleum products to bind road surfacing, and concrete paving were all in the earliest experimental stages. The report is notable for its historical summary, its clear description of the state of road-building at the time when it was written, and its recommendation that geologists play a role in providing information to highway engineers about sources of construction material.

The publication also contains sections on block pavements, paving brick, the action on roads of rain, frost, and wind, the effect of geological structure on grades of roads, and the sources of supply of road stone by district within the country. The author makes a final recommendation for "...the institution of a system of surveys and reports, with appropriate maps, by which our roadmasters may, as quickly as possible, be put in possession of the required knowledge as to the nature, locality, and mode of treatment of the substances available for use". He goes on to conclude "With this provision made, we may safely trust to the sagacity of our highway engineeers for the rest of the work".

In 1895 another U.S. Geological Survey publication described the geology of road materials in Massachusetts (Shaler, 1895b), and in 1897 still another report on the same subject was published by the New York Geological Survey. This publication, entitled "Road materials and Road Building in New York" contained a map that shows the distribution of the rocks most useful for road material — one of the earliest engineering geology maps in the United States (Merrill, 1897). Before much more progress could be made along these lines, however, the advent of the automobile created new problems. The great speeds (as much as 45 miles an hour) attained by this new vehicle caused additional wear and tear on the roads and made hard-surfaced roads essential. The narrow wheels of the early autos dug into the mud in the wet season, rendering the vehicle useless, and churned both unsurfaced and macadamized roads into pools of dust during the dry season. All of us have seen pictures of early motorists covered head to foot with the loose coats called "dusters". Such clothing was a necessity (Rose, 1976). The complaints about road conditions became so great that some system had to be found to surface the roads. With the use of bituminous material to lay the dust and later to bind the surface, and with the use of concrete to surface the roads, road-building quickly entered a new era (Rose, 1976).

Engineering geology in the 20th century

It is evident that although geologic factors influenced the location of very early routes and settlements in the United States, no close attention was given to the geologic conditions of individual sites. Influential elements included the locations and characteristics of mountain chains, lakes, and rivers, which in turn were determined largely by geologic factors. Stratigraphic sequence, jointing, and erosion formed the canyons and mesas of the west, folding and faulting created the mountain barriers of the Appalachians, glacial activity influenced the location of the Great Lakes, and faulting and warping of the earth's crust formed the basin of San Francisco Bay. Indian dwellings were built on the tops of mesas, routes were sought through the mountains, and settlements were established on the shores of the lakes and rivers and at places on the seacoast where good harbors were available; but the foundation problems posed by muds close to the shores or by landslides in mountainous terrain were not considered in selecting these construction sites. It was only after geology and engineering became more closely integrated, near the end of the 19th century, that the precise location of roads and structures was directly affected by studies of the geologic conditions of the route or site.

By 1900, the clear relationship between geology and civil engineering was being amply demonstrated by Prof. J. F. Kemp of Columbia University in New York, who worked as a consultant for the Metropolitan Board of Water Supply of New York City on the construction of the Catskill Aqueduct (Kemp, 1887, 1895, 1908, 1912a and b). Engineering geology came of age with the work of this able pioneer in engineering geology and his famous student, C. P. Berkey. Berkey's final report on the aqueduct (Berkey, 1911) provided a model for future reports of this kind.

At the end of the 19th century the settlement and major geographic expansion of the conterminous United States was drawing to a close. Not only was the frontier gone, but in some urban areas large parts of the most desirable land had been used, and building on steeper hillsides and in areas of filled land was becoming more common. The role of engineering geology increased with increasing urbanization and construction. The detailed story of developments in engineering geology from this time onward could only be covered in many additional pages; it is beyond the scope of this report. The application of earth science to land-use problems in the United States, particularly after 1900, has been summarized by Nichols (1982). A short history of the Engineering Geology Branch of the U. S. Geological Survey, which was established in 1944, is provided in a recent article by Eckel, Varnes, McGill, and Schuster (1979).

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Much of the source material for any study of early engineering works in the United States is to be found in Record Group 77 of the National Archives of the United States, particularly in the Textual Records of the Office of the Chief of Engineers, the Civil Works Map File, and the Fortification Map File. Other documents that were used in this study are in the Consolidated Correspondence File of Record Group 92.

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