TRENCHING THE ROSE CANYON FAULT ZONE
SAN DIEGO, CALIFORNIA

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ABSTRACT

Two trenches were excavated, logged, and interpreted across mapped projections or locations of the Rose Canyon fault zone in the Cities of San Diego and Coronado, California.

The trench in the City of San Diego extended for approximately 1,645 m across mapped projections of the Coronado fault, Old Town fault, and Rose Canyon fault. The inspection and analysis of the trench exposures indicated one area of normal faulting in the vicinity of Broadway between Front Street and First Avenue in the downtown area of San Diego. The fault strikes generally north-south and has apparent vertical stratigraphic separations of 3 to 4 m in sediments dated by amino acid racemization rates as approximately 360,000 to 560,000, ±75,000 years old. A paleosol estimated to be at least 75,000 to 128,000 years old is displaced 60 cm; a younger paleosol, estimated to be at least 20,000 years old, did not show evidence of displacement.

It is concluded that this fault is an antithetic or subsiduary feature consistent with an extensional stress environment in the San Diego area.

No other evidence of faulting was found in the trench exposures, thus leading us to conclude that major north-south faulting does not extend through Middle to Late Pleistocene deposits exposed along the trench in the downtown San Diego area.

The trench in the City of Coronado was extended across a break in slope previously identified as the fault scarp of the Coronado fault branch of the Rose Canyon fault zone. Detailed logging and analysis of the trench exposures indicated the feature to be an erosional bluff.

INTRODUCTION

This Final Technical Report for U.S. Geological Survey Contract No. 14-08-0001-19118 documents and describes the results of logging two trenches in areas suspected of being part of the Rose Canyon fault zone. The trenches were located in Coronado and San Diego, California (Fig. 1).

The purpose of this study was to obtain geological data to aid in evaluating the location and degree of fault activity of the Rose Canyon fault zone.

The study involved logging and evaluating the exposures excavated in Pleistocene deposits across mapped traces of the Rose Canyon fault zone.

SCOPE OF STUDY

The scope of the investigation for this study included:

(1) Inspection, interpretation, and logging of the exposures in two test trenches excavated across projections of previously mapped faults.

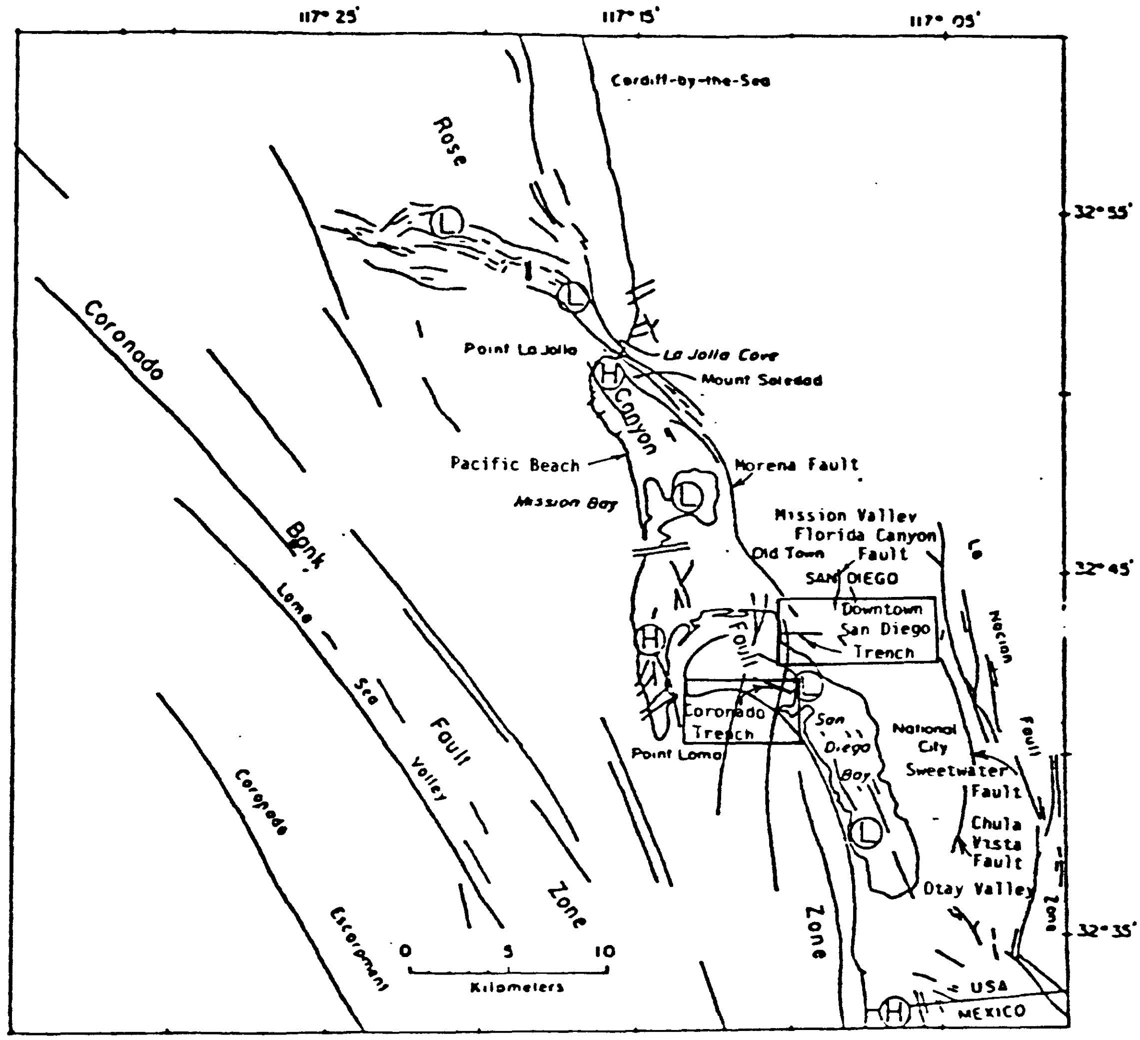
(2) Dating soil samples by radiocarbon and racemization techniques as well as relative age estimates by physical properties, degree of soil formation, and faunal assemblages.

(3) Evaluation of the data in the context of other information regarding faulting in San Diego.

Field Investigation

Trench in San Diego

A 1,645-m (5,400-foot) long, 1.9- to 6.7-m (6- to 22-foot) deep trench was excavated through downtown San Diego (Fig. 2).



Modified after Kennedy and Legg (1980)

FIGURE 1. LOCAL FAULT MAP

Index map showing mapped fault locations in the general area of study, and general locations of trench investigation.

FIGURE 2 TRENCH LOCATION DOWNTOWN SAN DIEGO

The excavation was generally perpendicular to previous mapped fault locations. Geologic conditions in the trench were logged and evaluated, and geological samples were collected for dating. Various absolute dating techniques were used, including radiocarbon, amino acid racemization, and uranium/thorium. Relative ages of units were estimated by regional correlation based on physical properties, faunal assemblages, and criteria developed by Quaternary soils specialists.

This investigation was made with the cooperation of the City of San Diego and a private contractor. The private contractor excavated the trench for installation of a new sewer line, and took field measurements (in feet) for the trenching operation. Our logs and station locations (Appendix A) are based on those field measurements. The logging of the trench began 15 m (50 feet) east of the middle of the intersection of Kettner Boulevard and "E" Street. Sections of trench about 15-m (50-foot) long were open for variable time spans. Some sections remained open for several days, but other sections were open for only a couple of hours before backfilling operations began.

Although the trench was started on February 12, 1980, rainstorms delayed operations until about March 14, 1980. A union strike halted all trenching operations from June 25 to July 28, 1980. Construction delays, such as cave-ins and broken water mains, caused many other short time delays. The final field work was completed October 10, 1980.

Trench in Coronado

The geological conditions of a 3-m (10-foot) deep, 61-m (200-foot) long test excavation across a scarp in the City of Coronado (Fig. 3) were logged and evaluated. The logs of the trench are presented as Appendix B. The scarp has been identified as the Coronado fault branch of the Rose Canyon fault zone (Kennedy and Welday, 1977; Kennedy and Welday, 1980). The excavation was made between November 17 and December 12, 1980, generally perpendicular to and across the mapped fault location. Geological samples were collected for dating by amino acid racemization. Relative ages of units were estimated by regional correlations based on physical properties, faunal assemblages, and criteria developed by Quaternary soils specialists.

This investigation was made with the cooperation of the City of Coronado. The study was done to coincide with and slightly precede a street repair contract issued to a private contractor by the City of Coronado.

BACKGROUND

The Rose Canyon fault zone has been shown to extend for approximately 15 km south on land from the La Jolla Cove Shores area (Kern, 1973a; Ziony, 1973; Kennedy, 1975) (Fig. 1). Fault branches have been shown on maps to extend into and across downtown San Diego and the City of Coronado (Wiegand, 1970; Kennedy, 1975; Leighton and Associates, 1978).

In the San Diego area, investigators have suggested evidence of tectonic displacement of the Rose Canyon fault zone in Late Pleistocene and younger sediments (Kennedy, 1975; Moore and Kennedy, 1975; Kennedy and others, 1975; Kennedy and Welday, 1977; Kennedy and others, 1978). The evidence includes scattered micro-earthquake activity in the general San Diego area, and suggested displacement of apparent Holocene age sediments on the sea floor (Moore, 1972; Moore and Kennedy, 1975; Kennedy and Welday, 1977; Kennedy and others, 1978).

Kennedy (1975) states, "The possibility of Holocene fault activity in the area is not ruled out, though no direct field evidence supports this fact." Kennedy and Peterson (1975) conclude, "Holocene seismic activity along several faults that lie within 10 km of the area is supported by the historic seismicity believed to be associated with the Rose Canyon fault zone in the San Diego Bay area. . ."

No direct evidence has been reported for tectonic displacement of material younger than Pleistocene on the Rose Canyon fault. The youngest displacements of the Rose Canyon fault and onshore fault branches crossing Coronado have not been dated.

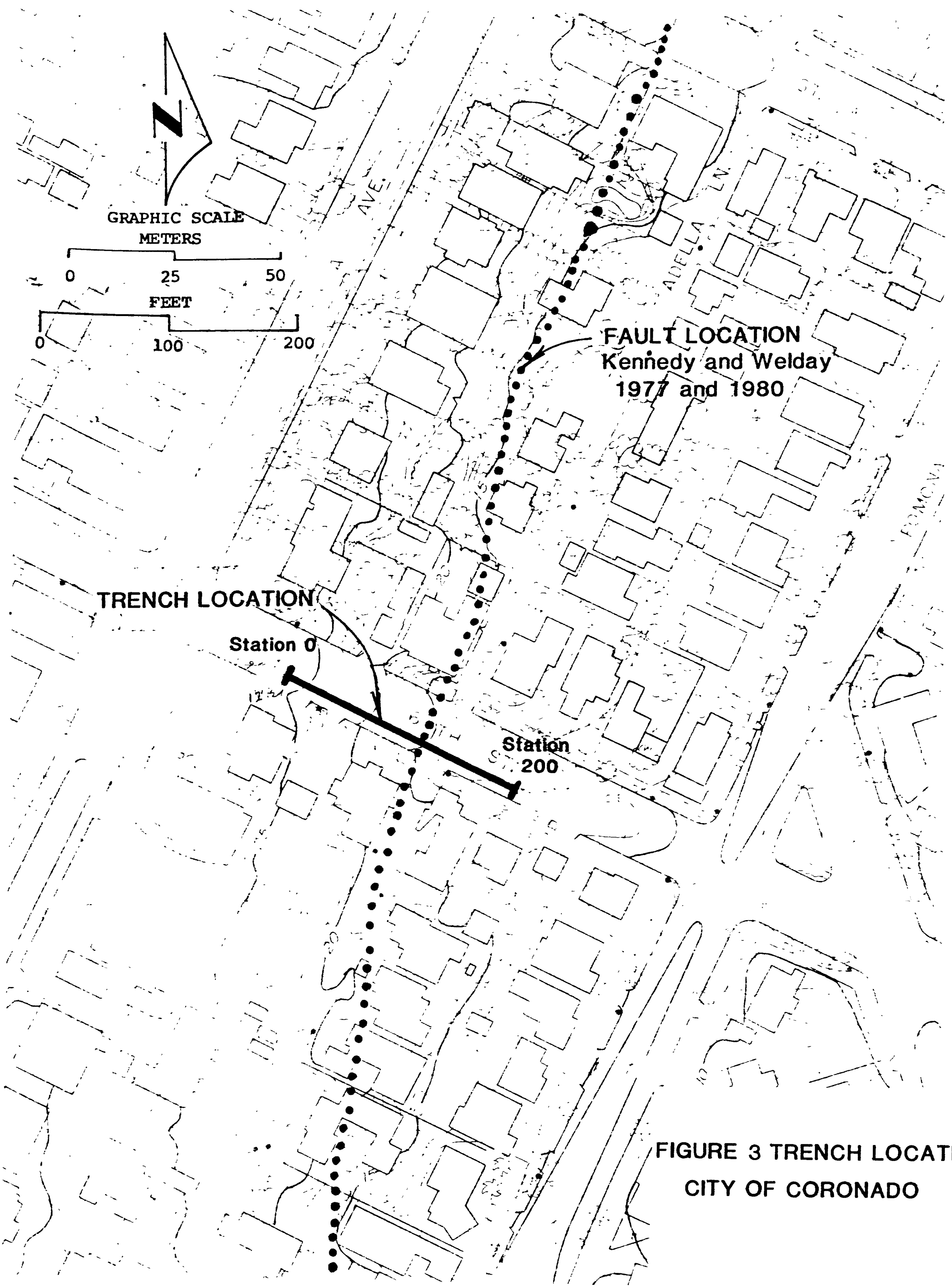


FIGURE 3 TRENCH LOCATION
CITY OF CORONADO

Regional Tectonic Setting

San Diego lies within a region traversed by many faults (Fig. 4). Regional fault patterns and plate tectonic theory indicate that the faults are related to the boundary and margin of two crustal plates: the North American Plate and the Pacific Plate. The present boundary of these two plates closest to San Diego is a system of faults in the Imperial Valley commonly referred to as the San Andreas fault system. Faults related to the system include the Elsinore fault, the San Jacinto fault, the Imperial fault, and the San Andreas fault.

The northwest-striking, right-lateral regional fault system in southern California and northern Baja California includes the San Clemente fault zone, the San Diego Trough fault zone, and the Coronado Banks fault zone to the west offshore; and the Agua Blanca fault, the San Miguel fault zone, the Vallecitos fault, and the Calabasas fault to the south in Baja California. Historic earthquake records show that the portion of this region presently exhibiting the greatest earthquake activity in Southern California is along the Imperial and San Jacinto faults (Fig. 4). In comparison, the San Diego area, approximately 100 km west of the San Jacinto fault, has a relatively minor historic record of earthquake activity.

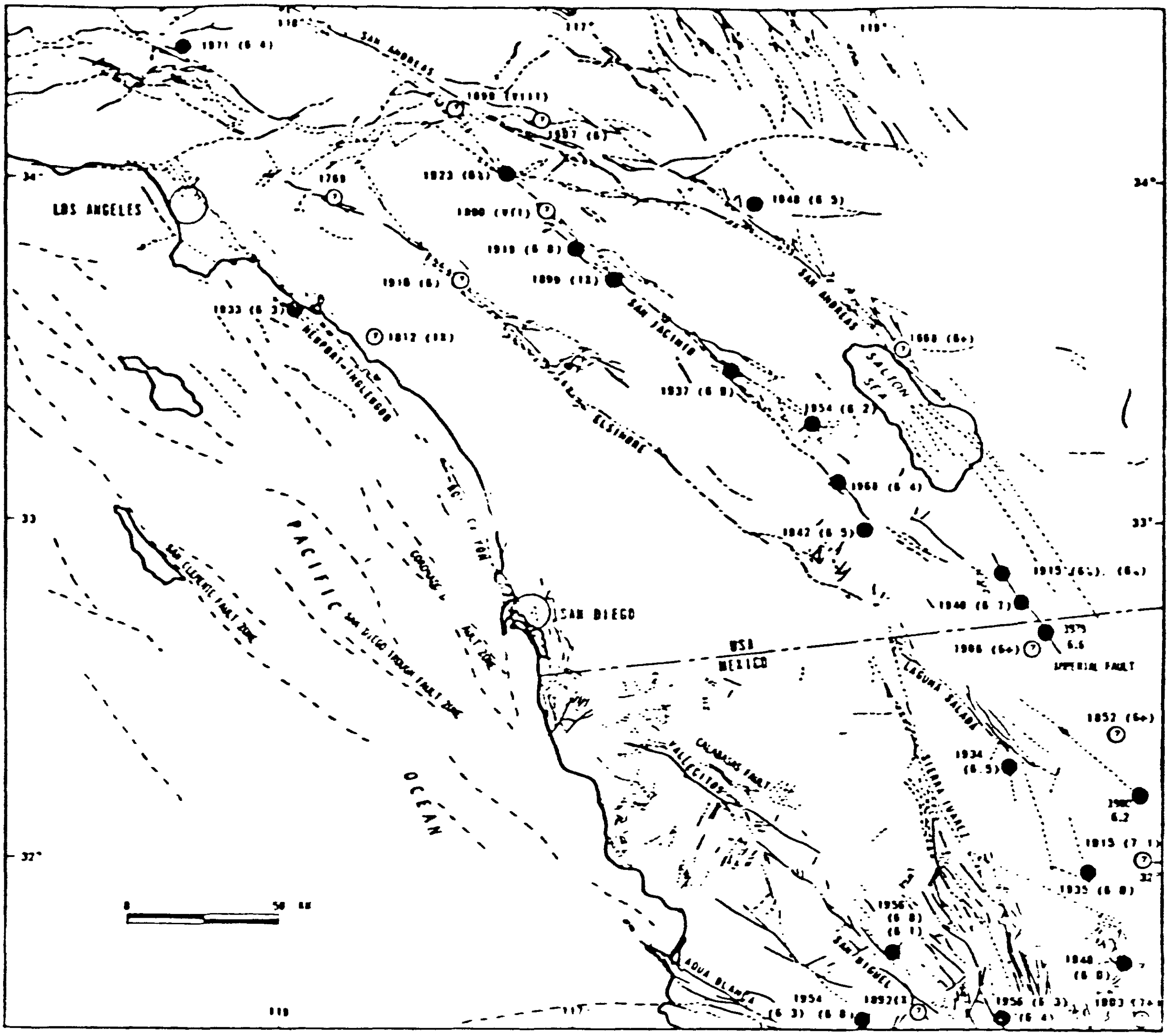


FIGURE 4. GENERALIZED REGIONAL FAULT MAP

Fault map of the Southern California area showing epicenters of earthquakes of magnitude 6 and greater. Solid circle show epicenters with year of earthquake, along with magnitude maximum intersity. Open circles with question marks indicate poorly known epicenters. Epicenters are compiled from Hileman and others (1973), and Thatcher and others (1975); faults are compiled from Gastil and others (1975), Jennings (1977), and Legg and Kennedy (1979).

Local Tectonic Setting

The San Diego area is within the coastal subprovince of the Peninsular Range Province. The area is characterized primarily by Cretaceous, Tertiary and early Quaternary sedimentary formations, capped by late Quaternary marine and nonmarine deposits. Generally, the Tertiary and Quaternary sedimentary formations are nearly flat-lying, except for locally deformed areas such as Mount Soledad.

A relatively recent erosion surface has been incised onto the Tertiary and Quaternary sedimentary formations. The topographic features and geologic setting have also been partially modified by Quaternary faulting.

The geologic structure of the San Diego area includes en echelon, north-northwest-striking faults that characteristically dip steeply and have apparent normal displacement. These faults lie subparallel to the regional tectonic grain and are believed to result from an extensional tectonic environment. The component of extensional stress in southwestern San Diego County is aligned generally east-west; the resulting strain is expressed by normal faults that strike generally north-south.

The roughly defined San Diego Bay graben, a structurally depressed block, is bounded on the east by the La Nacion fault zone, on the west by the San Diego Bay faults and offshore faults, and on the north by the Rose Canyon fault (Fig. 1). These faults are discussed in more detail in the following sections.

La Nacion Fault Zone

The La Nacion fault zone extends north from near the U.S.-Mexico border to at least the south side of Mission Valley (Artim and Pinckney, 1973a, 1973b). This fault zone is composed of a number of closely to widely spaced, parallel to subparallel faults (including the Sweetwater fault and the Chula Vista fault) that displace Tertiary and Quaternary deposits. The main branch of the fault system displaces the Early Pleistocene Lindavista Formation with stratigraphic separation as much as 70 m. Several traces (as long as 1.2 km), exposed between San Diego Bay and the main branch of the fault system, displace Pleistocene deposits with stratigraphic separation of as much as 30 m. Ziony (1973) reported:

> *The youngest stratigraphic unit definitely displaced by the fault is the Lindavista Formation, which is offset vertically as much as 200 feet at several places. Offsets of basal Holocene deposits along the fault are cited (Artim and Pinckney, 1973) but have not been confirmed by field investigations. As observed at the surface, alluvium of stream valleys extends unbroken across the fault trace. More importantly, topographic features commonly associated with Holocene faulting elsewhere in coastal California, such as sag depressions or well-defined scarps, have not been observed along the La Nacion fault. The existence and recency of movement of other faults are inferred from topographic lineaments or subdued scarps of probable Late Pleistocene age, which appear to disrupt the terrace underlain by the Lindavista Formation.*

Kennedy and others (1975) report that the faults of the La Nacion fault system cut the lower Pleistocene Lindavista Formation and are overlain by apparently unfaulted Holocene soil. Kennedy and others (1975) also modified their estimate of the age of faulting by stating, "The maximum age for this displacement is Early Pleistocene, although terrace deposits that may be younger than the Lindavista Formation are faulted." The exact ages of the Late Pleistocene sediments that are apparently offset were not established.

In his explanations of trench interpretations, Kennedy and others (1975) list differences of topsoil-bedrock contacts and topsoil thicknesses over faults at several locations. The remainder of Kennedy's 1975 report indicates that anomalous topsoil-bedrock contacts are common along the La Nacion fault, and that such irregular contacts are numerous and exhibit a relatively consistent pattern of apparent displacement.

Rose Canyon Fault Zone

The Rose Canyon fault zone comprises a number of closely spaced, subparallel faults that displace Cretaceous and Tertiary strata near Mount Soledad. The fault zone, as mapped, continues offshore to the north, and it has been suggested that the fault continues to the south under San Diego Bay and offshore of Coronado. South of Mission Bay, the limits of the Rose Canyon fault zone are diffuse and unclear. Studies of the Rose Canyon fault zone (Kennedy, 1975) have included the Morena fault and the Old Town fault, which are the most easterly faults associated with the zone. More recently, the major zone of faulting has been projected across Coronado to connect with offshore fault features (Kennedy and Welday, 1980).

The main fault and some fault branches displace the Early Pleistocene Lindavista Formation. Approximately 140 m of vertical separation of the base of the Lindavista Formation has been recognized near Mount Soledad. The Late Pleistocene Bay Point Formation lies across some fault branches, and may be faulted.

Kennedy (1975) shows two concealed faults, one extending to within about 0.5 km northwest of downtown San Diego, and one to within about 0.8 km. More recently, Kennedy (1979, oral communication) projected the Rose Canyon fault 1.2 to 1.8 km west of downtown San Diego to connect with offshore faults identified near Coronado Island. The Old Town fault is now not considered by Kennedy (1979, personal communication) to be a part of the Rose Canyon fault zone.

San Diego Bay Faults and Offshore Faults

A set of inferred faults, including the Coronado Fault and the Spanish Bight fault, may displace Quaternary sediments in San Diego Bay and just offshore of San Diego (Kennedy and Welday, 1977; Kennedy and Welday, 1980). These faults have recently been described as the southern extension of the Rose Canyon fault zone (Kennedy and Welday, 1980). The faulting is largely based on interpretations of subbottom acoustical profiling investigations (Moore and Kennedy, 1975; Kennedy and Welday, 1977; Kennedy and Welday, 1980). The trends of these faults vary from slightly northwest to slightly northeast. Kennedy and Welday (1980) suggest that the faults displace an estimated 7 m of near-surface sediments, and that the most recent slip was in the Late Pleistocene or early Holocene. Their work suggests a set of short north-striking normal faults with the west side faulted relatively upward.

Other Local Faults

As more geologic studies are completed in the San Diego area, many relatively small faults are being identified. Two of these features include the north-striking Texas Street fault and Florida Canyon fault (Fig. 1). These normal faults displace Early Pleistocene deposits and conform to the extensional stress environment characteristic of the San Diego area.

Ages of Local Faults

Geologically young materials in San Diego have been displaced by faults. Faulted sediments in the southeast Mission Bay area, approximately 11 to 13 km northwest of the trench sites, have been radiocarbon dated at 28,000 ±1,500 years old (Liem, 1977). Unpublished information from Mr. William Elliott* (1980, personal communication) indicates that a fault

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* Consulting geologist, San Diego, California.

in Chula Vista has displaced sediments radiocarbon dated as approximately 25,000 years old. Sediments in the downtown San Diego area, dated by amino acid methods as approximately 200,000 to 300,000 years old, may have up to 3 m of displacement (unpublished Woodward-Clyde Consultants data). A deposit on Point Loma dated as approximately 120,000 years old has up to about 4.6 m of displacement (Kern, 1973a).

Sediments mapped as the Bay Point Formation (approximately 100,000 to 130,000 years old) are faulted in La Jolla, Point Loma, Chula Vista, and National City (Peterson, 1970a, 1970b; Kern, 1973a, 1973b; Moore and Kennedy, 1975; Kennedy, 1975; Kennedy and Welday, 1977). Most of these fault exposures may be in Middle Pleistocene deposits.

Studies of the offshore areas north of La Jolla, south of Coronado, and in San Diego Bay, have identified faults by subbottom geophysical profiling (Moore and Kennedy, 1975; Kennedy and Welday, 1977; Kennedy and others, 1978). These faults were interpreted as displacing Holocene (up to 11,000 years old) ocean bottom sediments; however, the inferred faulted material has not been dated. Therefore, there is some uncertainty regarding the age of faulting.

To date, no direct evidence for Holocene faulting has been established in the San Diego area. Topographic features such as sag ponds, offset stream courses, or sharply defined scarps, commonly associated with Holocene faulting elsewhere in

California, are not generally associated with local faulting; this suggests that these faults, if they are active, have a very low rate of activity.

GEOLOGICAL CONDITIONS IN THE SAN DIEGO TRENCH

Faulting

The stratigraphic sequence in the east-west excavation has been disrupted by faulting at one general location. The faulting strikes generally north-south in the vicinity of Broadway between Front Street and First Avenue (Station 1710 to 1870). The primary shear appears to be located at approximately Station 1795.

The main shears are approximately 0.6 to 1.3 cm wide; short, discontinuous shears were observed within a few centimeters of the main shears. Several paper-thin, clay-lined fractures are present subparallel to the main shears. Displacements along these fractures are usually less than a few centimeters.

The sheared material is composed primarily of brecciated and discolored sand containing silt and clay binder. Some weathered zones extend down into the shears. In some areas, the sheared materials have been altered to clay. A vertical fracture, backfilled with red oxidized sand, grades upward into an overlying paleosol. Neither clay gouge nor slickensided surfaces were observed along any of the shears.

The uppermost formational sand beds exposed in the trench have apparent vertical displacements of 2 to 3 m. Based on test boring correlations by Woodward-Clyde Consultants in the nearby area, a stratigraphic separation of 3 to 4 m is likely in a series of clay beds at depths between 16 and 20 m. The results of eight amino acid age dates indicate the sands represent a continuous depositional environment and are approximately 360,000 to 560,000 years old. A paleosol estimated to be at least 75,000 to 128,000 years old is displaced 60 cm.

No shears or fractures extend up into a younger overlying paleosol (estimated to be at least 20,000 years old), and no irregularities that were construed to be fault displacements were noted at the base of a recent topsoil contact or this paleosol.

The fault appears to be normal, with the east side down. No evidence in the exposures indicates significant strike-slip (horizontal) separation. The fault appears to be the result of an extensional stress environment present in western San Diego.

The fault area does not correspond to gravity survey anomalies (interpreted to be faults) in downtown San Diego (Harrington, 1980). No other faults were found in the trench.

Stratigraphy

Eleven significant stratigraphic units were exposed in the trench. These units are described below in order of increasing age. Each unit name is followed by a symbol or symbols used to identify that unit on the trench logs. Where possible, absolute ages of the materials are given. Absolute dating of geologic materials can be difficult because of a lack of datable geologic materials or because the age of the available materials is not within the age range of dating techniques. Where materials for dating techniques were lacking, other methods, such as degree of weathering, soil formation, and paleontologic or stratigraphic correlations, were used to estimate the ages of materials.

Holocene Aeolian and Alluvial Deposits (a)

These deposits consist primarily of brown to grayish-brown, clayey, silty fine- to medium-grained sand. A discontinuous, poorly formed stone line exists at places along the base of the unit. The deposits range in thickness from less than 20 cm to approximately 1 m. The deposits are friable, massive to poorly bedded, porous, and contain numerous worm and small animal burrows as well as decayed roots. A thin (0.1 to 0.5 cm thick) organic mat (entisol) is preserved in some areas. In most places, the upper surface shows disturbance by grading, and in some areas these deposits have been removed. A poorly developed soil profile grades from a thin "A" horizon to a "C" horizon with no development of a clay "B" horizon layer.

The aeolian and alluvial deposits post-date paleosols and formational units upon which they have been deposited. Available results of radiocarbon dating performed on similar alluvial soils from the San Diego area indicate approximate ages of 2,000 to 3,000 years (Charles J. Pinckney,* 1980, personal communication). Based on the lack of a well-defined soil profile on these deposits, we estimate the deposits to be less than 5,000 years old; however, some areas may be only as old as a few hundred years. Geologic evidence in the trench exposures indicates no fault displacements in this unit.

Holocene Embayment Deposits (Q_1)

This unit was exposed in the western end of the trench below Elevation 8 feet [Mean Sea Level Datum]. The unit consists of grayish-brown to dark gray, silty clay. The deposits have a decaying organic odor and contain local lenses of silty sand. The deposits are covered by approximately 2 m of fill.

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Buried Paleosol (S_1)

This unit consists primarily of dark brown to dark yellowish-brown, sandy clay. The soils are firm to hard, and contain numerous small roots and some animal burrows. The soils have a poorly to moderately well-developed, medium angular to blocky structure, and thin to moderately thick clay skins. Manganese oxide staining is common and often concentrated in the lower part of the unit.

This unit has developed on formational materials and older paleosols, and was exposed along most of the length of the trench. The unit is roughly parallel to what can be interpreted as the original topographic surface prior to development of the downtown area. Based on a comparison of the degree of soil profile development in other areas of San Diego, we estimated this paleosol to be at least 10,000 years old; however, some parts of the paleosol may be much older, perhaps as old as oxygen isotope Stage 5* (Shackleton and Opdyke, 1973).

Pleistocene Channel Fill and Estuary Deposits (Q_{3a}, Q_{3b}, Q_{3c}, Q_{3d})

This sand and gravel unit includes nonmarine, brown to dark brown, gravelly fine- to coarse-grained sand, and dark

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* Oxygen isotope Stage 5 lasted from approximately 75,000 to 128,000 years ago.

brown to grayish-brown, sandy to silty clay. The sand and gravel sequences may be alluvial deposits, whereas the clay deposits appear to be estuarine deposits locally containing up to 15 percent organic matter. The sand beds are typically lightly oxidized with local weak cementation. The unit has numerous channel fills, and cross bedding is common in the sands. The base of the deposit is marked by two distinct gravel sequences.

A radiocarbon date performed on a bulk sample at Station 975 gave an age of 19,300 ±2,100 years.

Buried Alluvial Deposits (S_{1a})

These deposits consist of dark brown to dark yellowish-brown, clayey, silty fine- to medium-grained sand. The deposits are firm, porous, and massive to poorly bedded; they have numerous animal burrows in-filled with material from the overlying horizons. Concentrations of hematite and poorly formed manganese nodules are common and result in reddish-brown staining.

These deposits pre-date the paleosol (S_1) that has, in part, formed on them.

Older Buried Paleosol (S_2)

This paleosol consists of hard, dark brown to dark grayish-brown, sandy clay. The paleosol has a well-developed, coarse, blocky to prismatic structure, and moderately thick to thick clay skins. The lower part of this paleosol grades into hard, brown, sandy clay having a moderately well-developed, angular to blocky structure, and thick clay skins.

The minimum time required to form a paleosol with the above characteristics is at least oxygen isotope Stage 5 (post-Sangamon interglacial), (Bert Swan,* 1980, personal communication). Based on the degree of soil profile development compared to soil profile development in other areas of California, this paleosol is estimated to be at least 100,000 years old, (Kathryn Hanson,* 1980, personal communication). The paleosol is conceiveably much older than oxygen isotope Stage 5; it may be a few hundred thousand years old.

Pleistocene Alluvial Deposits (Q_2)

This unit consists of nonmarine, light reddish-brown to reddish-brown, gravelly, clayey fine- to coarse-grained sand. The deposits are typically lightly oxidized with weak cementation. The clasts are pebble size and bedding is essentially horizontal.

This unit pre-dates the paleosol (S_2) developed on the deposits, and post-dates the marine deposits (Qt) upon which it has been unconformably deposited.

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* Quaternary Soils Specialists, Woodward-Clyde Consultants, San Francisco, California.

Buried Paleosol (S_3)

The upper 30 to 45 cm of this paleosol consists of grayish-brown to dark grayish-brown, hard sandy clay having well-developed, coarse, blocky to prismatic structure, and thick, continuous clay skins. The paleosol grades down into hard, dark brown, sandy clay having moderately well-developed, medium angular to blocky structure, and numerous manganese oxide stains and nodules. This unit is faulted at Station 1795 and has a minimum of 60 cm of stratigraphic separation.

The minimum time required to form this paleosol is at least post-oxygen isotope Stage 5 (post-Sangamon interglacial), (Bert Swan, 1980, personal communication). This paleosol is probably much older than oxygen isotope Stage 5; it may be a few hundred thousand years old.

Middle to Late Pleistocene Marine Deposits (Qt_a, Qt, Qt_b)

This formation consists of fine to moderately bedded, light gray to light reddish-brown, silty fine- to coarse-grained sands containing thin, scattered pebble layers. The beds are friable and tend to be lenticular. Bedding thickness varies from a few millimeters to several centimeters. Some small shell fragments and local fossil lenses and layers are present. Faunal analyses of the fossils are included as Appendix C.

This formation underlies most of the downtown San Diego area along the trench alignment. The uppermost sand beds exposed in the trench, have been faulted with stratigraphic separation of 2 to 3 m at Station 1795.

This unit has been mapped as the Bay Point Formation. The Bay Point Formation (Sangamon) in San Diego is dated at approximately 120,000 ±10,000 years old (Kern, 1973). K.R. Lajoie (1980, oral communication) of the U.S. Geological Survey is of the opinion that many of the deposits in the downtown San Diego area, mapped as Bay Point Formation, may be significantly older than oxygen isotope Stage 5, and that they could be a couple to several hundred thousand years old. The results of several amino acid age dates performed on shells from this unit give ages ranging from approximately 200,000 to 560,000, ±75,000 years old. A summary report of the amino acid dating is included in this report as Appendix D.

Pleistocene Terrace Deposits (Qtt)

These deposits range from light to dark reddish-brown, sandy to clayey cobble conglomerate; to clean, pebbly medium- to coarse-grained sand. The beds are iron-stained and are cemented locally by iron oxide. Some of the sand beds are mottled light red in a generally reddish-brown sequence. The conglomerate beds are typically 0.3 to 1 m thick. Clasts are generally well-rounded and range from about 1 cm to cobbles more than 15 cm in diameter. The base of this unit is an irregular, scoured contact into beds of the San Diego Formation.

These deposits typically are present above an approximate elevation of 65 feet, and are, in part, gradational with the Middle to Late Pleistocene marine deposits.

Pliocene San Diego Formation (Tsd)

This unit consists of finely to massively bedded, light gray to light brown, silty fine- to coarse-grained sand. These sands contain thin layers and lenses of pebbles and at least two thin layers (less than 6 cm thick) of light gray, sandy clay. Most of the light gray sand beds are friable and subject to caving in vertical excavations. Bedding thickness varies from a few millimeters to a few meters.

The stratigraphic section exposed in the trench is lithologically similar to the type section of San Diego Formation. This section is known to contain rare but locally abundant fossils. The section is micaceous with biotite that weathers to reddish-yellow to yellowish-red halos.

The San Diego Formation generally has been considered Pliocene, but its exact position in the Pliocene has been variously placed by different authors. Hertlein and Grant (1944) assigned the San Diego Formation to the Middle Pliocene. Woodring and Bramlett (1950), by way of chart correlations, suggested a range from late Early Pliocene to Late Pliocene.

Hertlein and Grant (1954) suggested an age of Middle Pliocene to early Late Pliocene. Milow and Ennis (1961) considered the San Diego Formation upper Pliocene. Allison (1964) suggested an age of Early Pleistocene based on the presence of a fossil horse tooth. Ingle (1967) concluded that the formation was deposited no earlier than Early Pliocene and no later than Late Pliocene. Mandel (1974) suggested an age of very late Pliocene to earliest Pleistocene. Recently, several fossil horse teeth collected from the lower San Diego Formation were identified by Dr. Savage (1979, personal communication) of the University of California, Berkeley, as *Equus* and younger than 3.5 million years old.

Based on the available published and unpublished data and definitions, the San Diego Formation appears to be a Middle to Late Pliocene unit that extends into the Early Pleistocene, with an approximate age range of 1.5 to 4 million years old.

GEOLOGICAL CONDITIONS IN THE CORONADO TRENCH

Faulting

No faults or fractures were observed in this trench. The pivot point at the base of a fault scarp remains at relatively the same position (Philip Birkhan,* 1981, personal communication). A fault, if present, should have been encountered at approximately Stations 110 to 120.

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Stratigraphy

Four significant stratigraphic units are exposed in the trench. These units are described below in order of increasing age. The unit name is followed by a symbol used to identify that unit on the trench logs. Where materials for absolute dating were lacking, other methods, such as degree of weathering (soil formation), and stratigraphic or paleontologic correlations, were used to estimate the ages of materials.

Holocene Aeolian Deposits (a_1)

This unit consists of very porous, friable, pale brown, silty, very fine-grained sand, deposited unconformably on an erosional scarp.

The deposit appears to overlie and to be younger than an alluvial deposit (a_2). The age of the aeolian unit may vary from a few hundred to a few thousand years old.

Holocene Alluvial Deposits (a_2)

This unit consists of fine sand that is porous, friable, light reddish-brown and silty. A poorly formed soil profile has begun to develop in the upper 5 cm and consists of grayish-brown, slightly clayey, silty sand exhibiting local manganese oxide staining. The profile grades from an "A" horizon to a "C" horizon with no distinct "B" horizon present.

Based on the degree of weathering and soil profile development, this unit is estimated to be less than 5,000 to 10,000 years old.

Paleosol (S)

This paleosol consists of dark reddish-brown, clayey sand. The soil is hard, and has a poorly to moderately well-developed, medium angular to crumbly structure, and thin clay skins. Manganese oxide staining is concentrated along the base of this paleosol.

Based on the degree of weathering, this paleosol is estimated to be at least 10,000 years old.

Middle to Late Pleistocene Marine Deposits (Qt)

This unit consists of sand that is thin to moderately bedded, light gray to light reddish-brown, silty fine- to coarse-grained and contains thin, scattered pebble layers. The beds are friable and tend to be lenticular. The light reddish-brown color appears to be secondary and restricted to within 3 m of the ground surface. Bedding thickness varies from a few millimeters to several centimeters. Some small shell fragments are present in the trench, and a test boring placed at the west end of the trench recovered fossil shells from Elevation +5 to Elevation -8 feet (Mean Sea Level). A faunal assemblage in similar deposits was recovered from an excavation at 10th Street and "B" Avenue in the City of Coronado. Fossil shells were also recovered from lithologically similar deposits at Ynez Place and Pomona Avenue. A reference location map is included as page D-1 in Appendix D.

The results of several amino acid age dates performed on shells from this unit give ages of approximately 220,000 ±30,000 years. These results are comparable to unpublished amino acid dates obtained in the general area of the City of Coronado (Wehmiller, 1981, oral communication). A summary report of the amino acid dating is included in this report as Appendix D.

DISCUSSION AND CONCLUSIONS

San Diego Trench

A faulted area has been identified in the downtown area in the vicinity of Broadway, generally between Front Street and First Avenue.

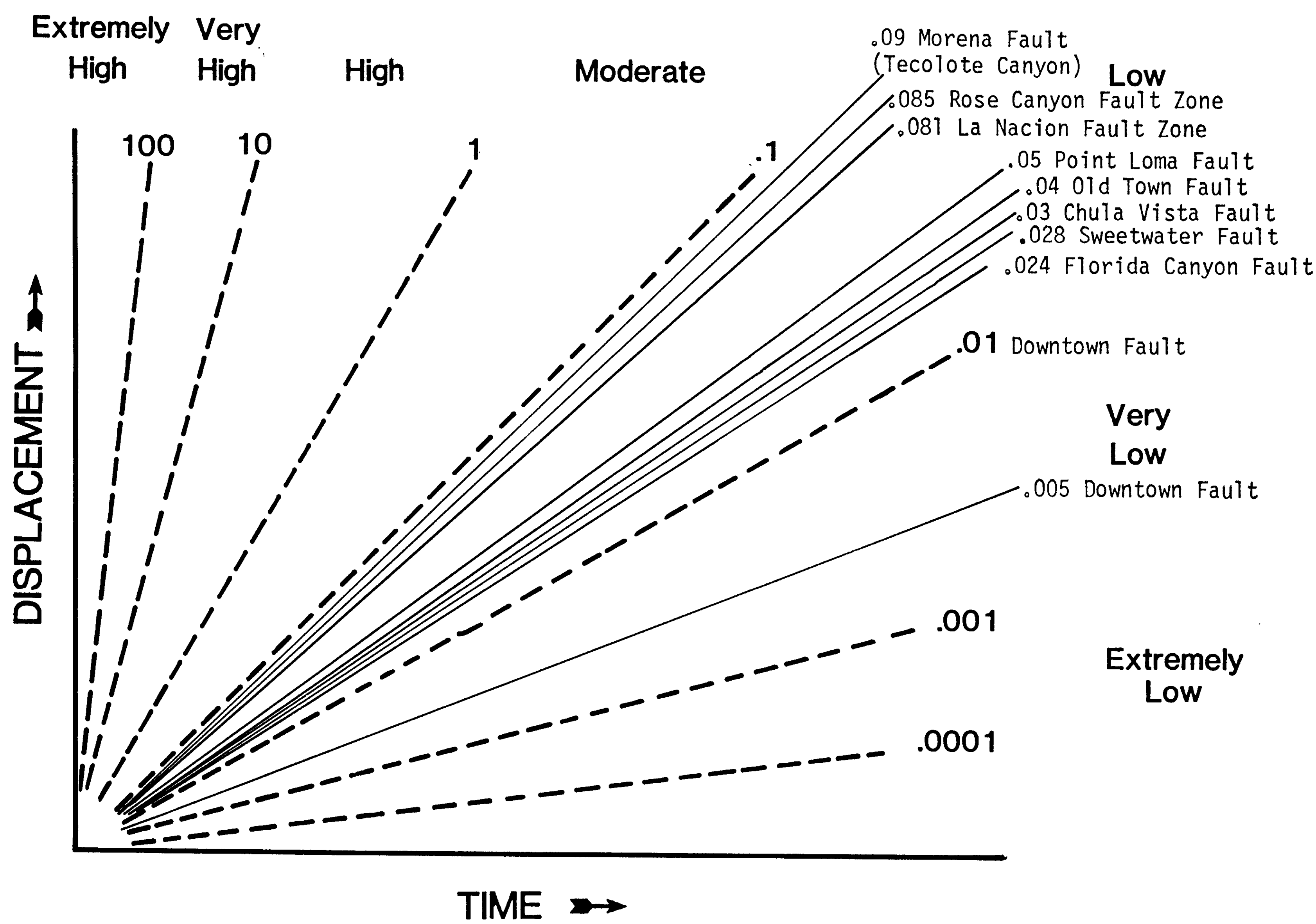
Formational sediments, amino acid age-dated at approximately 360,000 to 560,000 years old, have been displaced 3 to 4 m by the fault. The uppermost sand beds have a stratigraphic separation of 2 to 3 m. A paleosol estimated to be at least 75,000 to 128,000 years old is displaced a minimum of 60 cm. A younger paleosol estimated to be at least 20,000 years old did not show evidence of stratigraphic separation. In our opinion, the fault has not been displaced in the last 20,000 years and probably not in the last 75,000 years.

A fault that has a displacement of 3 to 4 m in 360,000 to 560,000 years has an average displacement rate of 0.007 to 0.011 mm per year. The average displacement rate calculates to 0.005 to 0.008 mm per year for 60 cm of displacement in the last 75,000 to 128,000 years. As a relative index of fault activity, this rate is compared to estimated rates of other San Diego faults (Fig. 5).

Assuming that the average displacement on this fault has been 30 cm per event, an average recurrence interval between events of surface faulting would be approximately 27,000 to 56,000 years over the past 360,000 to 560,000 years. The average recurrence interval between events of surface faulting has been approximately 54,000 to 112,000 years, if an average displacement of 60 cm is assumed.

Based on its lack of surface expression, relatively little displacement in geologic time, sense of displacement, and lack of direct tie-in to more pronounced fault features in the San Diego area, we consider this fault to be an antithetic or subsidiary feature. Such features are not unusual in an extensional stress environment as is present in the San Diego area. Similar faults with very short horizontal extent and limited vertical displacement may also be located elsewhere in downtown San Diego.

We found no other evidence of faulting in the trench exposures, thus leading us to conclude that major north-south



DEGREE OF ACTIVITY SLIP RATE IN MM/YEAR

Modified after Cluff (1979)

Figure 5 Comparison of Rates

faulting does not extend through Middle to Late Pleistocene deposits exposed along the trench in the downtown San Diego area.

Coronado Trench

We found no evidence to support suggestions that the scarp through the City of Coronado is a fault, or is a fault-related feature. However, we found evidence to suggest that the scarp is an erosional feature not unlike numerous other bluffs in the San Diego shoreline area.

ACKNOWLEDGMENTS

This work was supported by the U.S. Geological Survey's National Earthquake Hazards Reduction Program (Contract No. 14-08-0001-19118). Mrs. Dorian Mills and Mr. David Nelson of Woodward-Clyde Consultants, San Diego, assisted with the geological field investigation. Ms. Kathryn L. Hanson and Dr. Frank Swan of Woodward-Clyde Consultants, San Francisco, provided information and interpretations regarding Quaternary soils.

Dr. Lloyd Cluff of Woodward-Clyde Consultants, San Francisco, provided input into interpretations of fault activity, recurrence intervals, and tectonic setting.

We wish to thank Ms. Margaret Kelly, Ms. Cynthia Hayman, and Ms. Jerri Samuels for their patience and assistance in the preparation of this report.

We also wish to acknowledge the input and contributions in age dating by Dr. John Wehmiller of the University of Delaware, working under a separate U.S. Geological Survey grant.

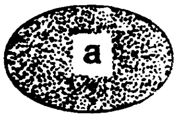
APPENDIX A

KEY TO LOGS

AND

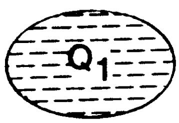
LOGS OF TRENCH IN SAN DIEGO, CALIFORNIA

KEY TO LOGS



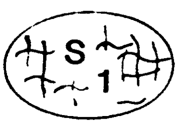
HOLOCENE AEOLIAN AND ALLUVIAL DEPOSITS

Brown to very dark brown to grayish-brown, clayey silty fine to medium-grained sand. The deposits are friable, massive to poorly bedded, and porous.



HOLOCENE EMBAYMENT DEPOSITS

Grayish-brown to dark gray, fine, sandy silty clay. The deposits have an organic odor and contain local lenses of silty sand.

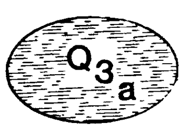


BURIED PALEOSOL

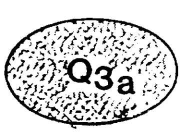
Dark brown to dark yellowish-brown sandy clay. The soils are firm to hard and have a poorly to moderately well-developed, medium angular to blocky structure and thin to moderately thick clay skins.

PLEISTOCENE CHANNEL FILL AND ESTUARY DEPOSITS

Light brown to light reddish-brown to dark brown, gravelly silty fine to coarse-grained sand and dark brown to grayish-brown sandy to silty clay.

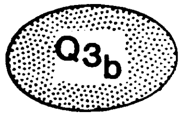


Mainly estuary deposits consisting of dark gray to grayish-brown silty clay.

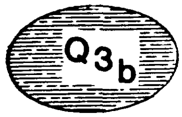


with interbeds and channel fills consisting of dark gray to grayish-brown fine to medium-grained sand.

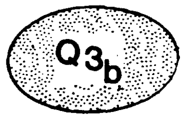
KEY TO LOGS (Con't)



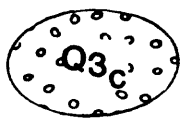
Mainly alluvial deposits consisting of light brown to brown, silty to clayey fine to coarse-grained sand containing pebble and gravel layers.



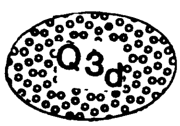
and grayish-brown, silty to clayey fine grained sand and fine-grained sandy silt and clay containing thin interbeds of coarse-grained sand.



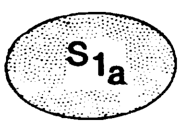
and brown, clayey to silty, fine to medium-grained cross-bedded sand.



Dark brown to reddish-brown, locally lightly cemented medium to coarse-grained sandy gravel containing friable coarse sand beds.

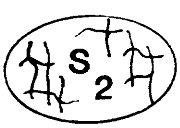


Light brown to brown, sandy pebble gravel containing sand interbeds; pebbles are typically stained with iron oxide or manganese oxide.



BURIED ALLUVIAL DEPOSITS

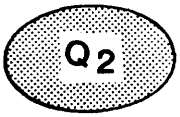
Dark brown to dark yellowish-brown, clayey silty fine to medium-grained sand. The deposits are firm, porous, massive to poorly bedded, and are stained with manganese.



OLDER BURIED PALEOSOL

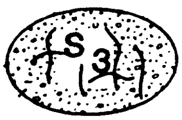
Dark brown to dark grayish-brown sandy clay. The soil is hard and has a well-developed, coarse, blocky to prismatic structure, and moderately thick to thick clay skins.

KEY TO LOGS (Con't)



PLEISTOCENE ALLUVIAL DEPOSITS

Light reddish-brown to reddish-brown, gravelly clayey fine to coarse-grained sand. The deposits are typically lightly oxidized and moderately to lightly cemented.

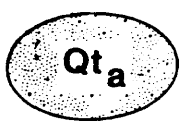


FAULTED BURIED PALEOSOL

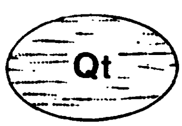
Grayish-brown to dark grayish-brown, hard sandy clay having well-developed coarse, blocky to prismatic structure and thick continuous clay skins.

MIDDLE TO LATE PLEISTOCENE MARINE DEPOSITS

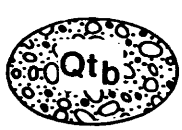
Light gray to light reddish-brown, silty fine to coarse sands containing thin pebble layers and rare but locally abundant fossil shell beds.



Light grayish-brown to brown, clayey fine to coarse sand containing local thin beds of sandy clay and pebbles. Slightly cemented and stained by iron oxide and manganese.

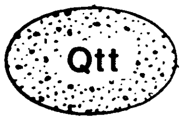


Light gray to light yellowish-brown silty fine to medium-grained sand containing thin coarse sand and pebble beds and local fossil shell layers. Beds are friable and lenticular.



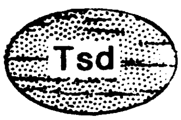
Brown to gray, sandy, pebble to cobble to boulder, conglomerate bed. Matrix is gray silty clay with white calcium carbonate stain on upper gravels, reddish-brown oxide stain on lower gravels.

KEY TO LOGS (Con't)



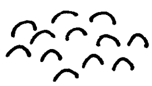
PLEISTOCENE TERRACE DEPOSIT

Light reddish-brown to dark reddish-brown sandy to clayey cobble çonglomerate; containing clean, pebbly medium to coarse-grained sand. Beds are iron stained and locally cemented by iron oxide.



PLIOCENE SAN DIEGO FORMATION

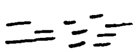
Light gray to light yellowish-brown to light brown silty fine-grained sand containing thin layers and lenses of pebbles and at least two thin clay layers.



FOSSIL SHELL LOCALITIES

COARSE SAND LENSES AND THIN SAND INTERBEDS

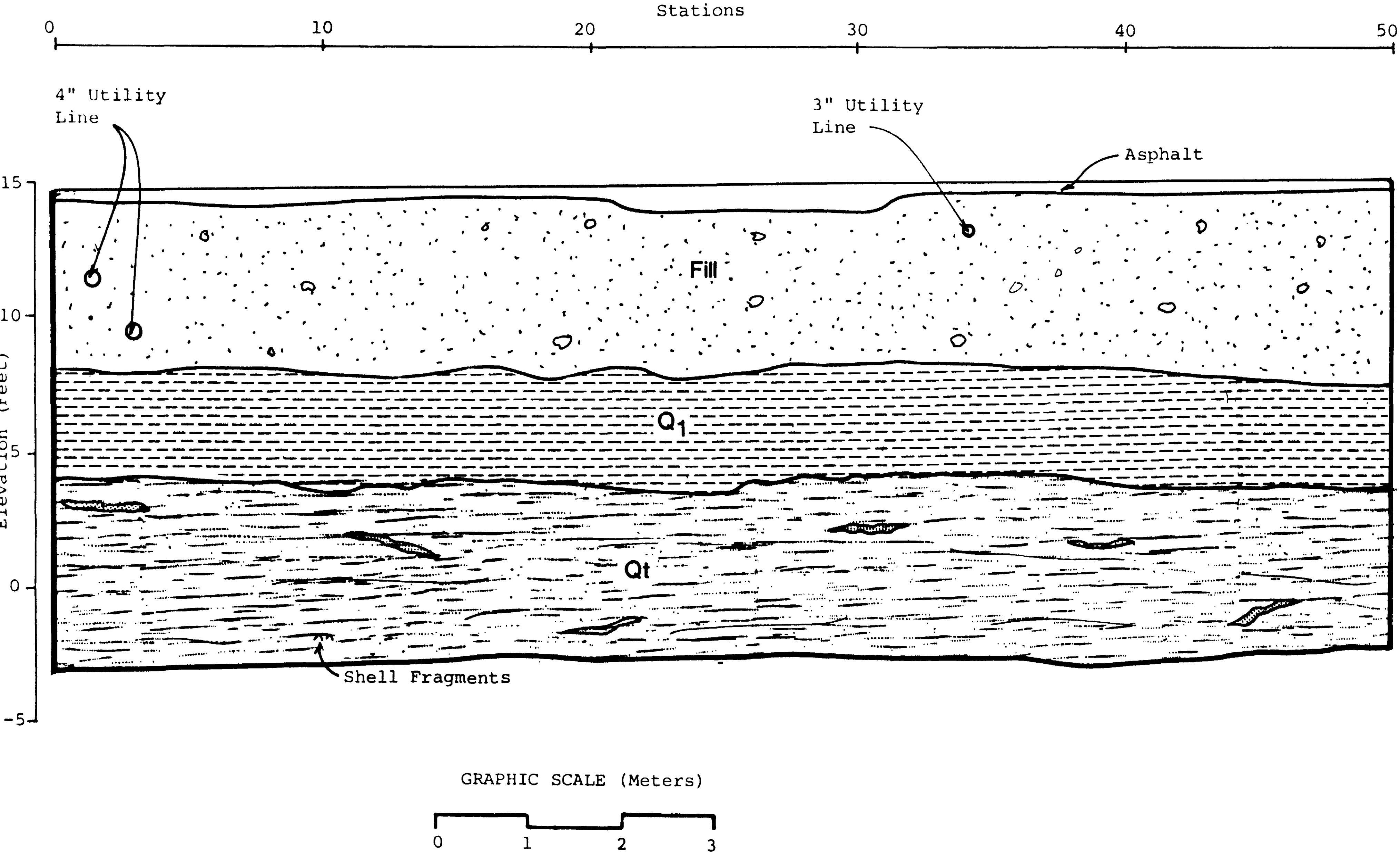
GRAVEL OR PEBBLE INTERBEDS



THIN CLAY LAYERS

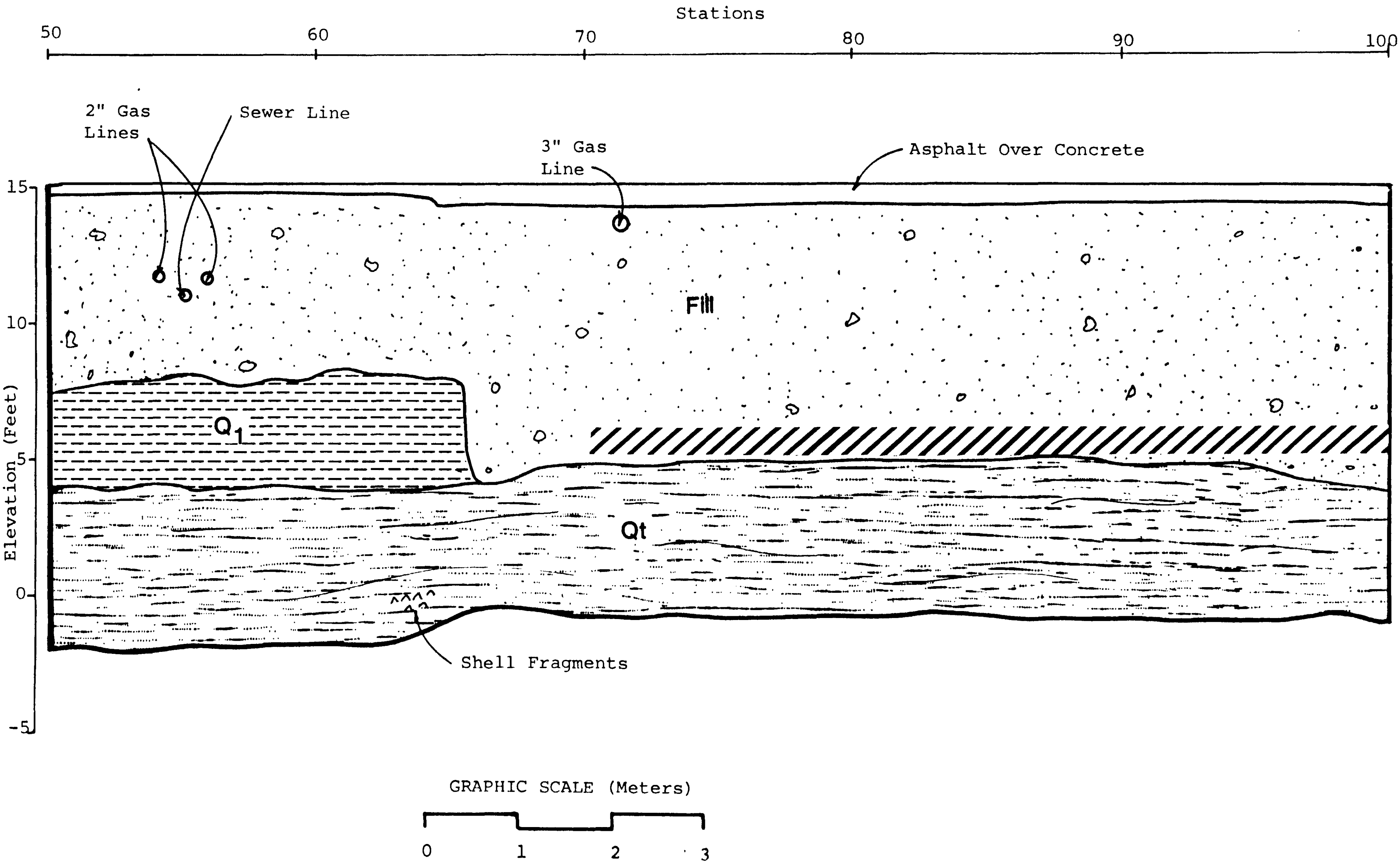
LITHOLOGIC OR GEOLOGIC UNIT CONTACT

FAULT



LOG OF TRENCH (NORTH WALL)
STATIONS 0 TO 50

DRAWN BY: mrk	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 8-25-80	FIGURE NO: A-5



LOG OF TRENCH (NORTH WALL)
STATIONS 50 TO 100

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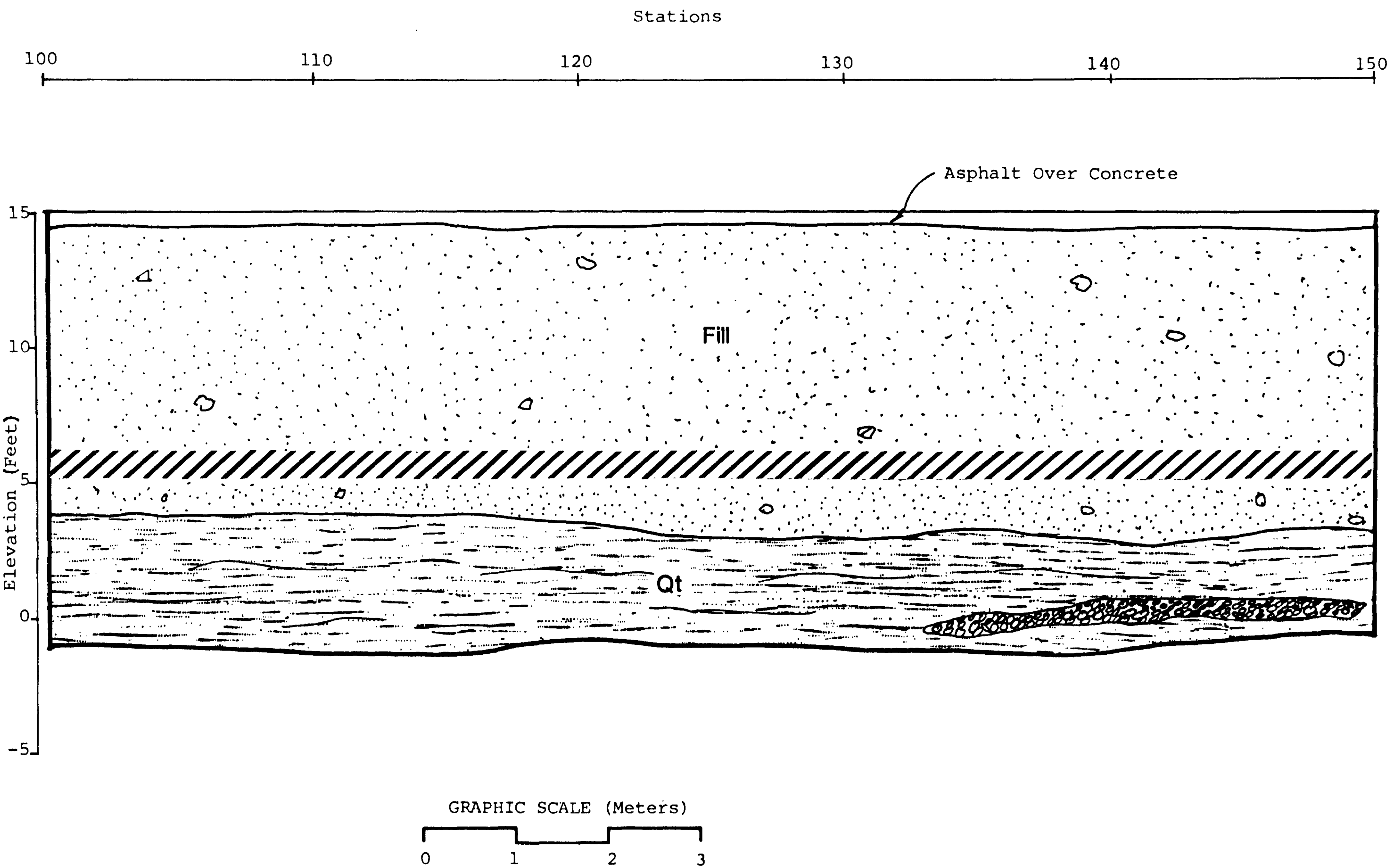

LOG OF TRENCH (NORTH WALL) STATIONS 100 TO 150				
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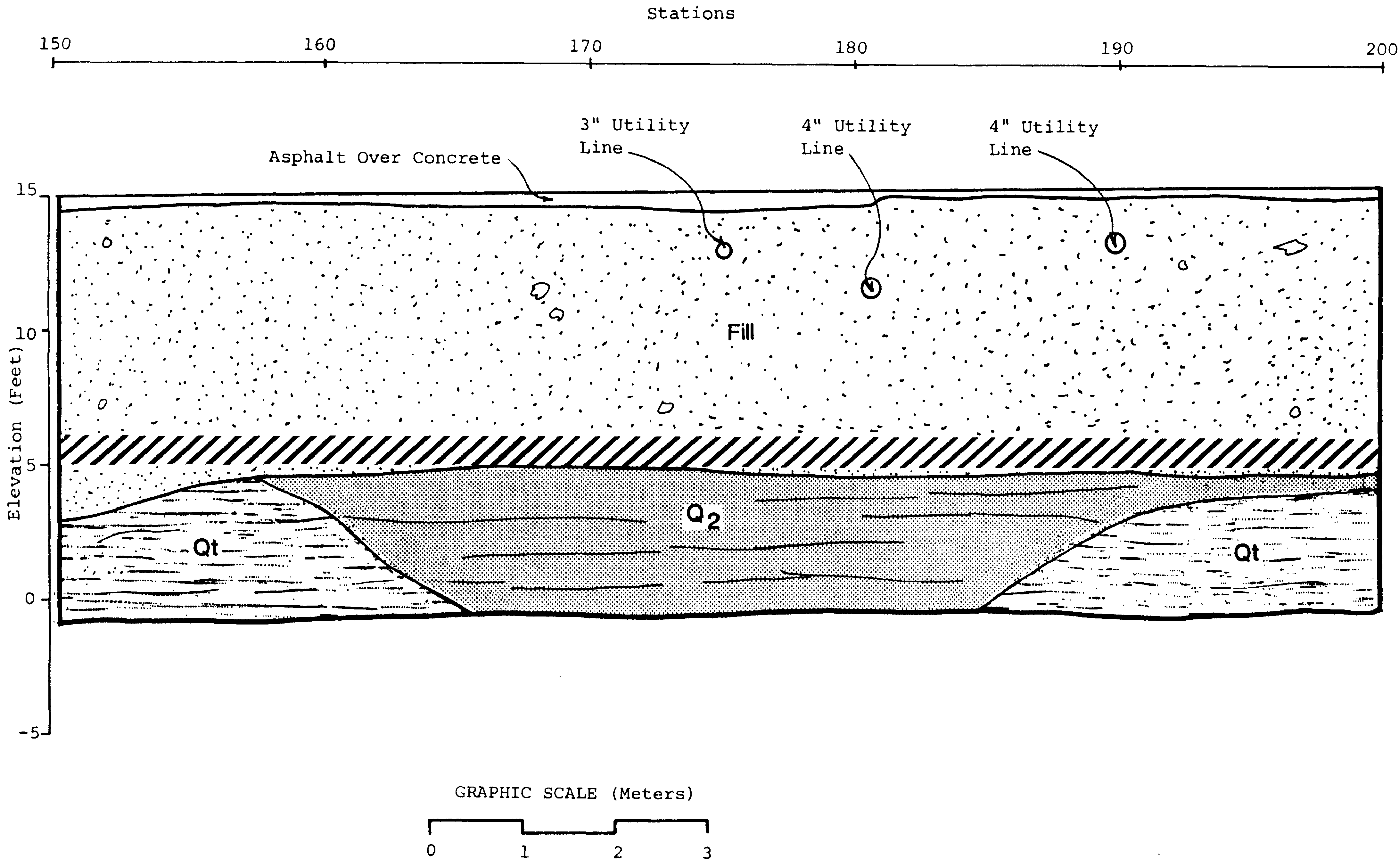

LOG OF TRENCH (NORTH WALL) STATIONS 150 TO 200				
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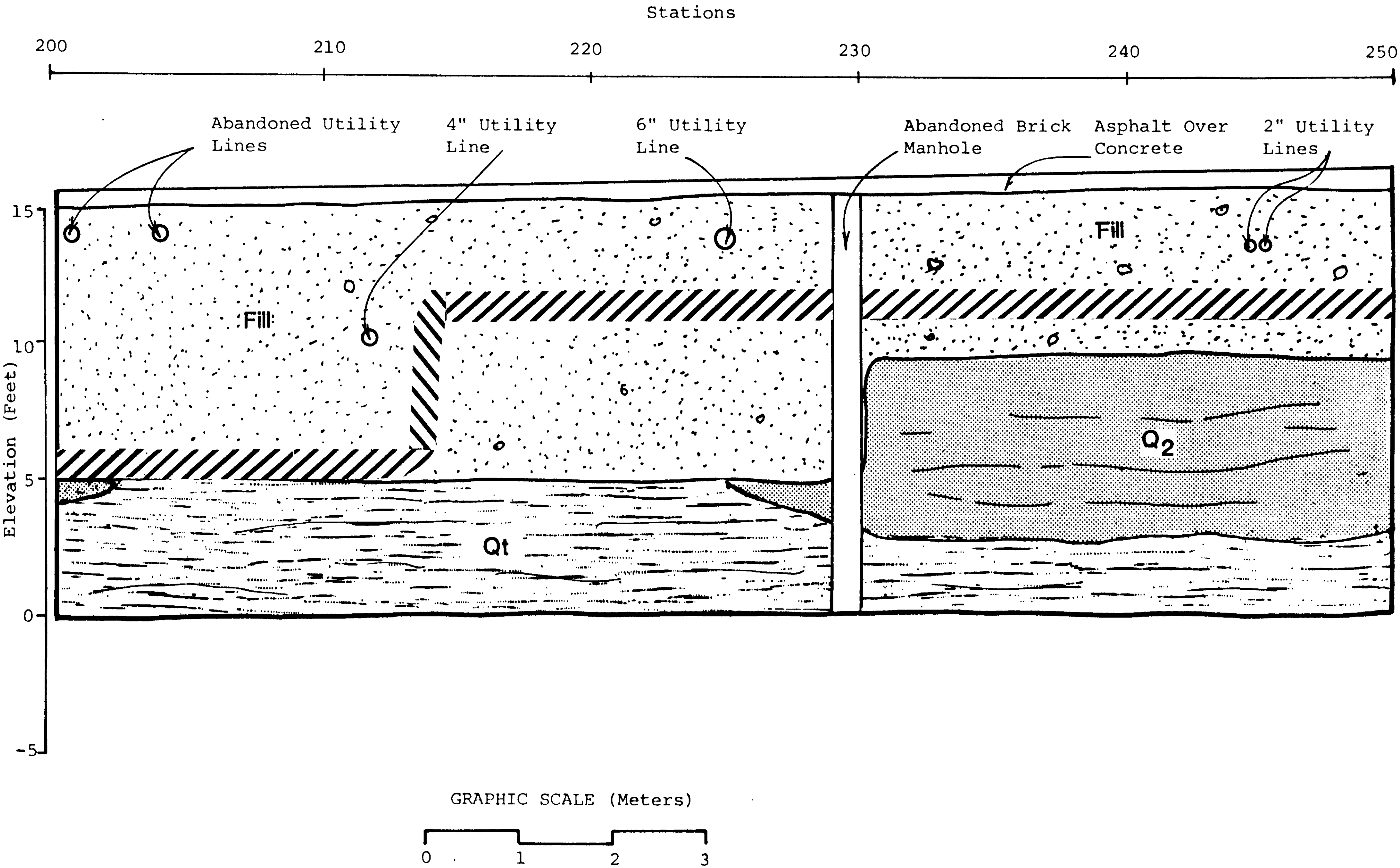

LOG OF TRENCH (NORTH WALL)
STATIONS 200 TO 250

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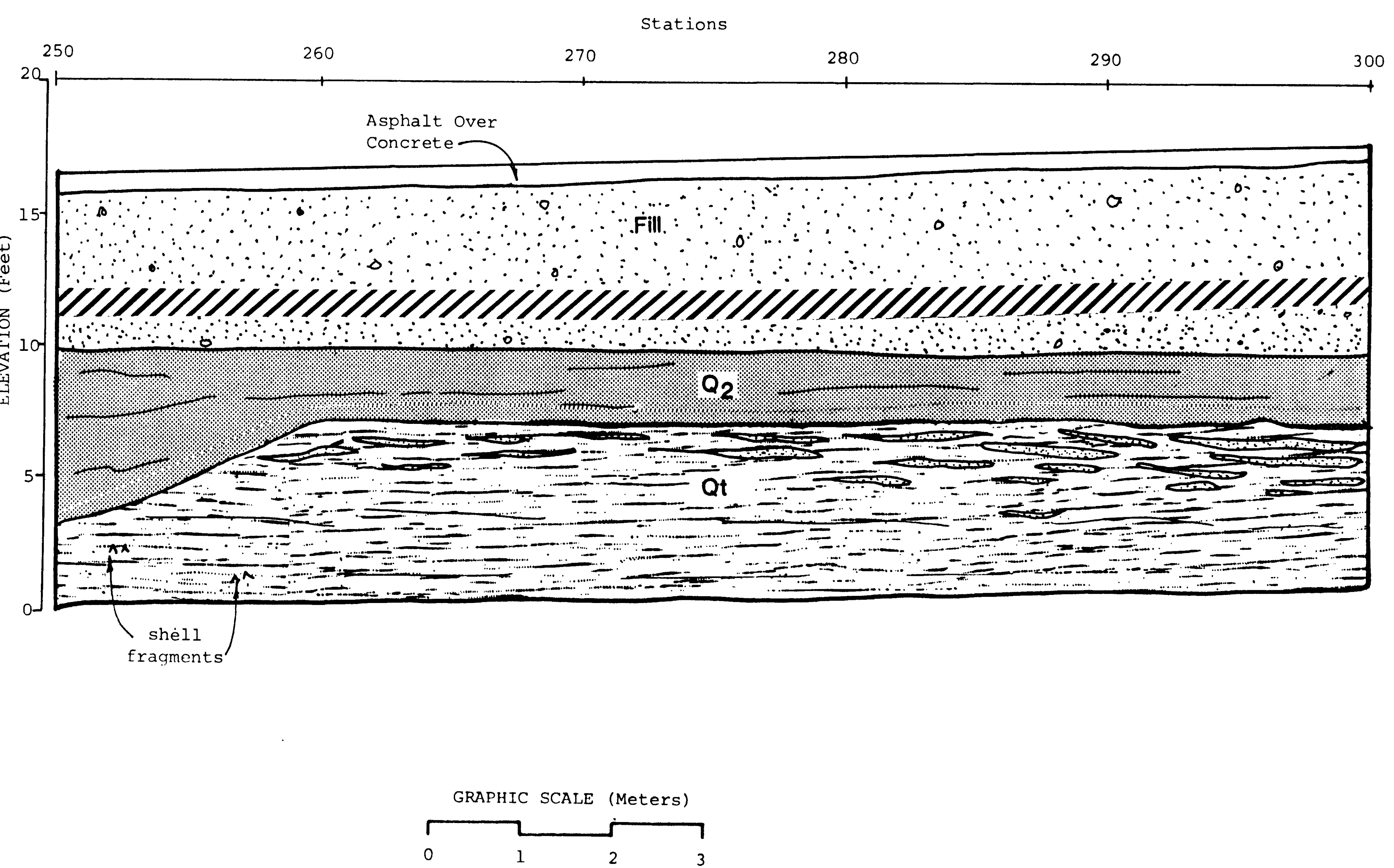

LOG OF TRENCH (NORTH WALL) STATIONS 250 TO 300				
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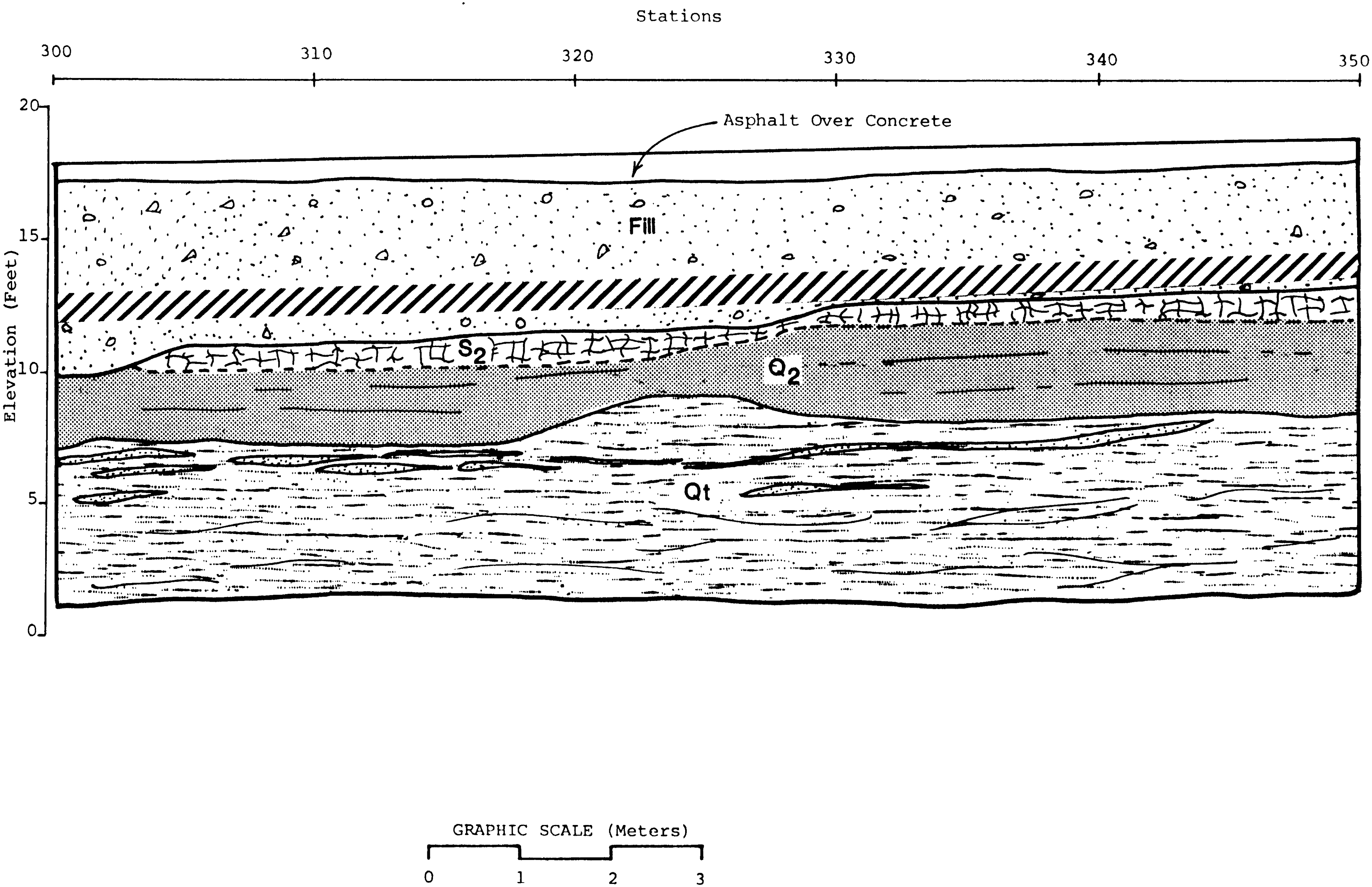

LOG OF TRENCH (NORTH WALL)
STATIONS 300 TO 350

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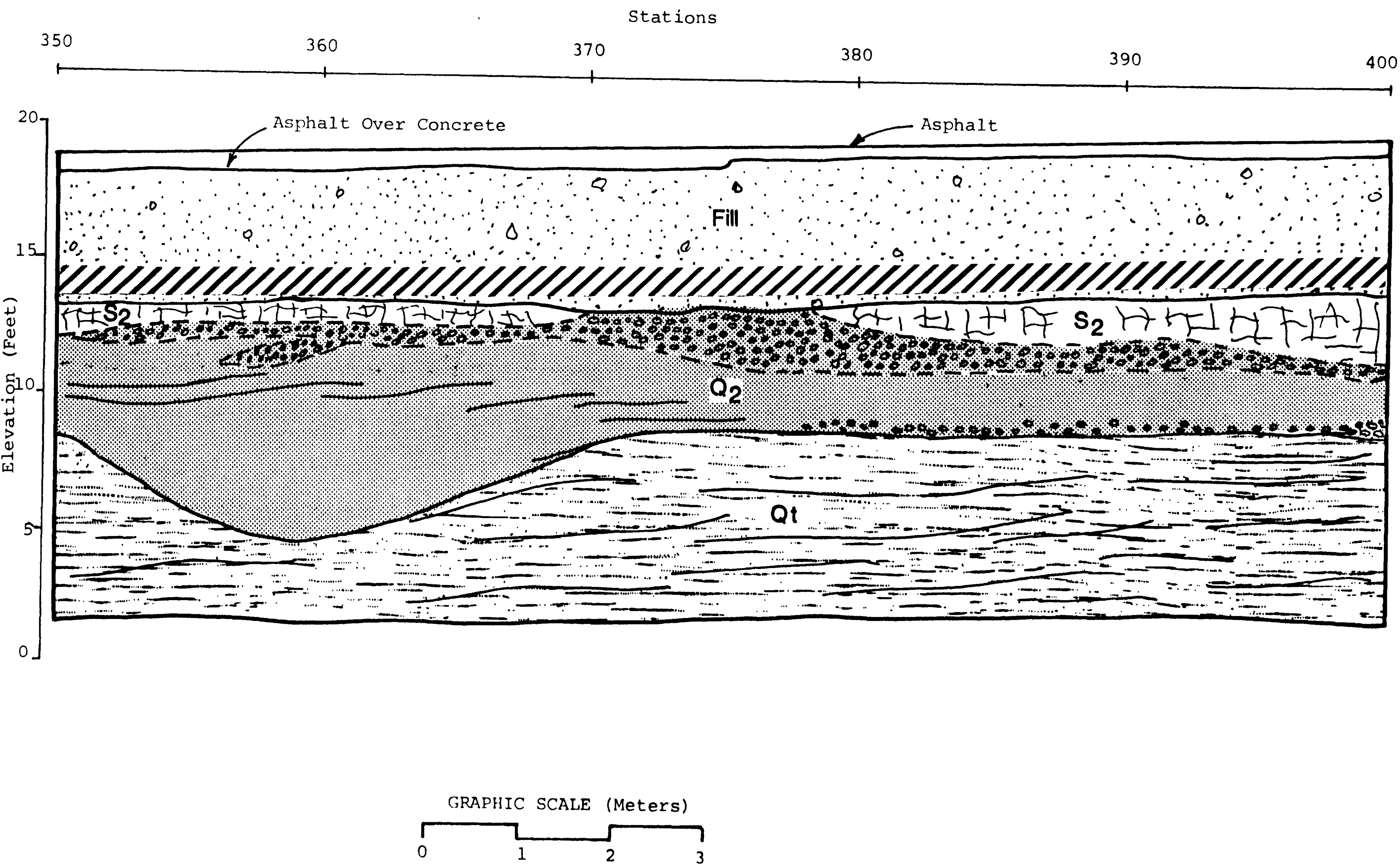

LOG OF TRENCH (NORTH WALL) STATIONS 350 TO 400				
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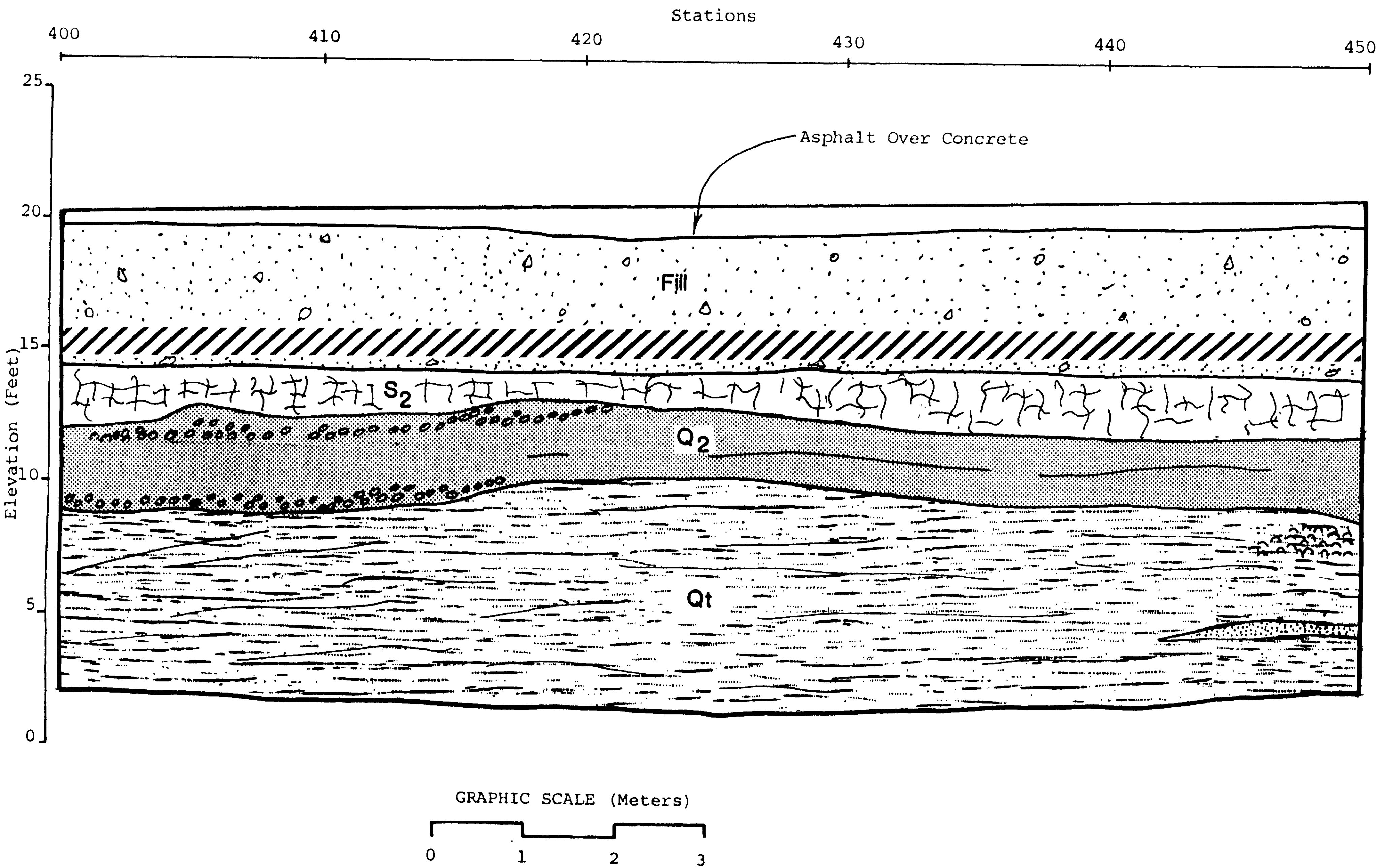

LOG OF TRENCH (NORTH WALL)
STATIONS 400 TO 450

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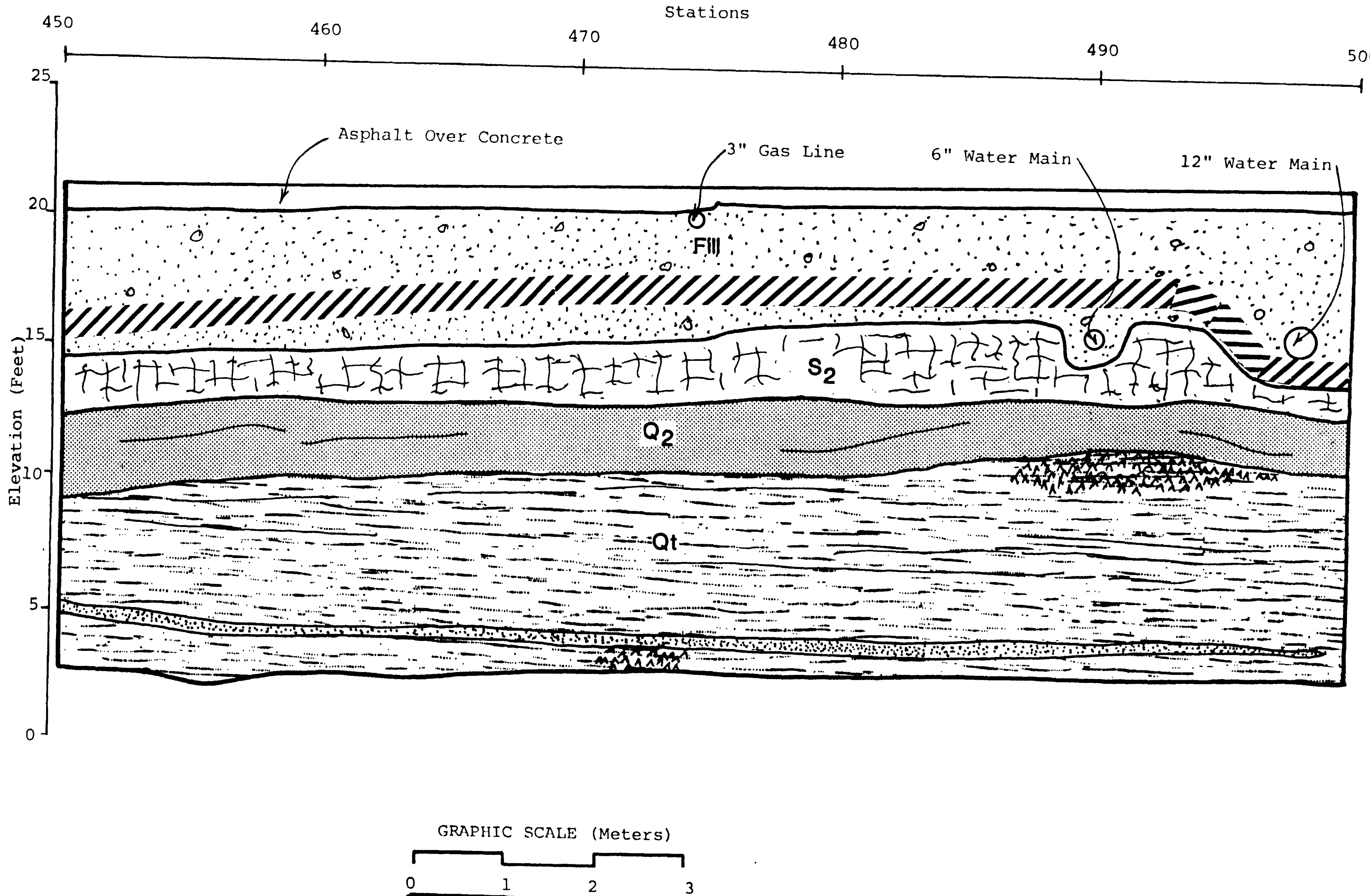

LOG OF TRENCH (NORTH WALL) STATIONS 450 TO 500				
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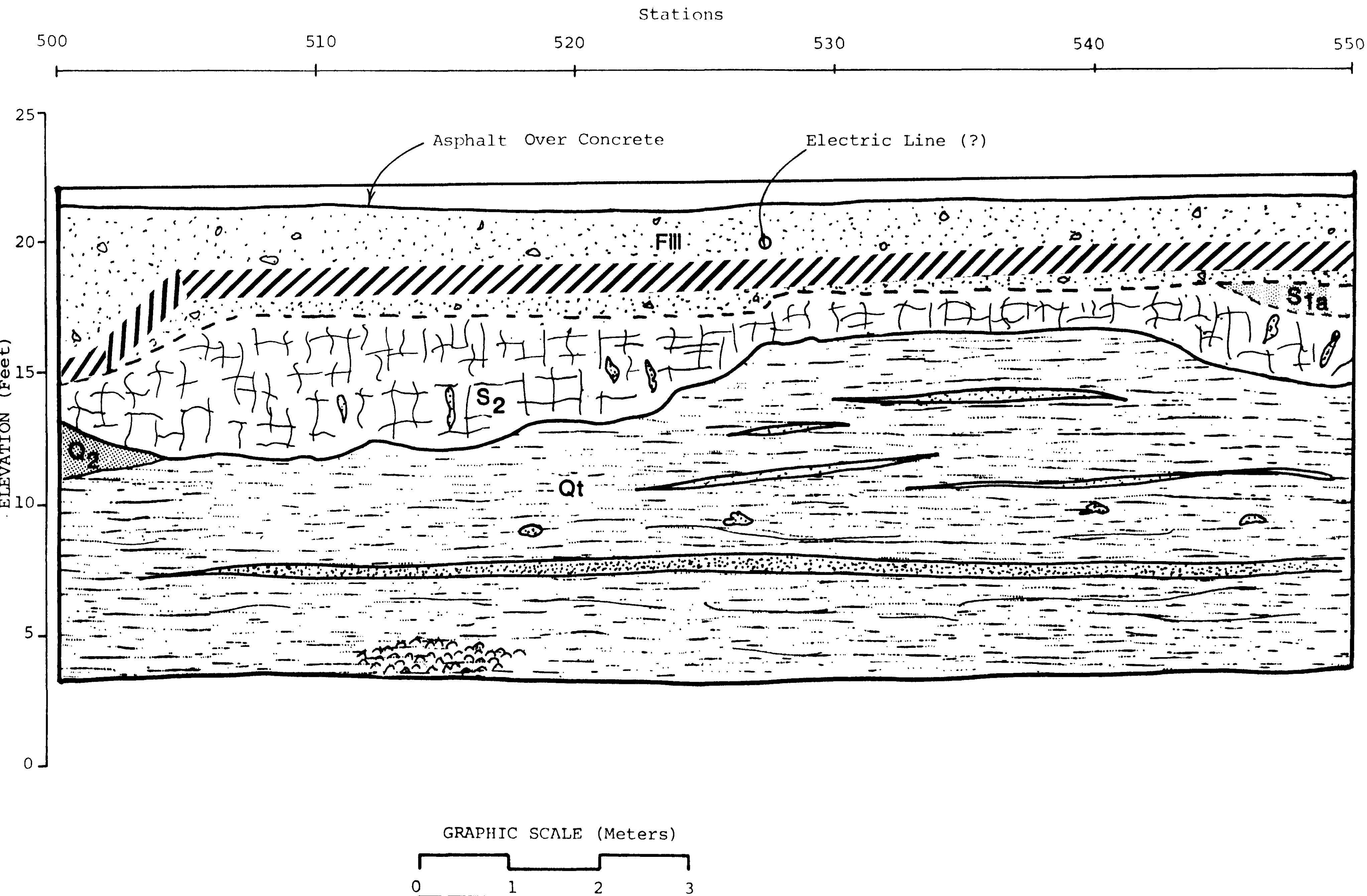

LOG OF TRENCH (NORTH WALL)
STATIONS 500 TO 550

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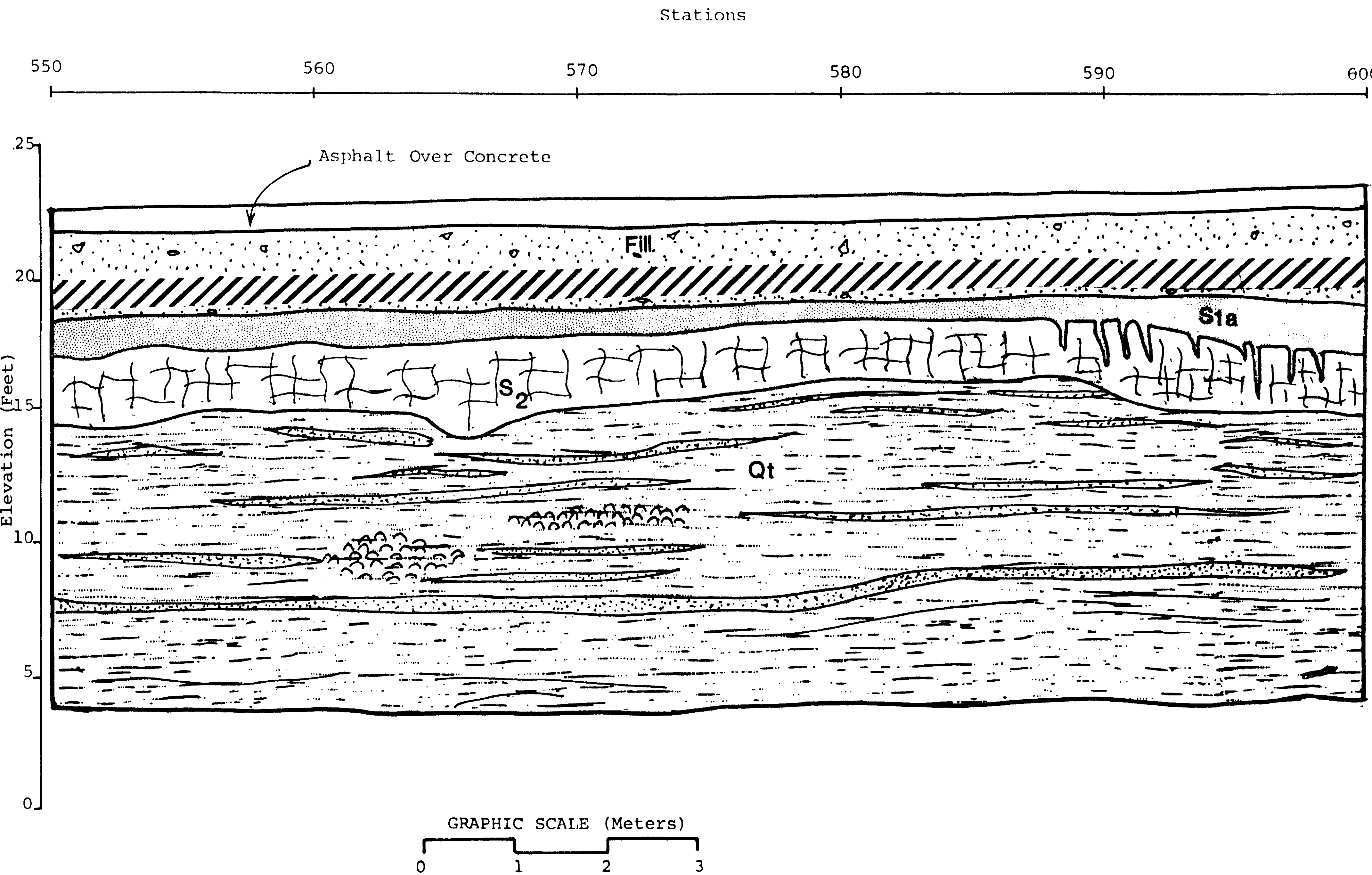

LOG OF TRENCH (NORTH WALL) STATIONS 550 TO 600				
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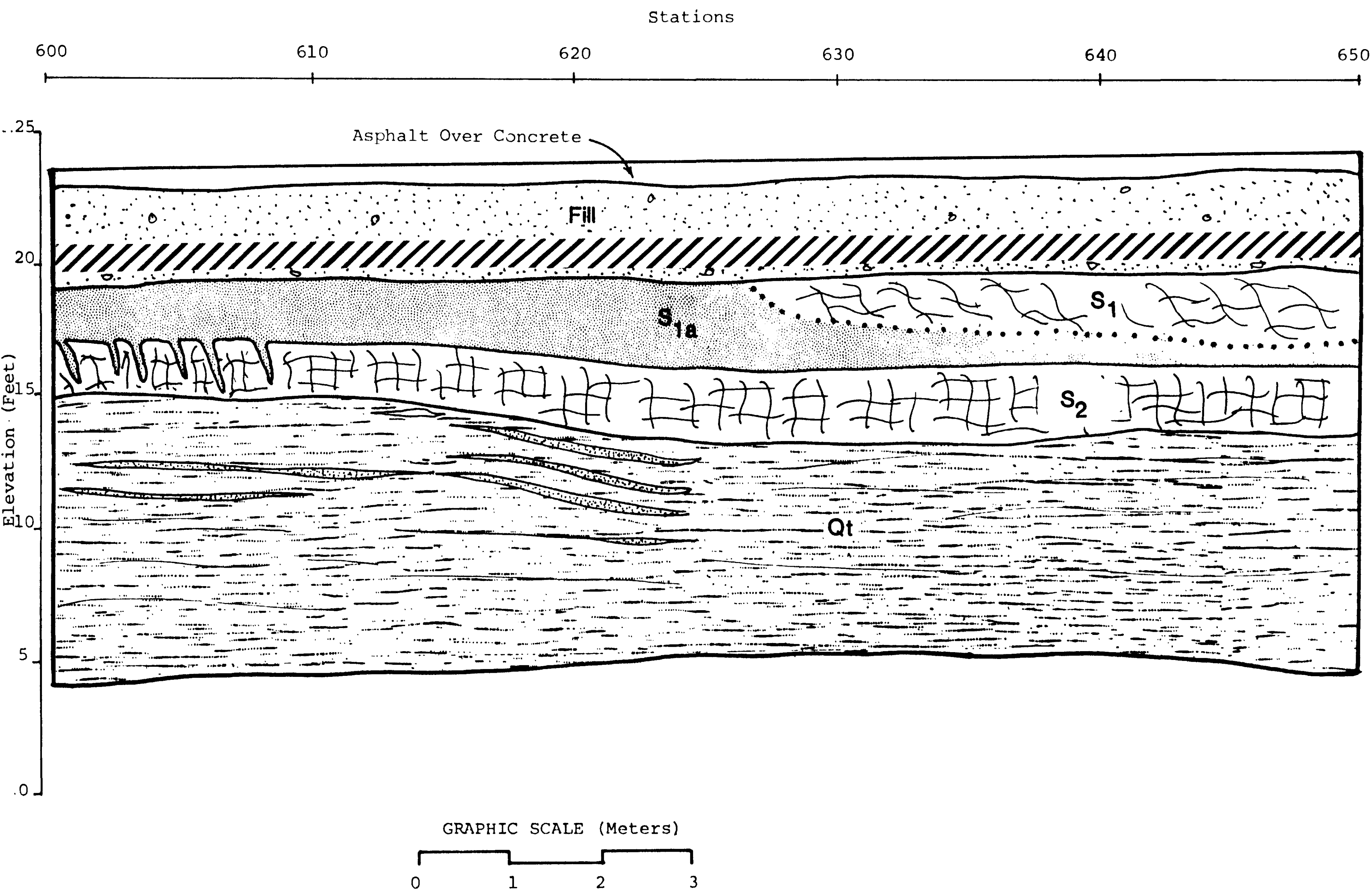
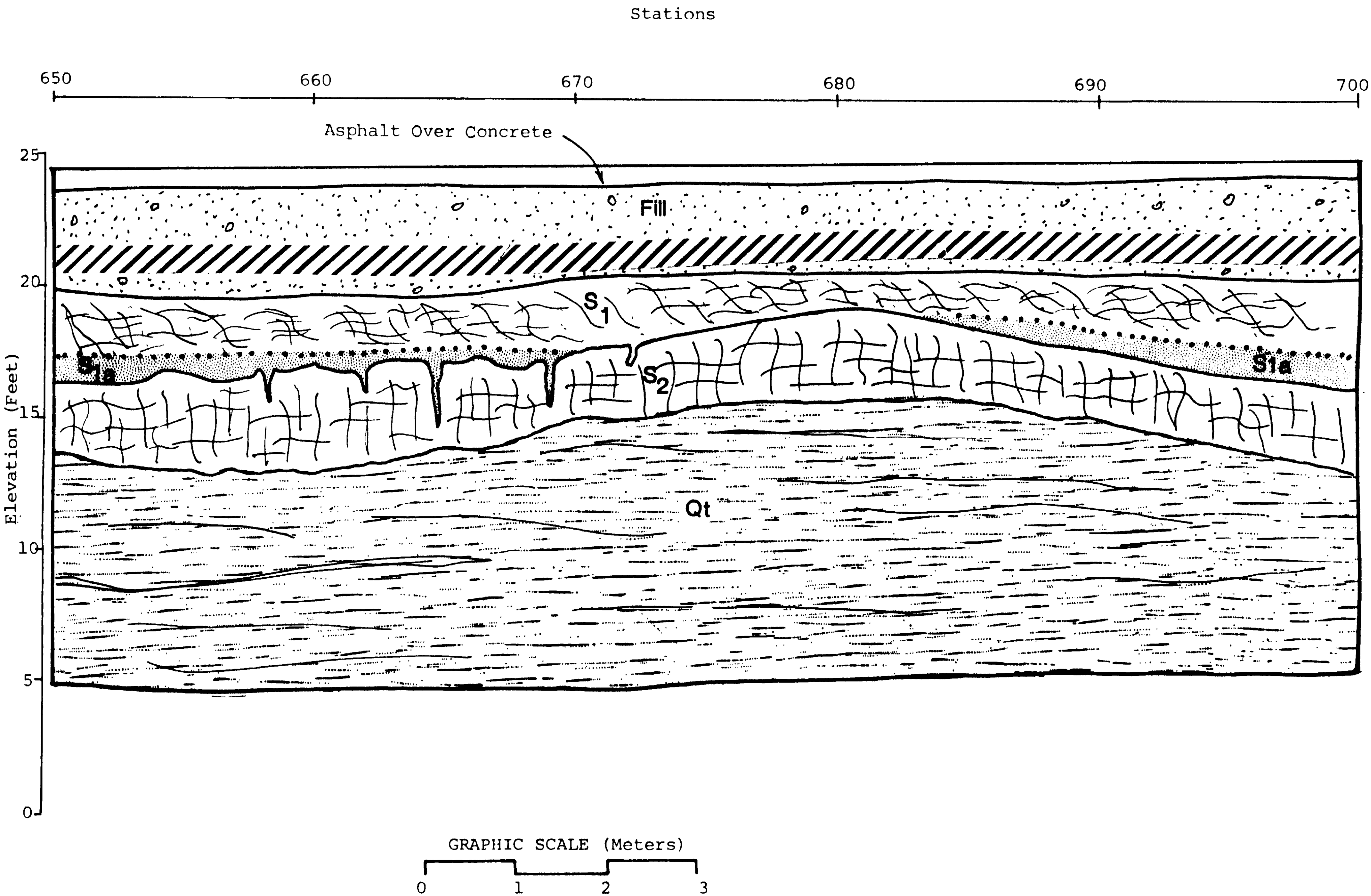


LOG OF TRENCH (NORTH WALL)
STATIONS 600 TO 650

DRAWN BY: ch	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 8-25-80	FIGURE NO: A-17



LOG OF TRENCH (NORTH WALL) STATIONS 650 TO 700				
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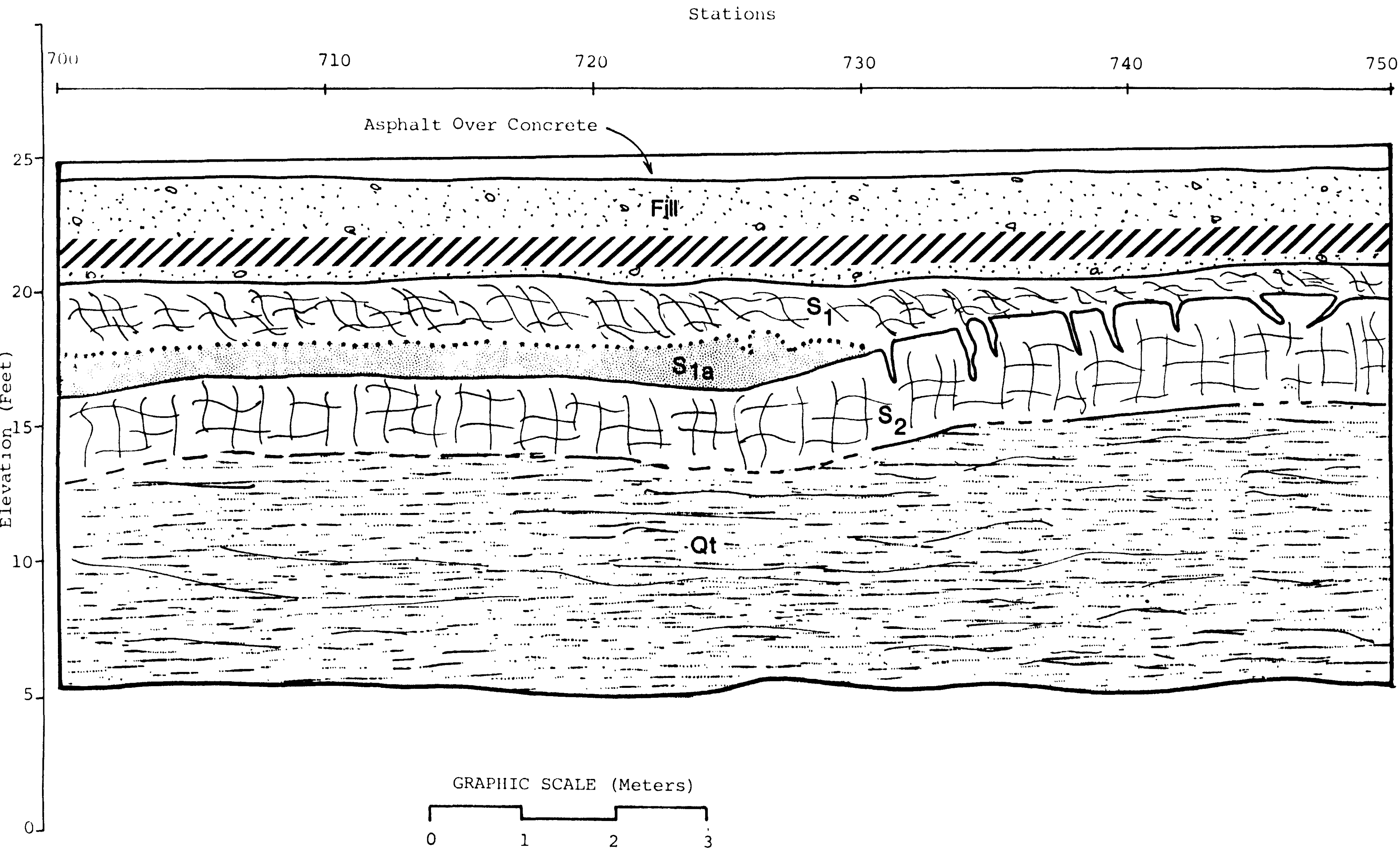

LOG OF TRENCH (NORTH WALL)
STATIONS 700 TO 750

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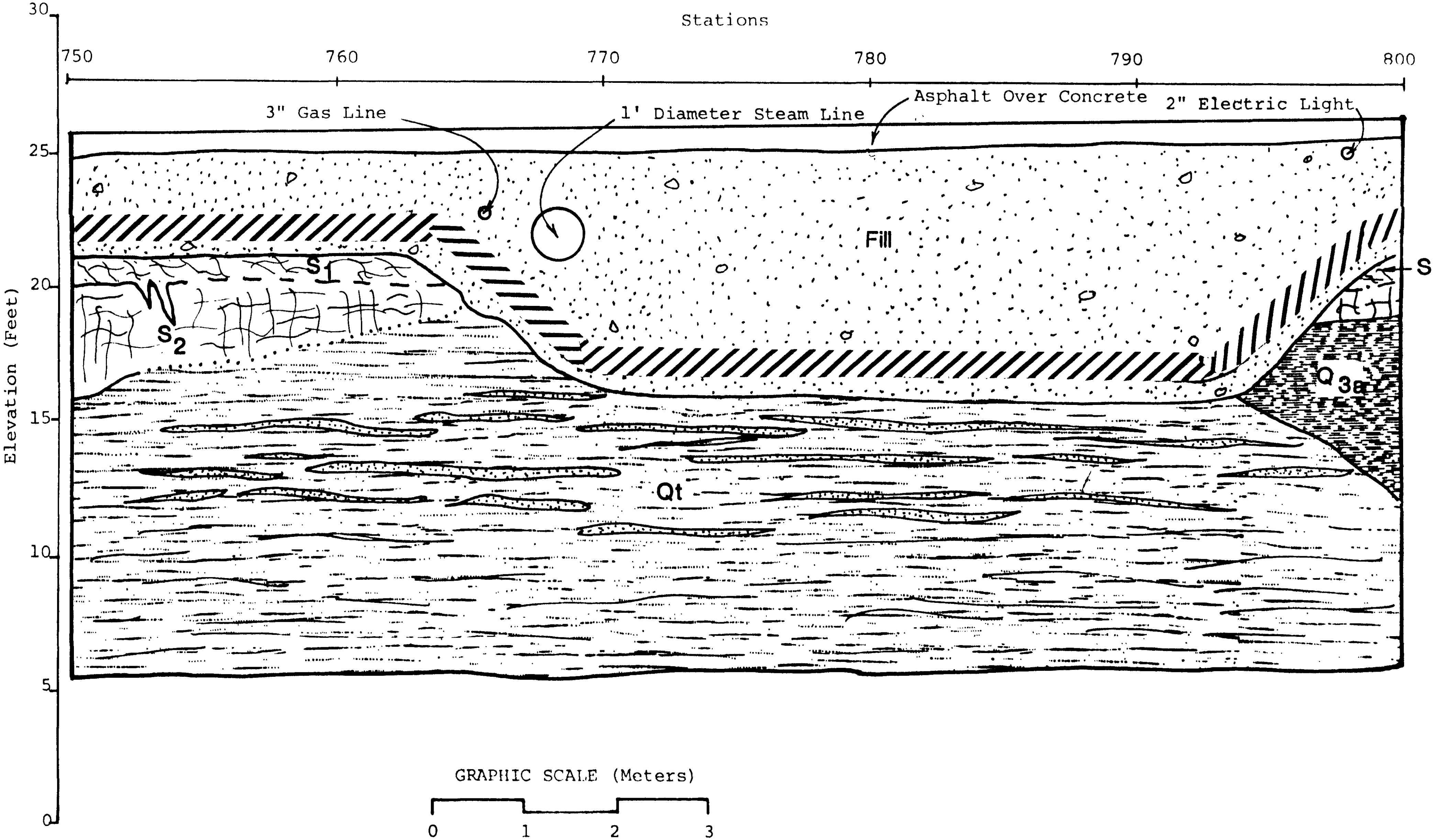
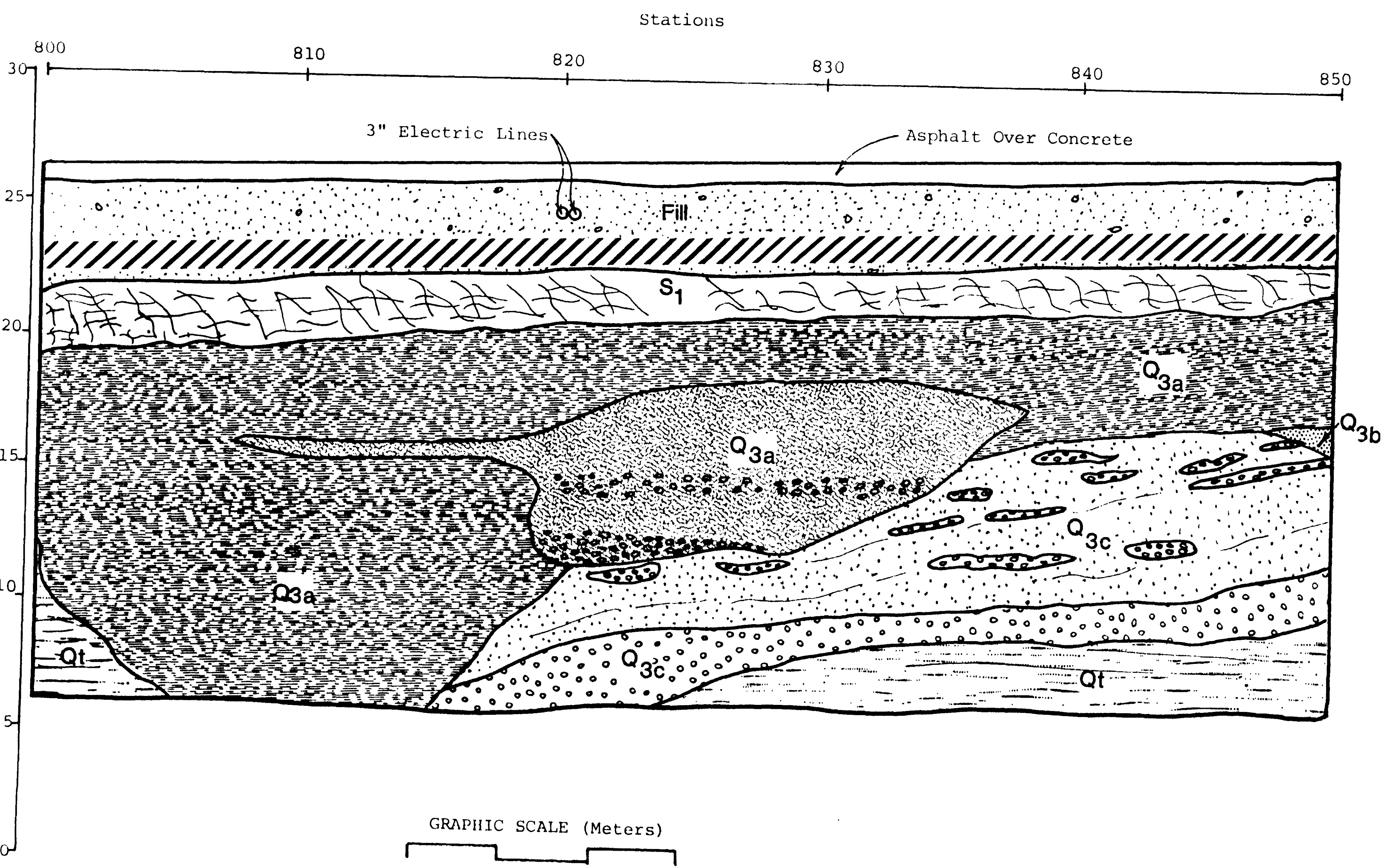


LOG OF TRENCH (NORTH WALL)
STATION 750 TO 800

DRAWN BY: ch	**CHECKED BY:** ea	**PROJECT NO:** 50135H-GEO1	**DATE:** 8-25-80	**FIGURE NO:** A-20



LOG OF TRENCH (NORTH WALL)
STATION 800 TO 850

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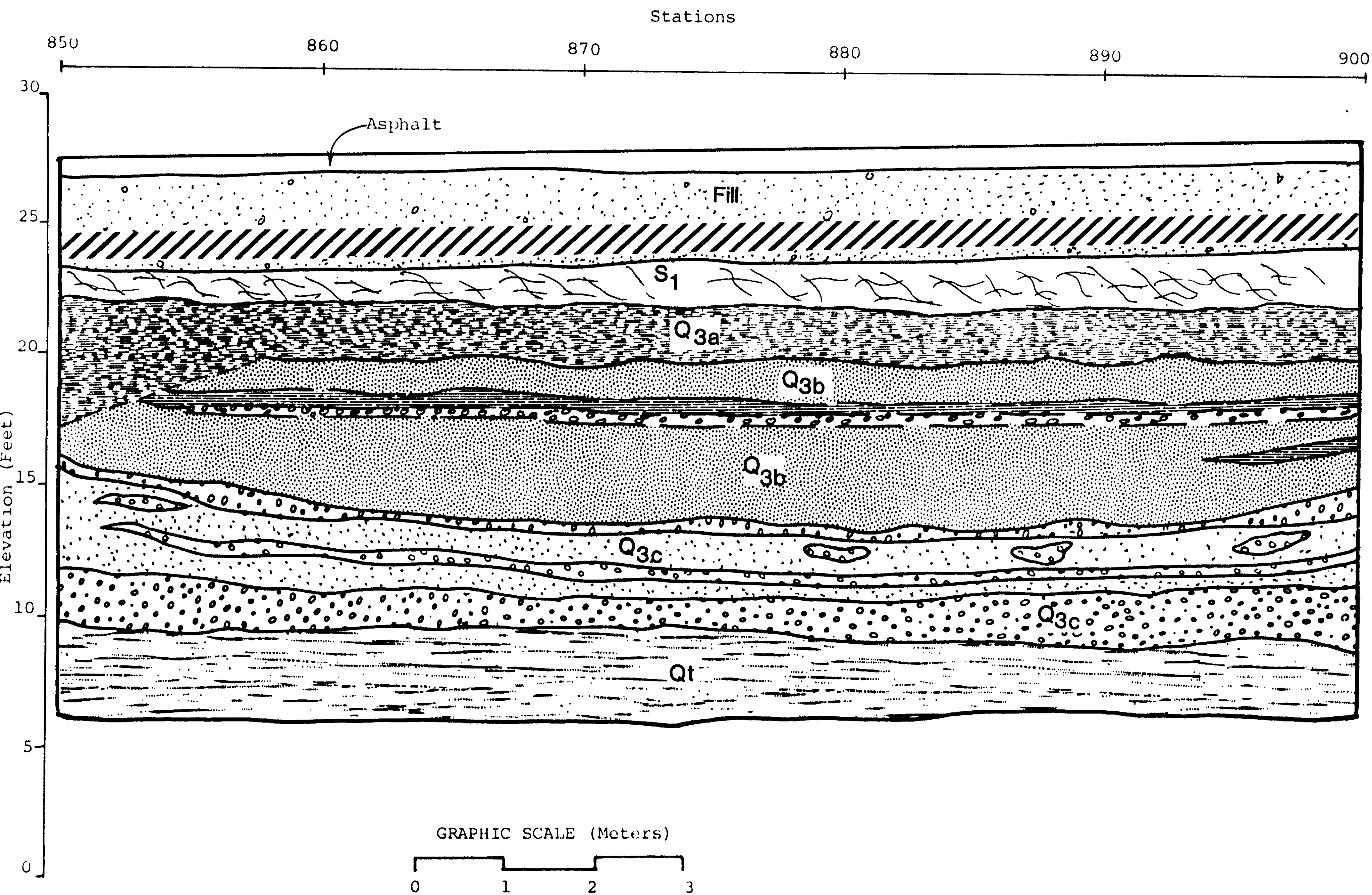
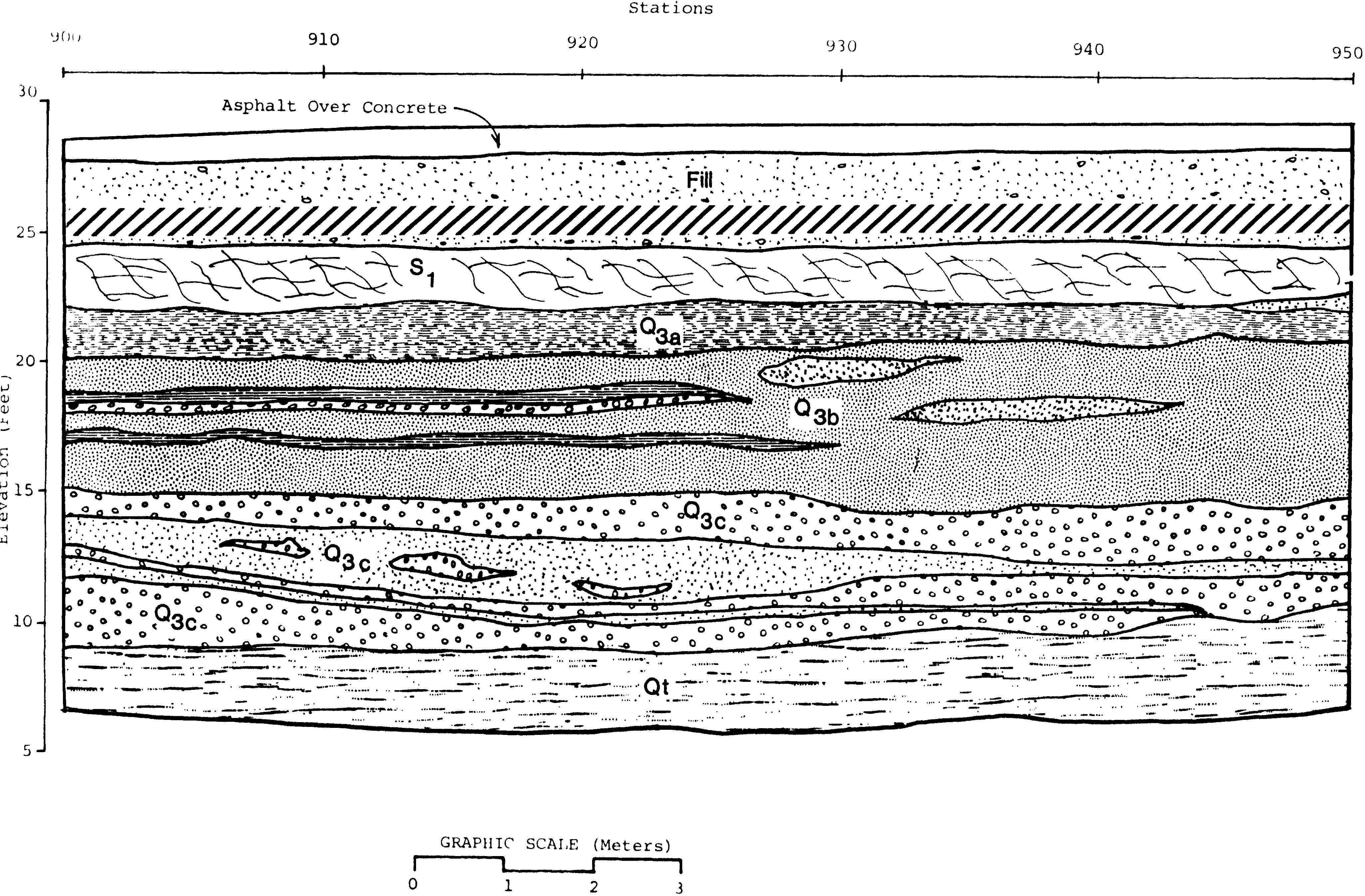


LOG OF TRENCH (NORTH WALL)
STATIONS 850 TO 900

DRAWN BY: ch	CHECKED BY: GA	PROJECT NO: 50135H-GEO1	DATE: 8-25-80	FIGURE NO: A-22



LOG OF TRENCH (NORTH WALL) STATIONS 900 TO 950				
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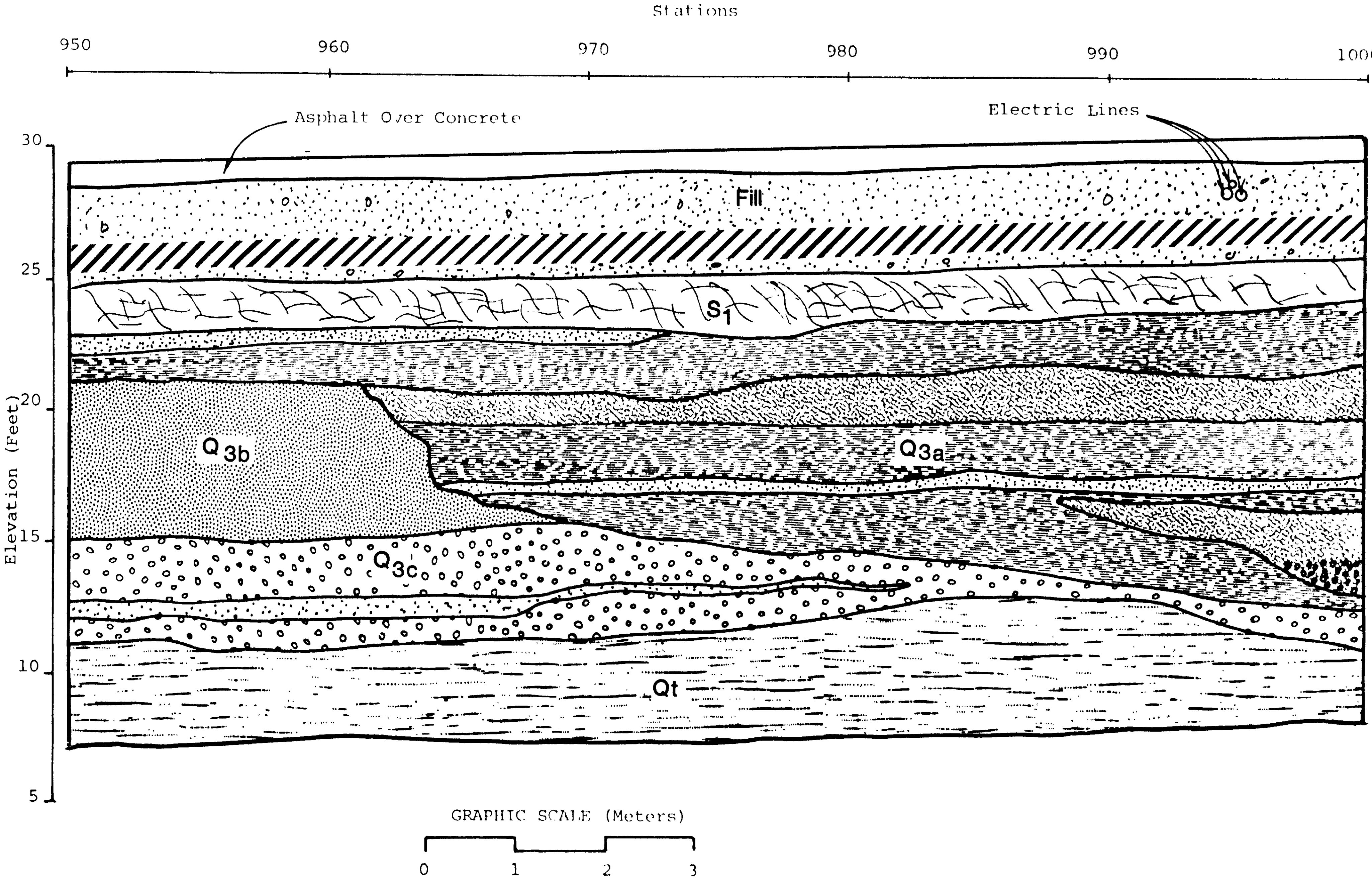
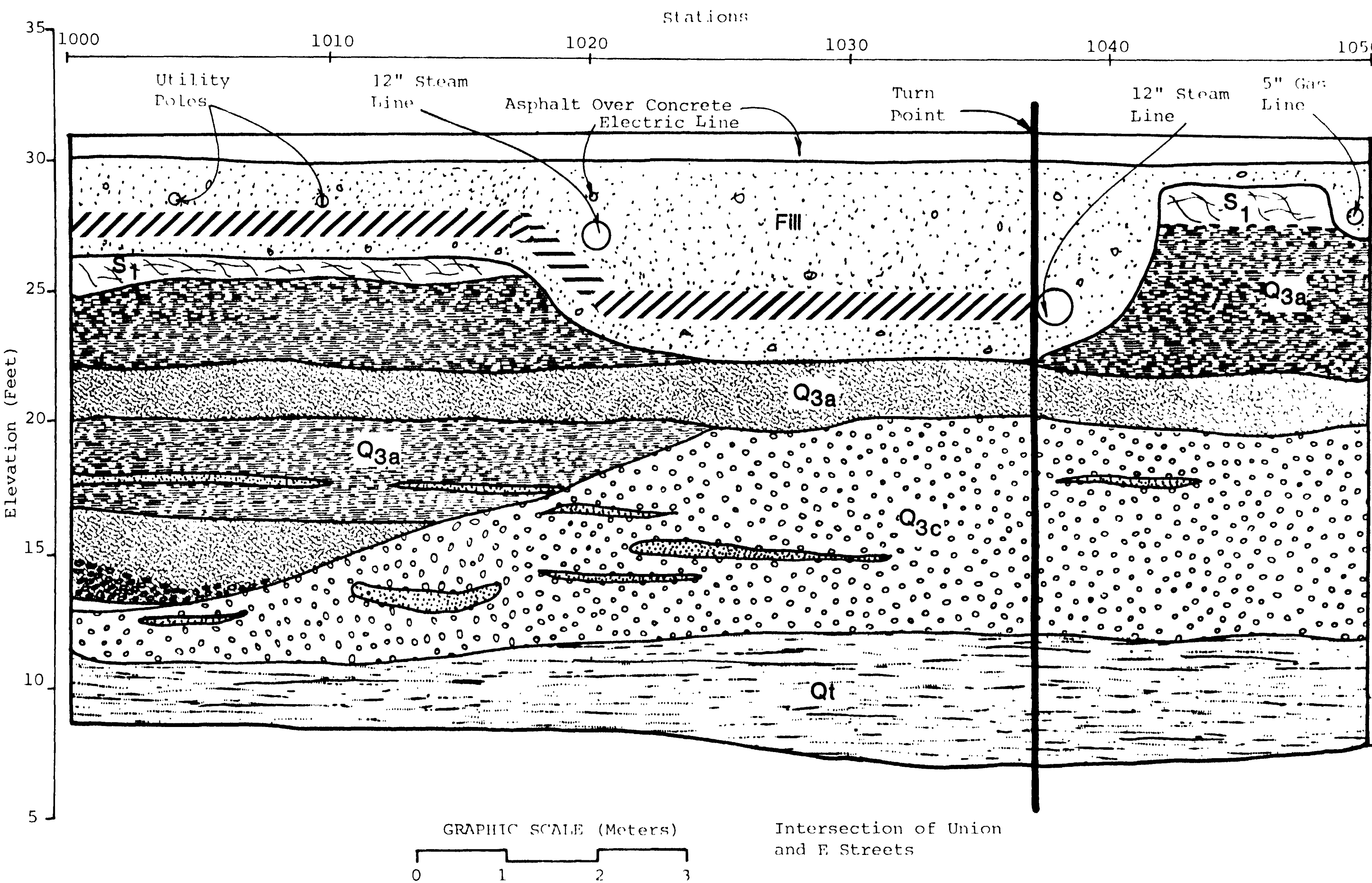
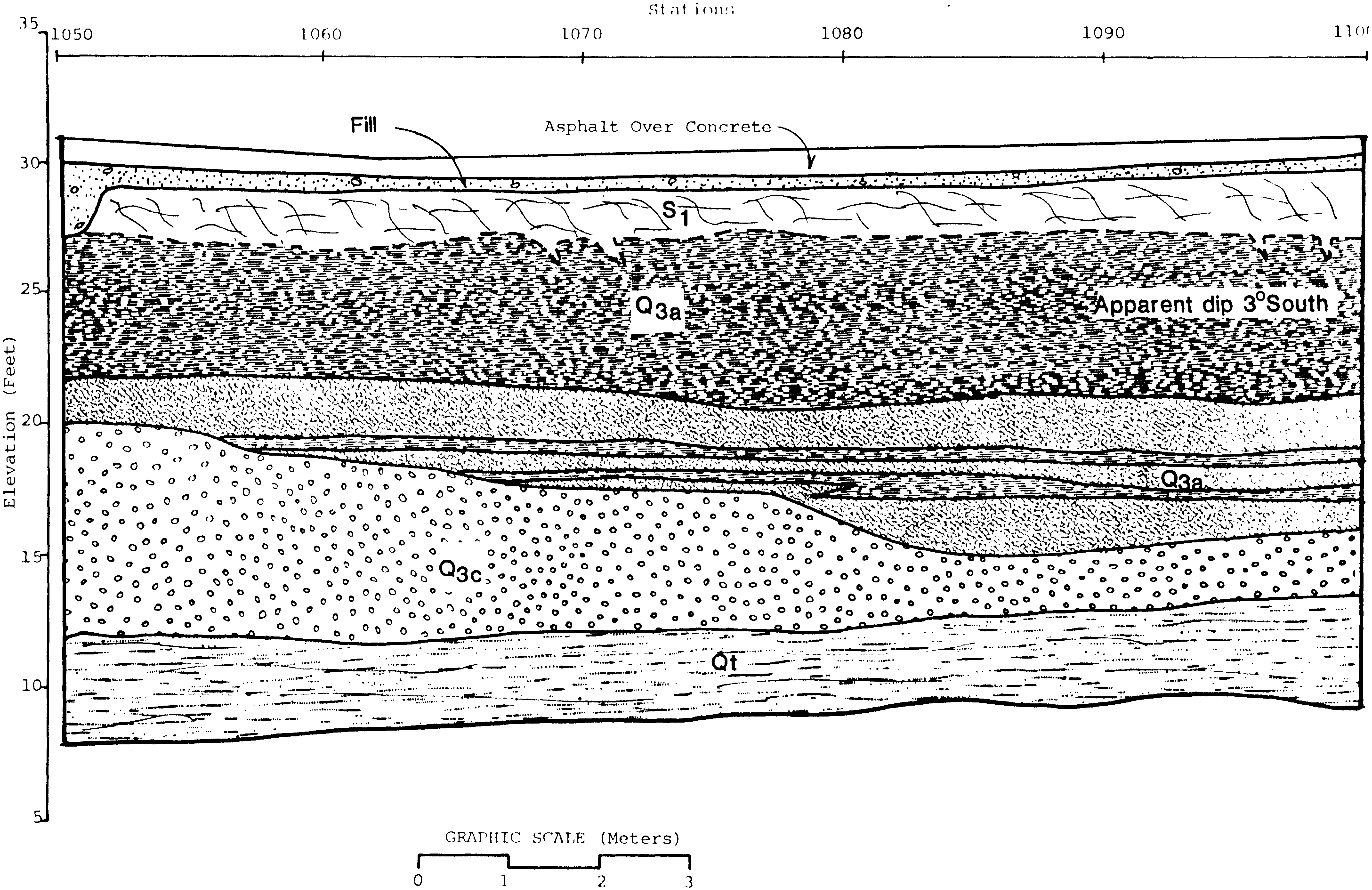


LOG OF TRENCH (NORTH WALL)
STATIONS 950 TO 1000

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GEO1	DATE: 8-25-80	FIGURE NO: A-24

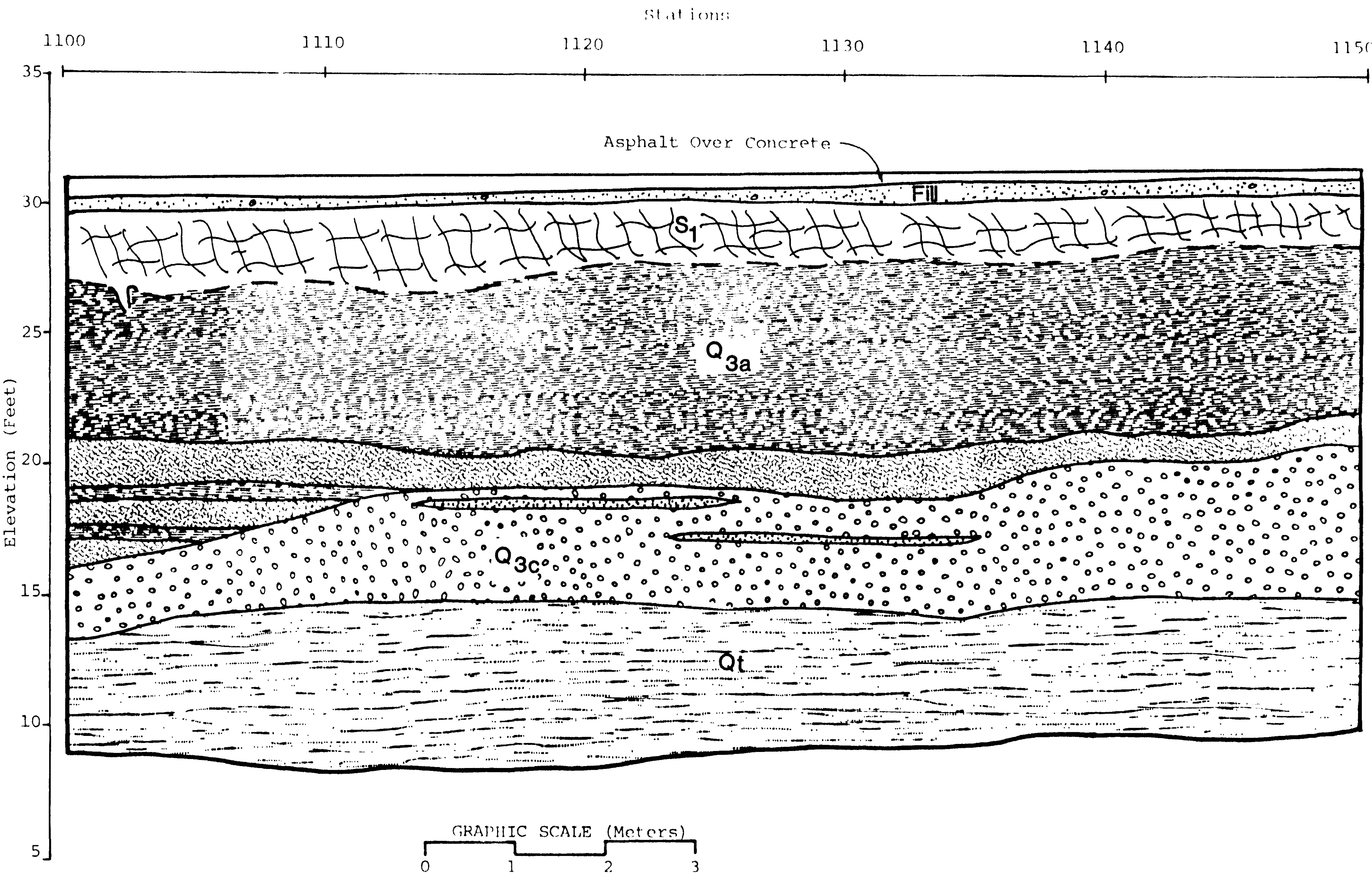


LOG OF TRENCH STATION 1000 TO 1050 NORTH WALL TO STATION 1037 - WEST WALL TO STATION 1050				
DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 8-25-80	FIGURE NO: A-25



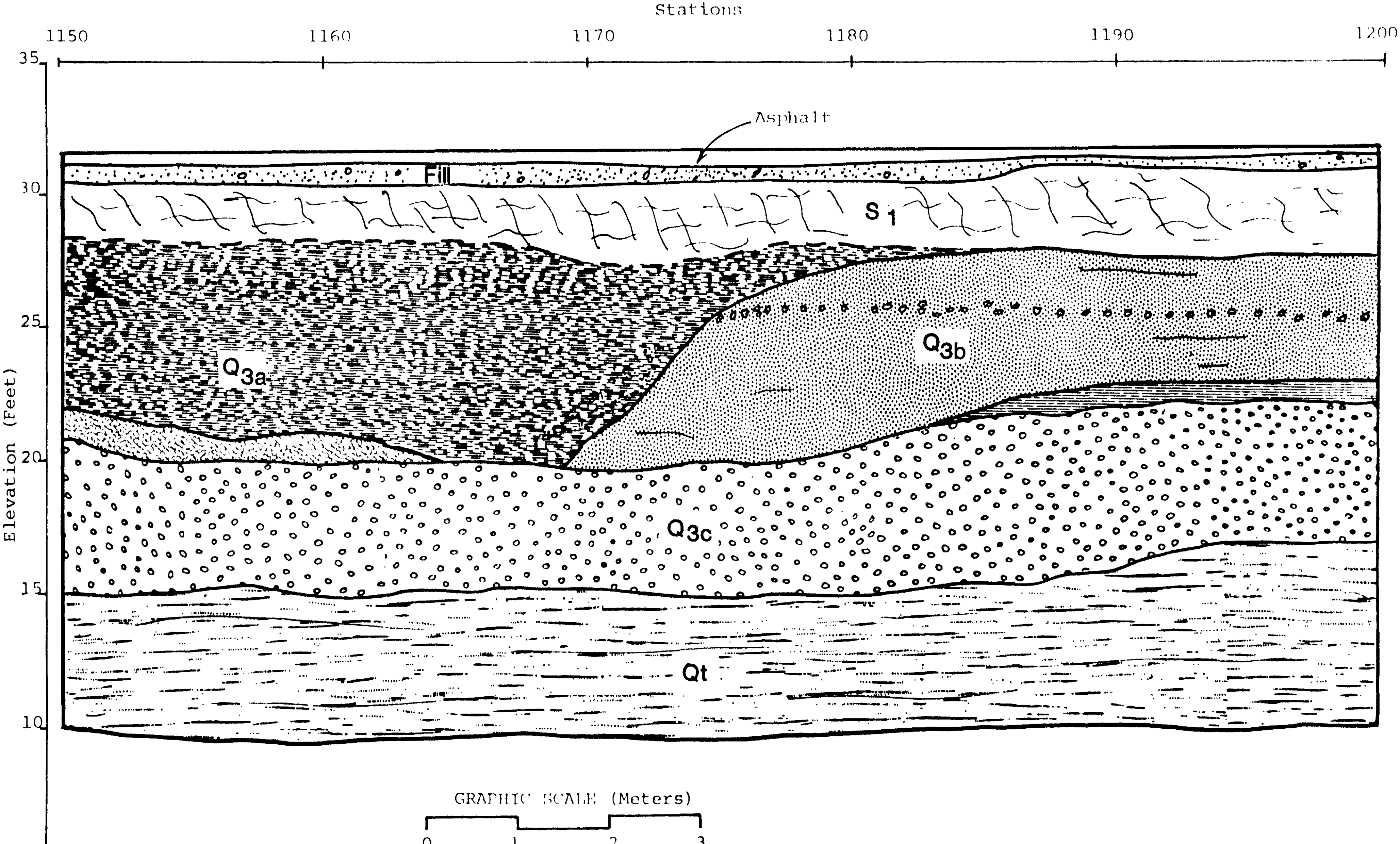
LOG OF TRENCH (WEST WALL)
STATIONS 1050 TO 1100

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GEO1	DATE: 8-25-80	FIGURE NO: A-26



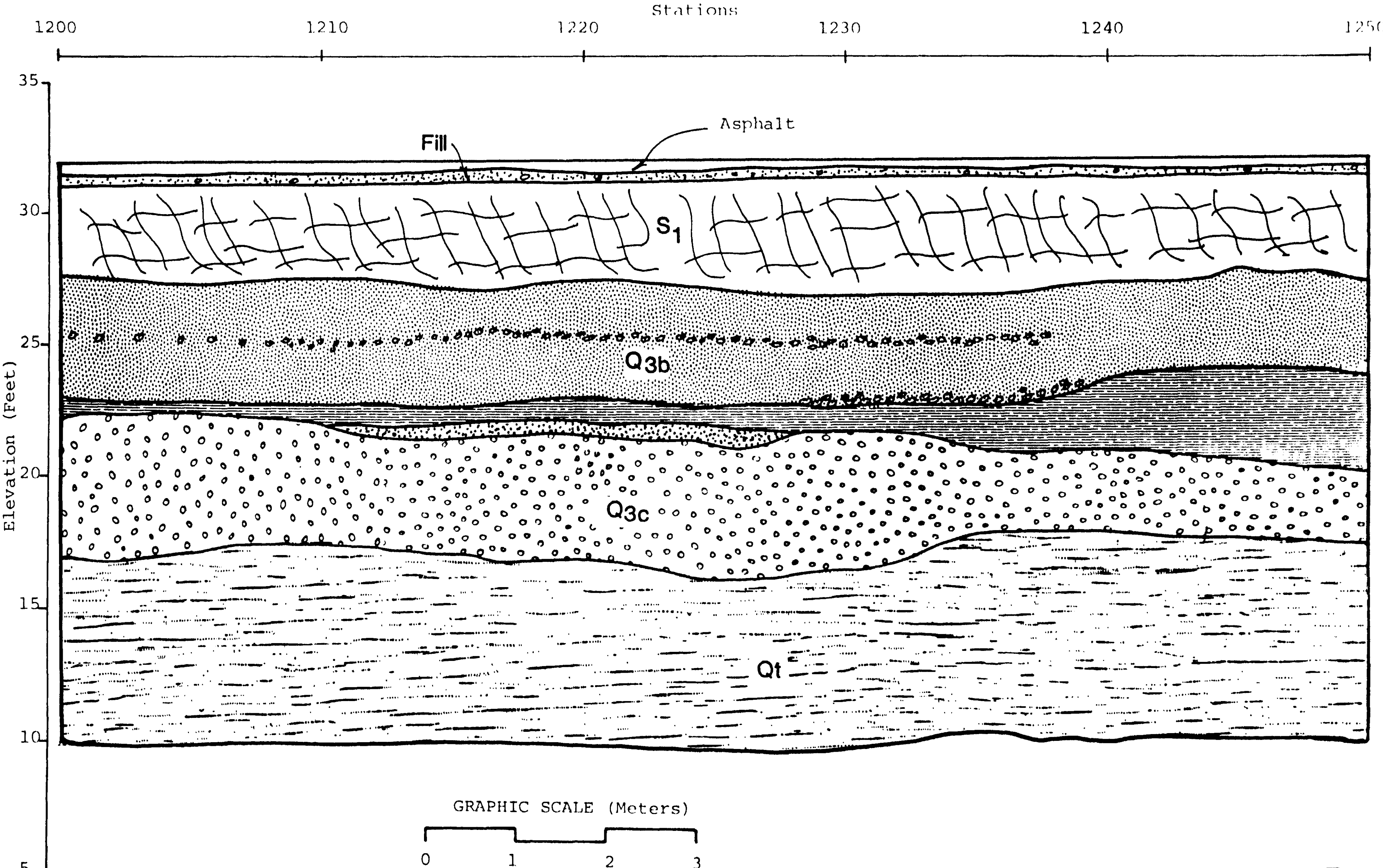
LOG OF TRENCH (WEST WALL)
STATIONS 1100 TO 1150

DRAWN BY: ch	CHECKED BY: GA	PROJECT NO: 50135H-GEO1	DATE: 8-25-80	FIGURE NO: A-?



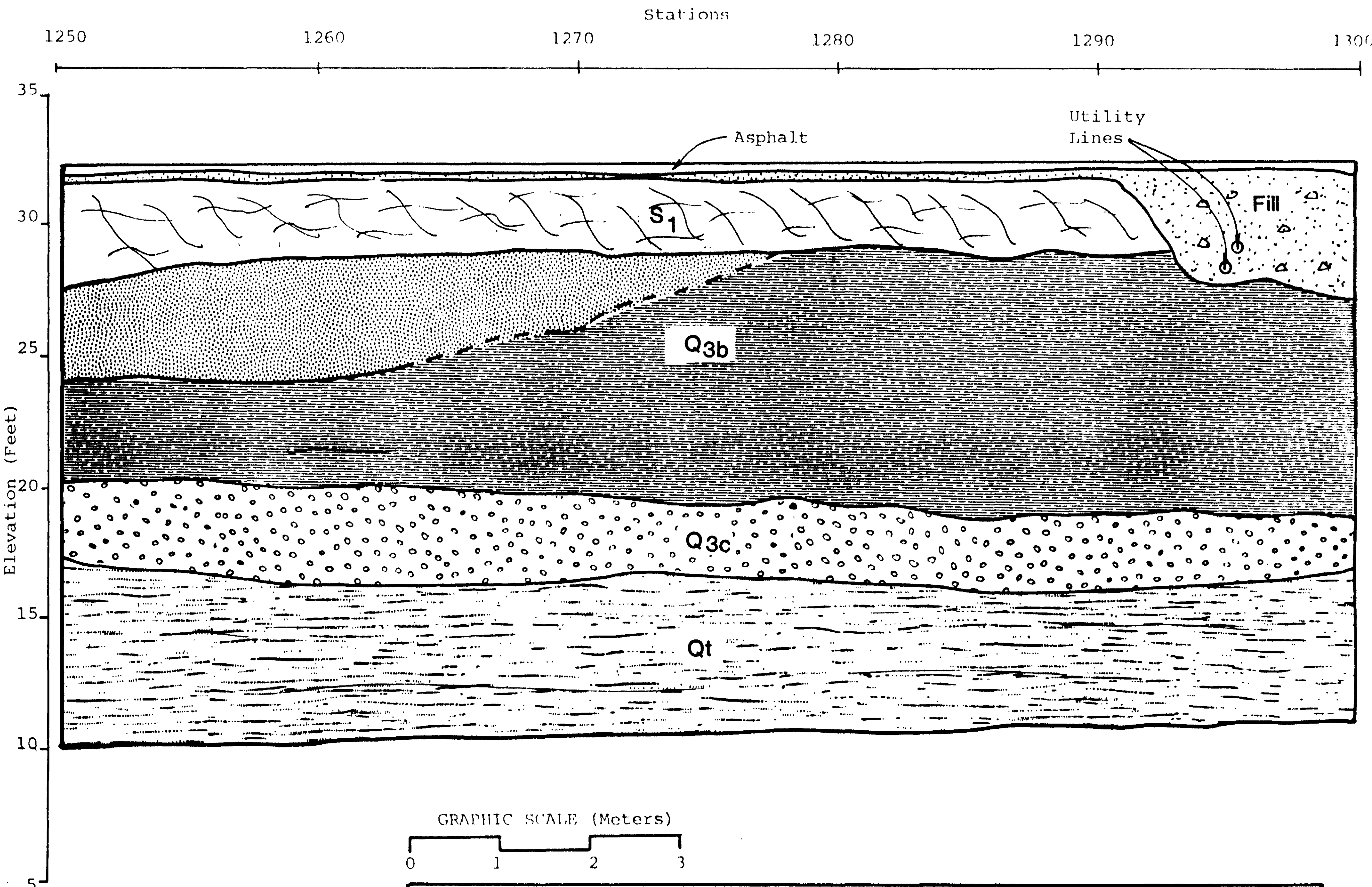
LOG OF TRENCH (WEST WALL)
STATIONS 1150 TO 1200

DRAWN BY: ch	CHECKED BY: GA	PROJECT NO: 50135H-GEO1	DATE: 8-25-80	FIGURE NO: A-28



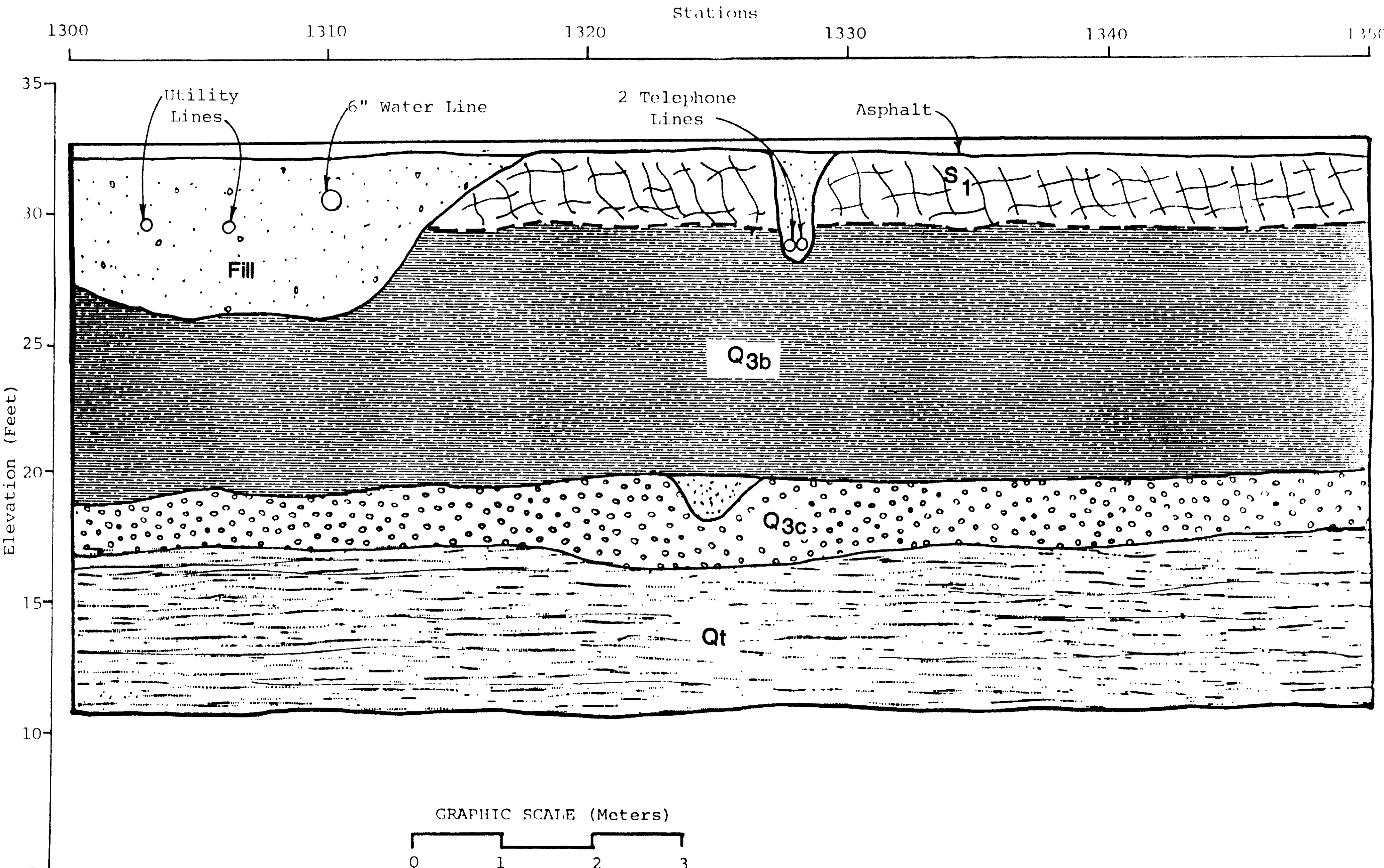
LOG OF TRENCH (WEST WALL)
STATIONS 1200 TO 1250

DRAWN BY: ch	CHECKED BY: GA	PROJECT NO: 50135H-GEOl	DATE: 8-25-80	FIGURE NO: A-29



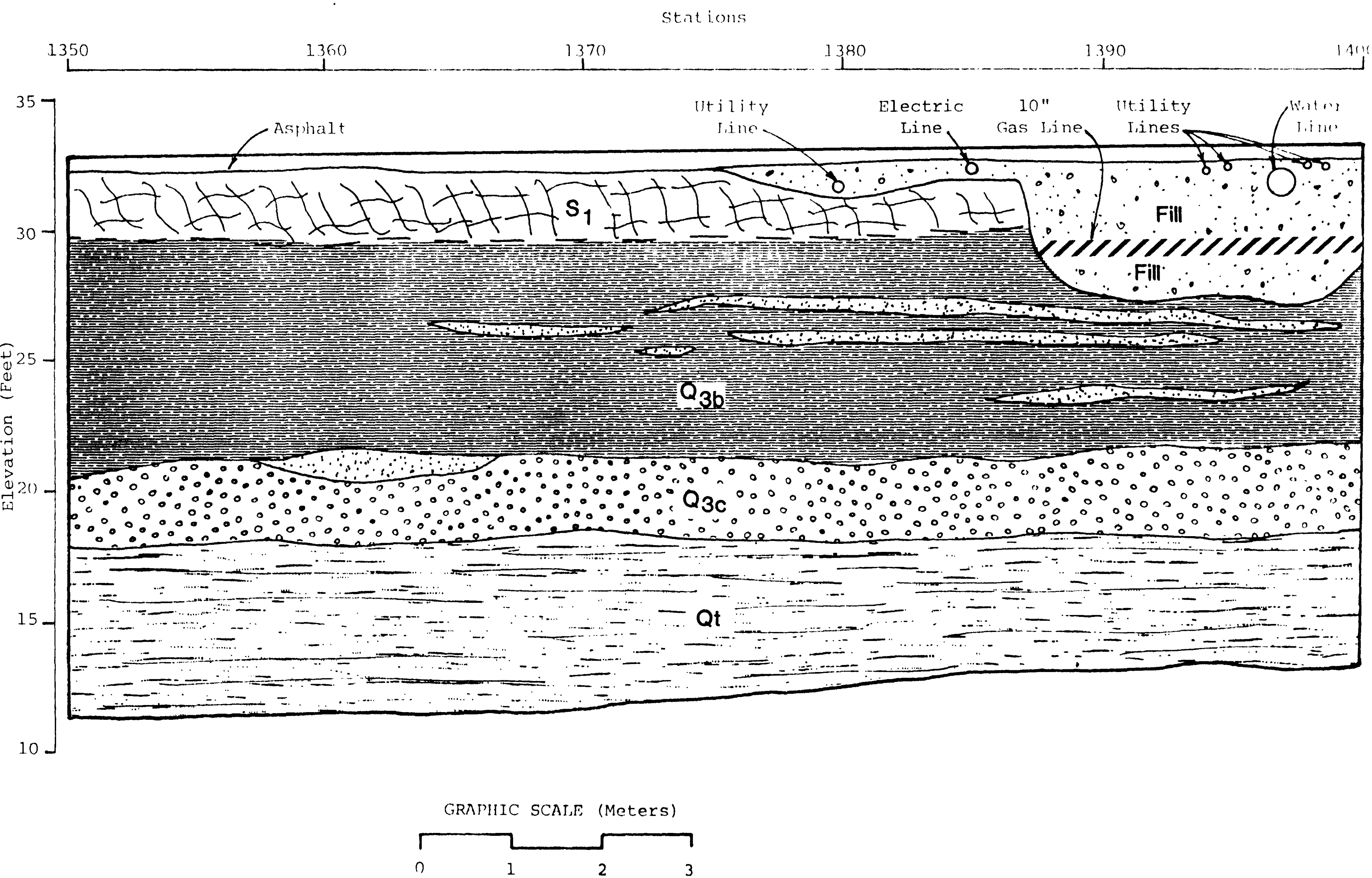
LOG OF TRENCH (WEST WALL)
STATIONS 1250 TO 1300

DRAWN BY: ch	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 8-25-80	FIGURE NO: A-30



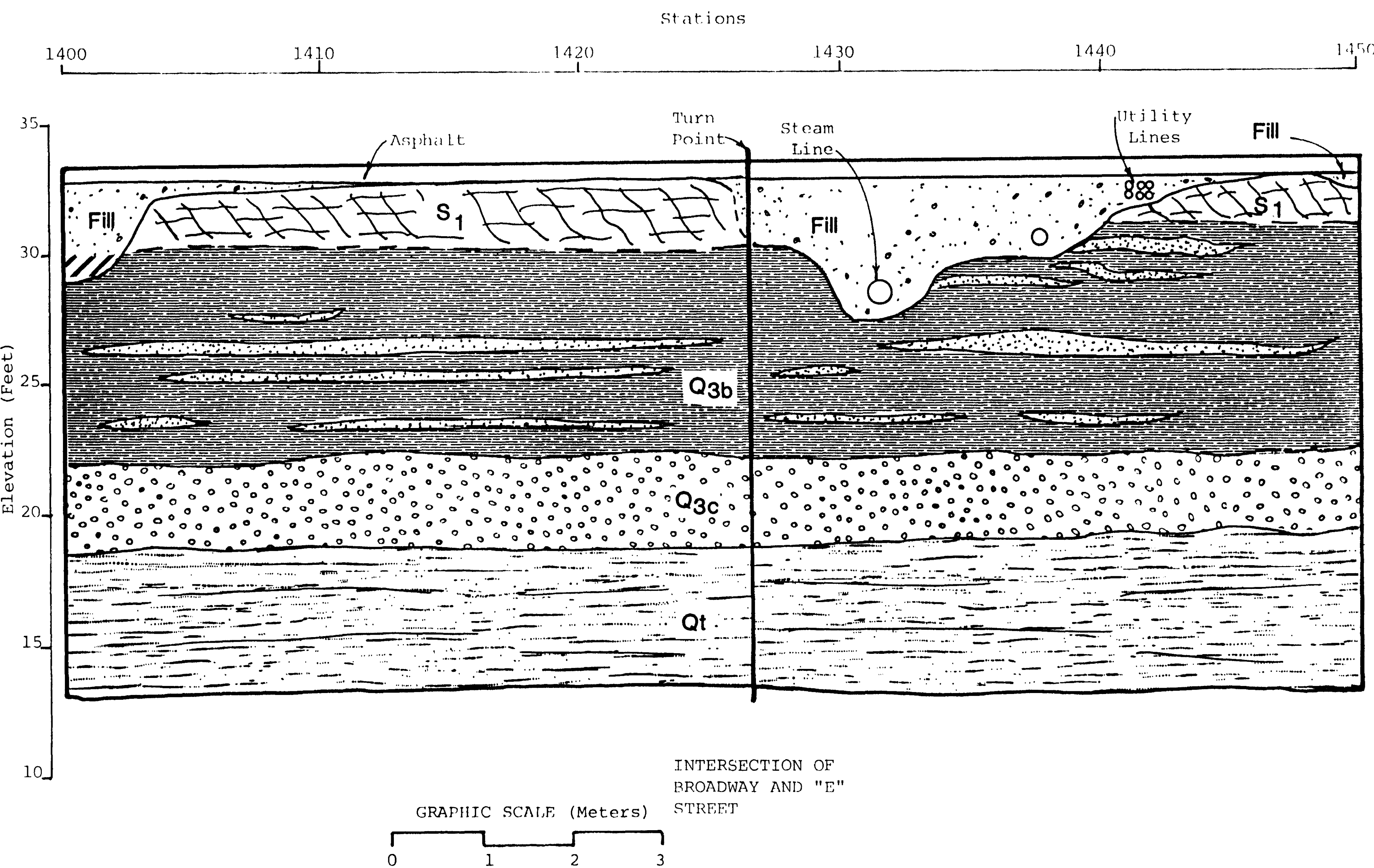
LOG OF TRENCH (WEST WALL)
STATIONS 1300 TO 1350

DRAWN BY: mrk	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-7-80	FIGURE NO: A-31



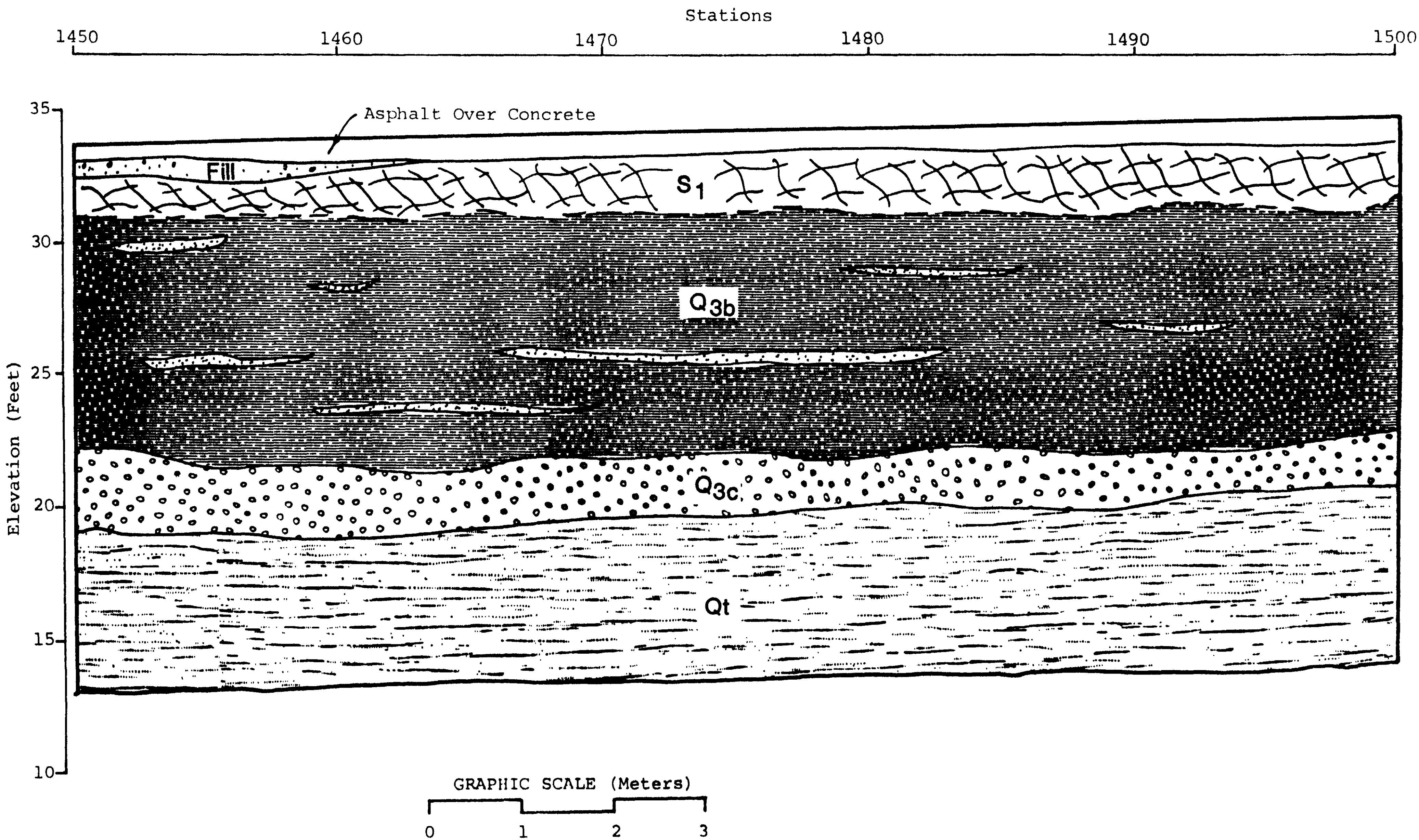
LOG OF TRENCH (WEST WALL)
STATIONS 1350 TO 1400

DRAWN BY: mrk	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 10-7-80	FIGURE NO: A-3?



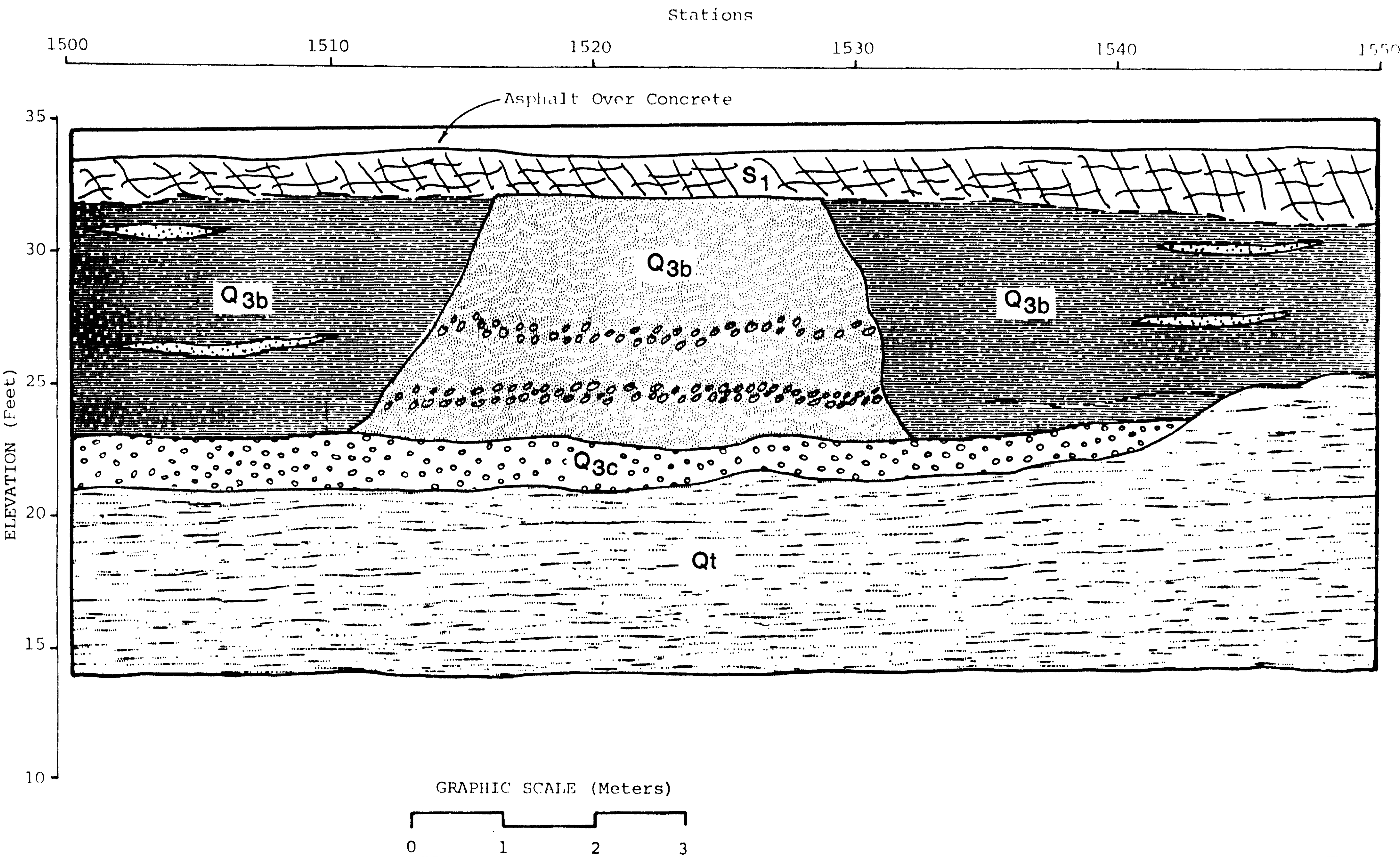
LOG OF TRENCH
STATIONS 1400 TO 1450
WEST WALL TO STATION 1426 - NORTH WALL STATIONS 1426 TO 1450

DRAWN BY: mrk	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-7-80	FIGURE NO: A-33



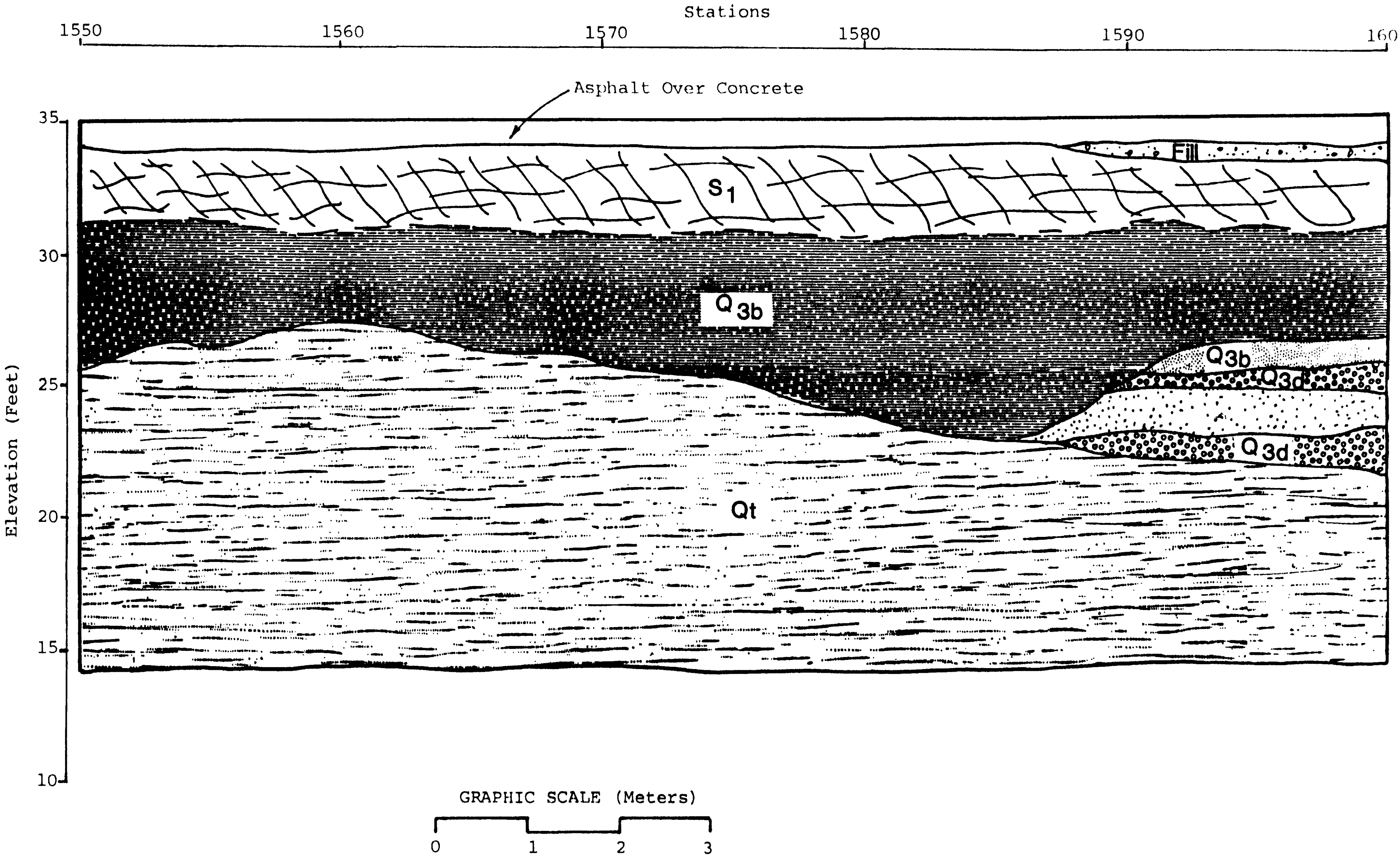
LOG OF TRENCH (NORTH WALL)
STATIONS 1450 TO 1500

DRAWN BY: mrk	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-7-80	FIGURE NO: A-34



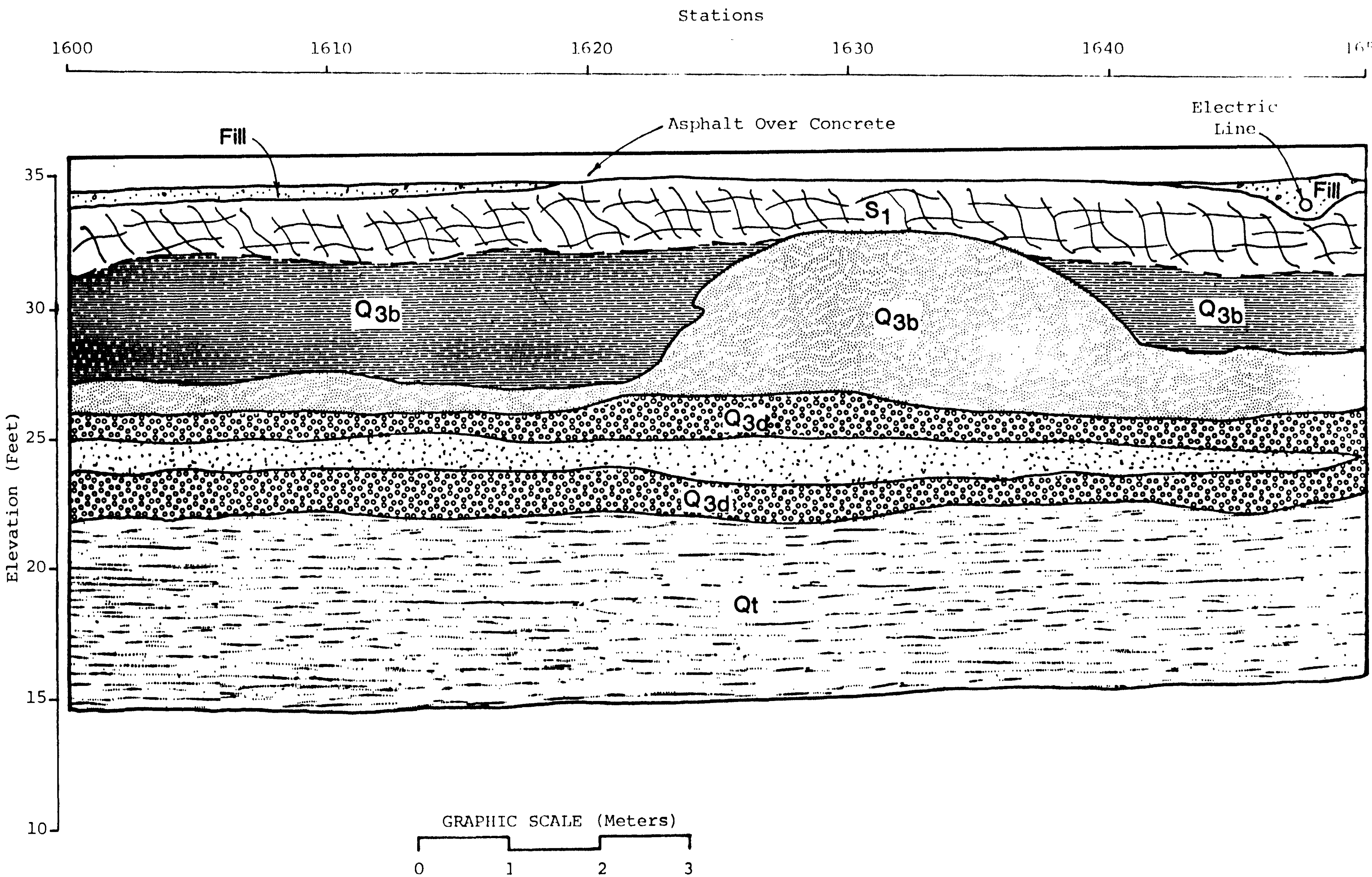
LOG OF TRENCH (NORTH WALL)
STATIONS 1500 TO 1550

DRAWN BY: mrk	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-7-80	FIGURE NO: A-35

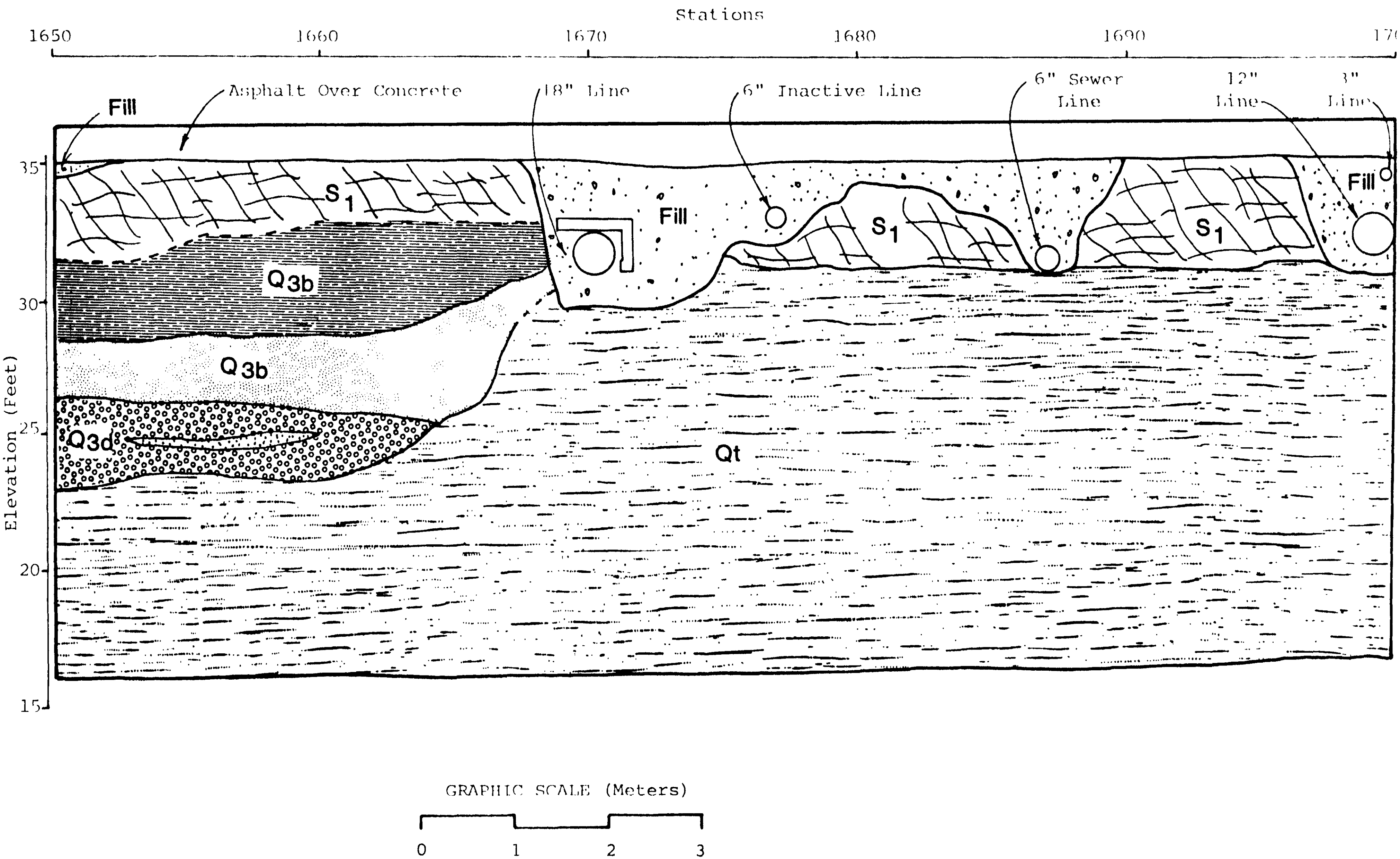


LOG OF TRENCH (NORTH WALL)
STATIONS 1550 TO 1600

DRAWN BY: mrk	CHECKED BY: [illegible]	PROJECT NO: 50135H-GE01	DATE: 10-7-80	FIGURE NO: A-36

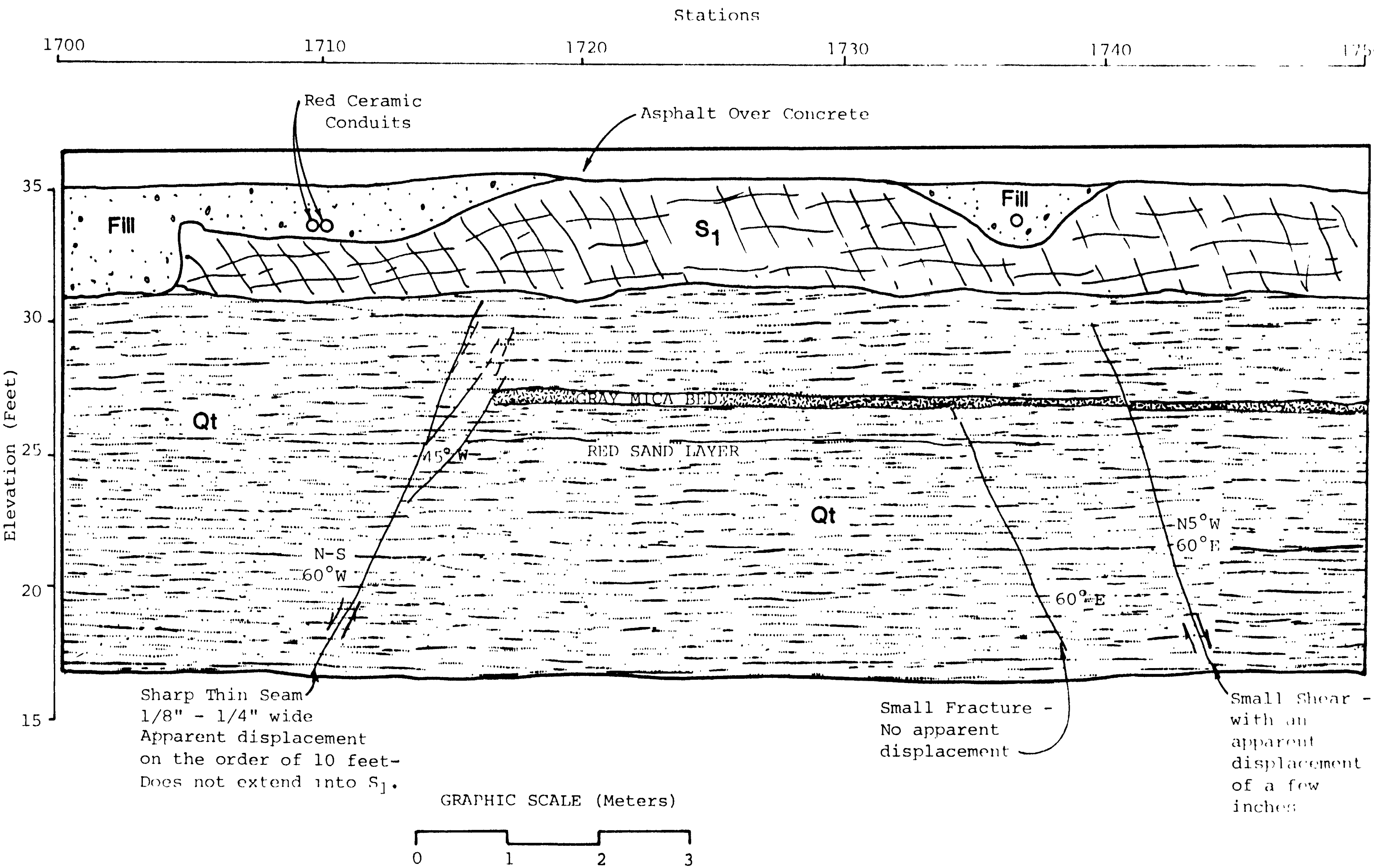


LOG OF TRENCH (NORTH WALL) STATIONS 1600 TO 1650				
DRAWN BY: mrk	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-37

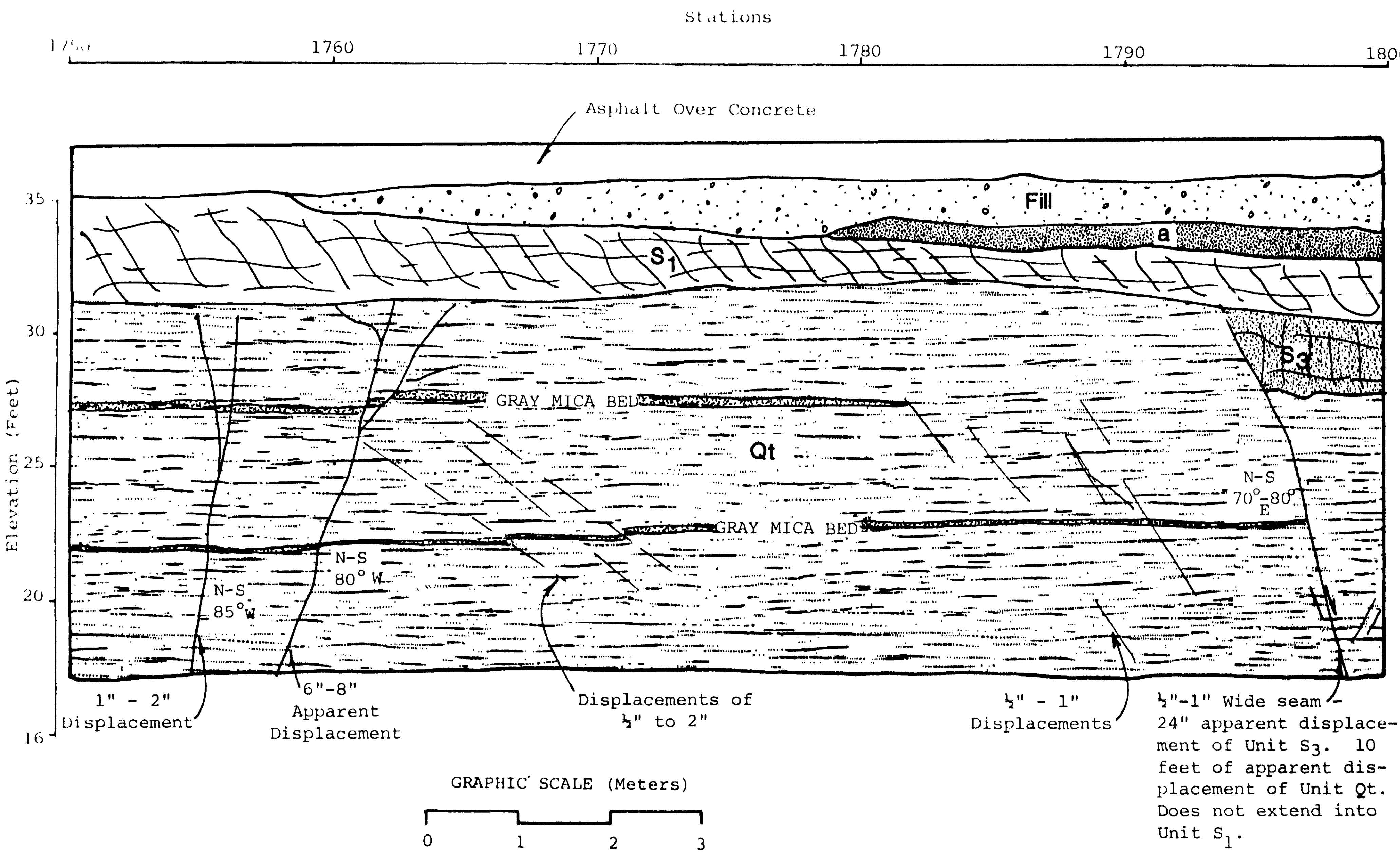


LOG OF TRENCH (NORTH WALL)
STATIONS 1650 TO 1700

DRAWN BY: mrk	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-38

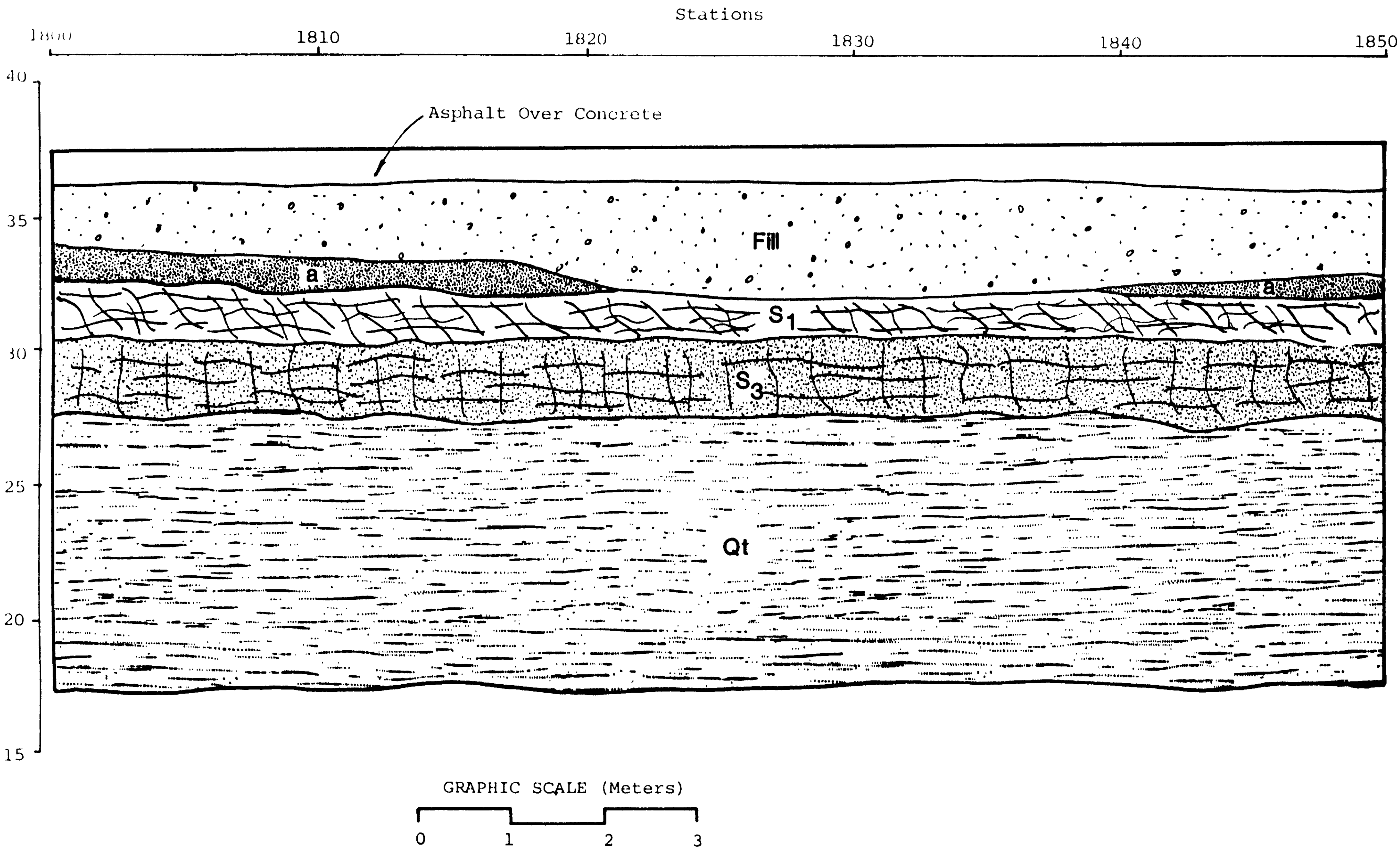


LOG OF TRENCH (NORTH WALL) STATIONS 1700 TO 1750				
DRAWN BY: mrk	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-39



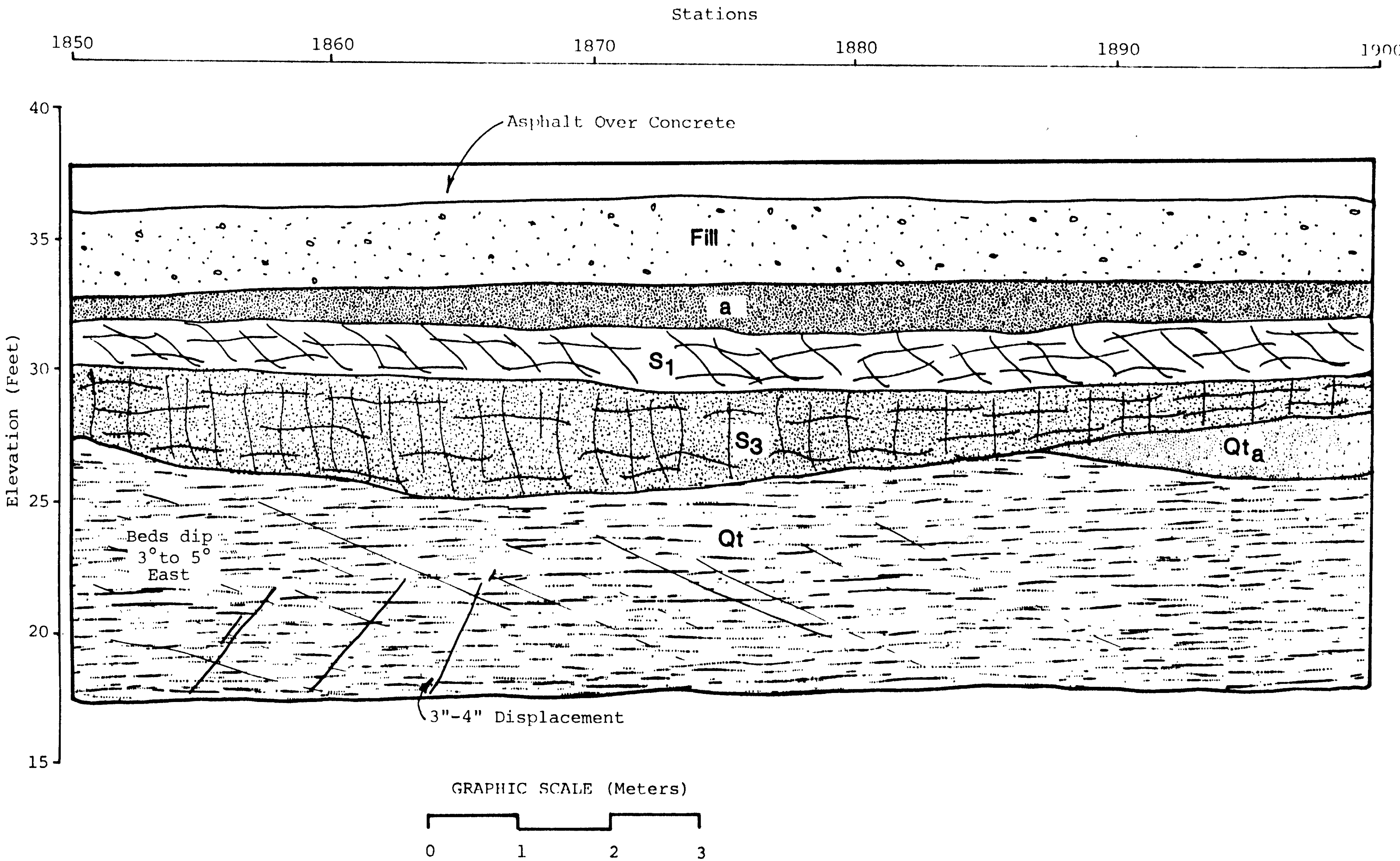
LOG OF TRENCH (NORTH WALL)
STATIONS 1750 TO 1800

DRAWN BY:	CHECKED BY:	PROJECT NO:	DATE:	FIGURE NO:
mrk	EA	50135H-GE01	10-8-80	A-40

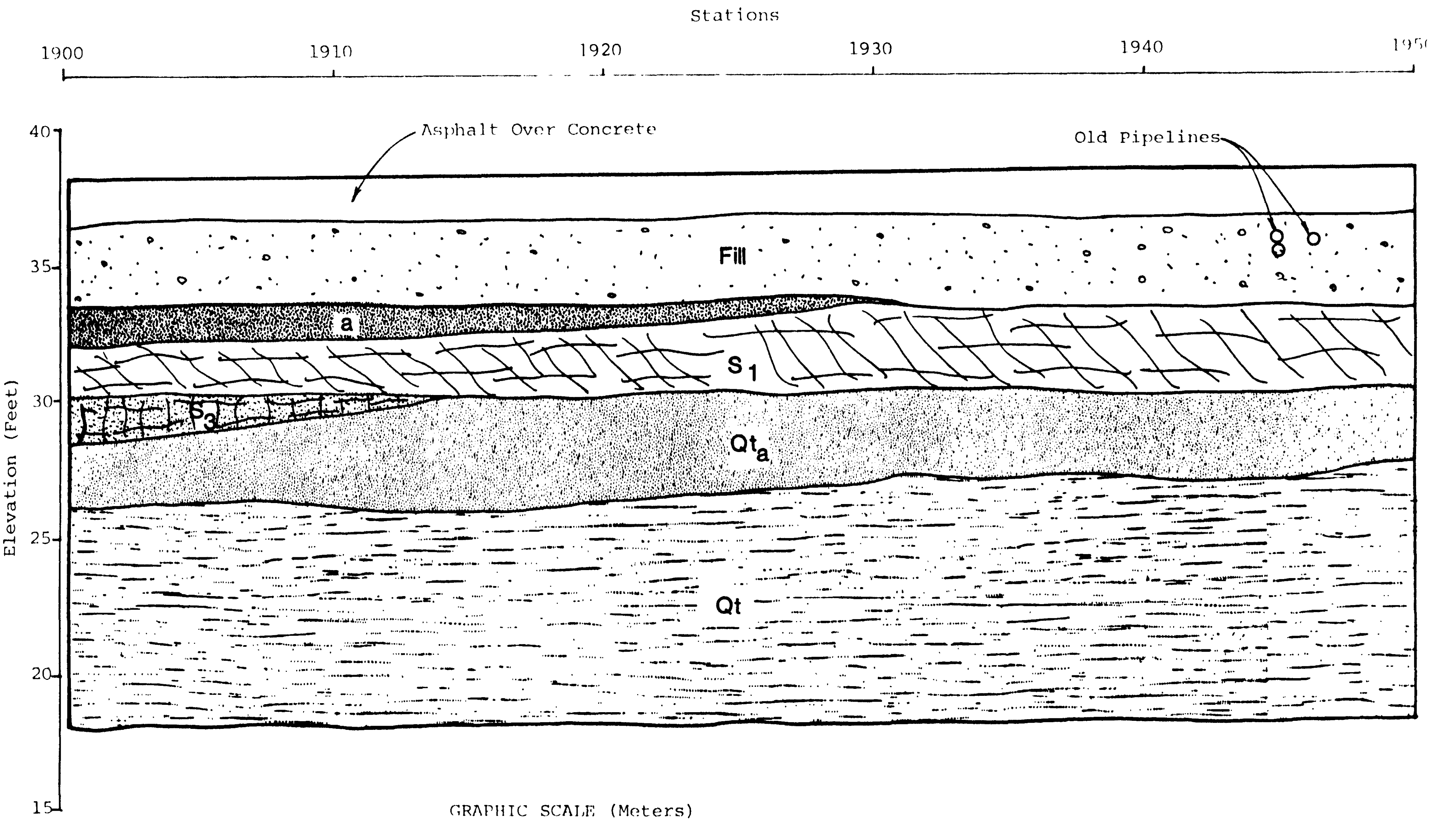


LOG OF TRENCH (NORTH WALL)
STATIONS 1800 TO 1850

DRAWN BY: mrk	CHECKED BY: CA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-41

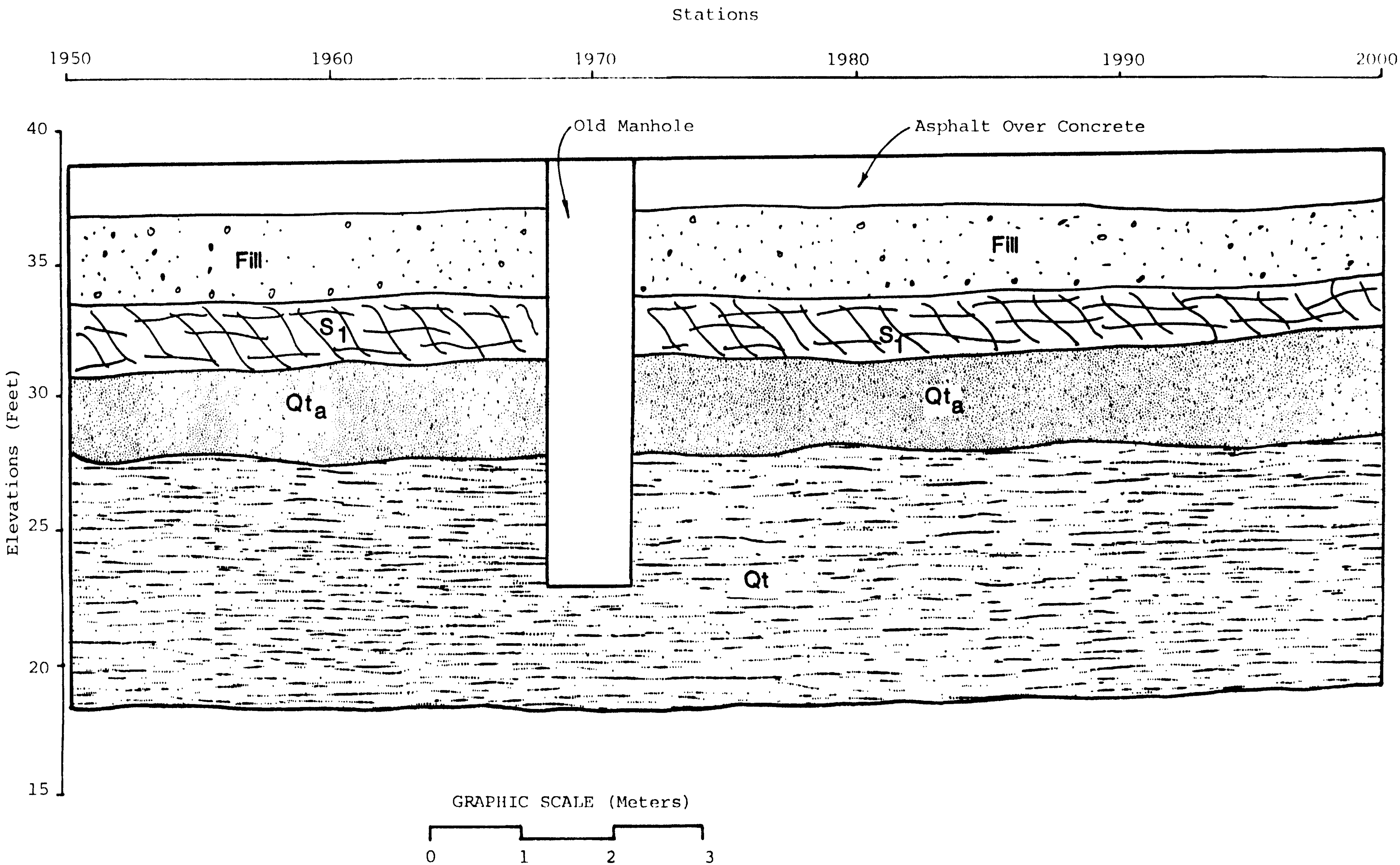


LOG OF TRENCH (NORTH WALL) STAIONS 1850 TO 1900				
DRAWN BY: mrk	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-42



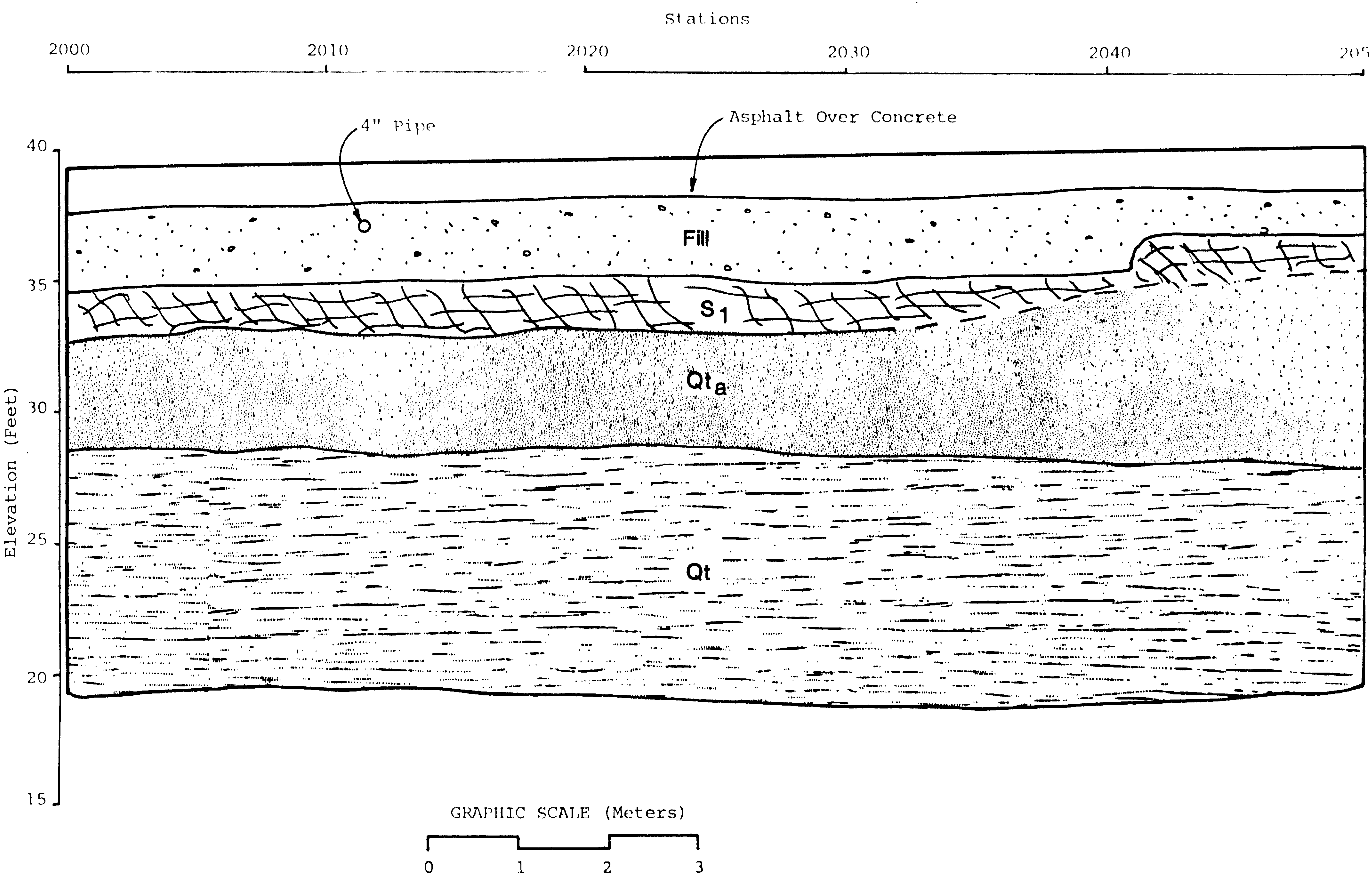
LOG OF TRENCH (NORTH WALL)
STATIONS 1900 TO 1950

DRAWN BY: mrk	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-43



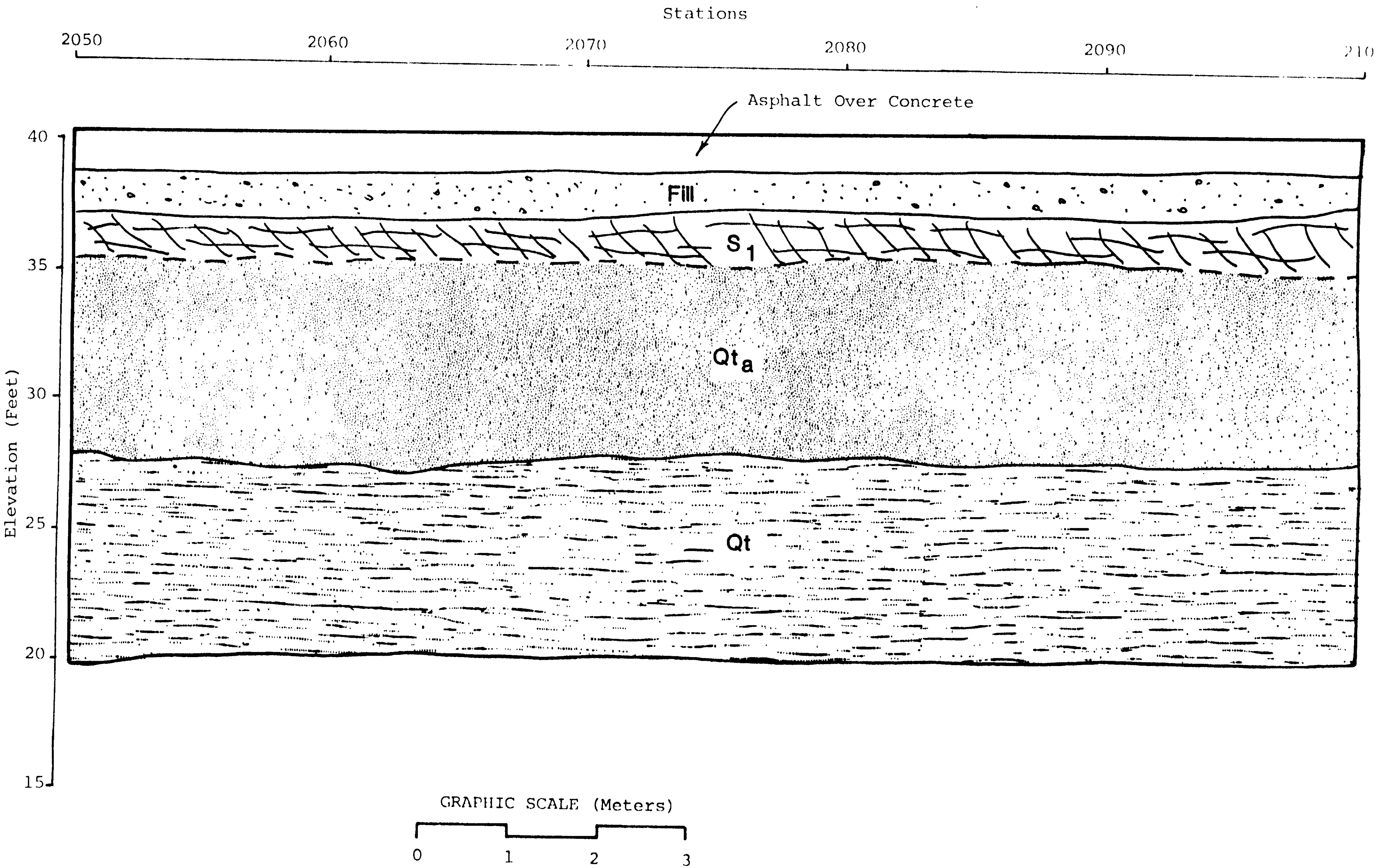
LOG OF TRENCH (NORTH WALL)
STATIONS 1950 TO 2000

DRAWN BY: mrk	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-41

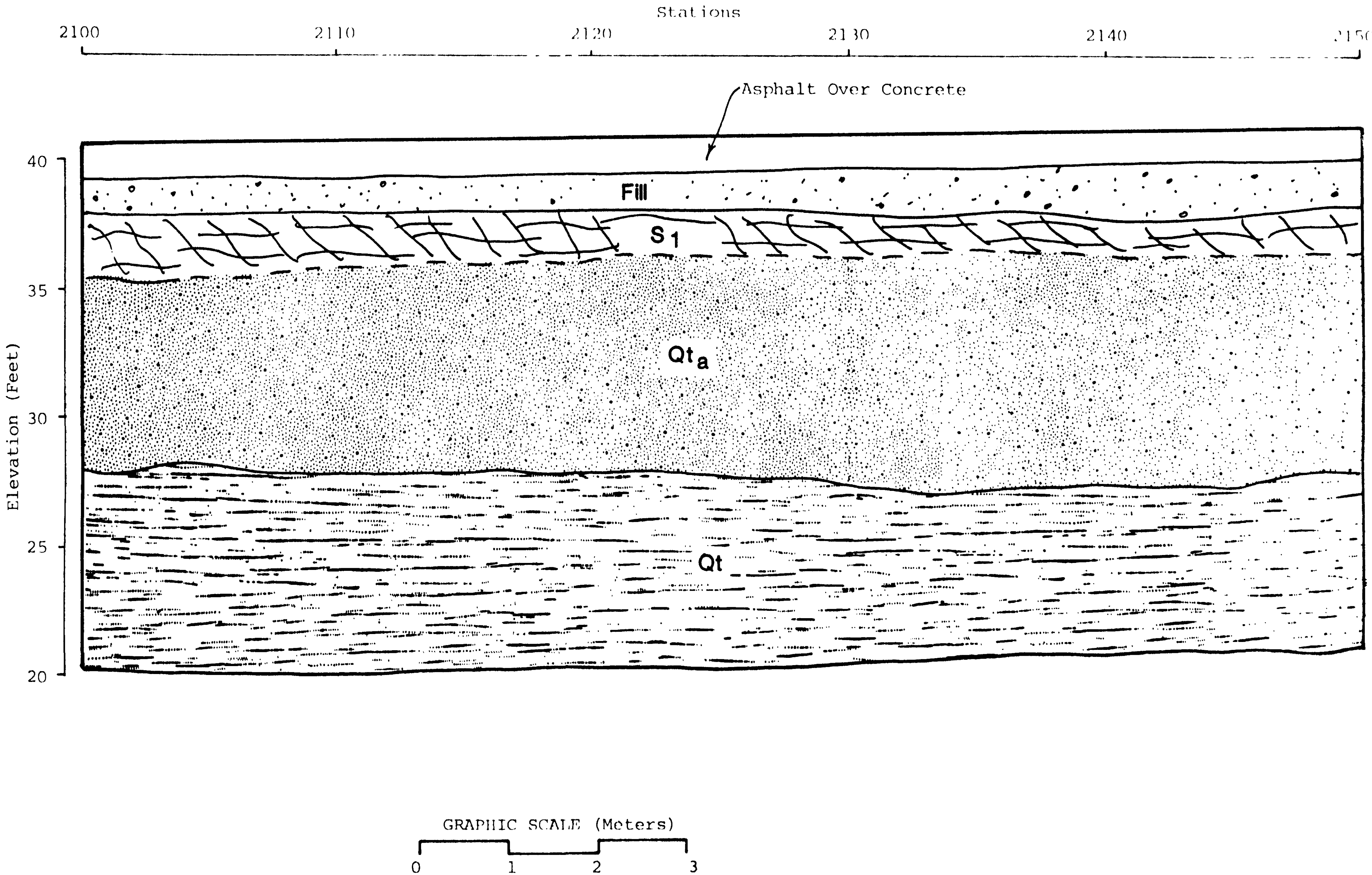


LOG OF TRENCH (NORTH WALL)
STATIONS 2000 TO 2050

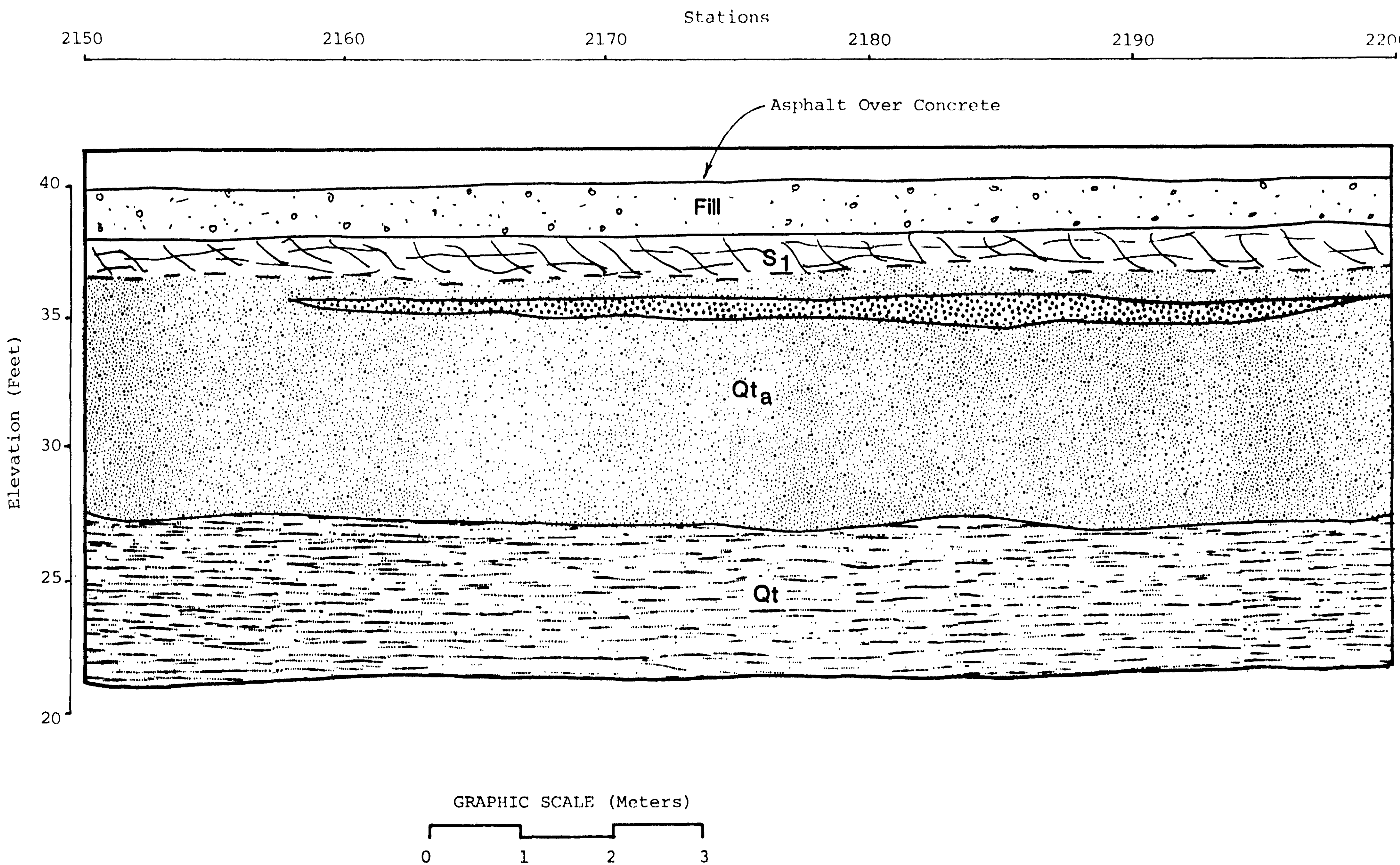
DRAWN BY: mrk	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-45



LOG OF TRENCH (NORTH WALL) STATIONS 2050 TO 2100				
DRAWN BY: mrk	**CHECKED BY:** EA	**PROJECT NO:** 50135H-GE01	**DATE:** 10-8-80	**FIGURE NO:** A-46

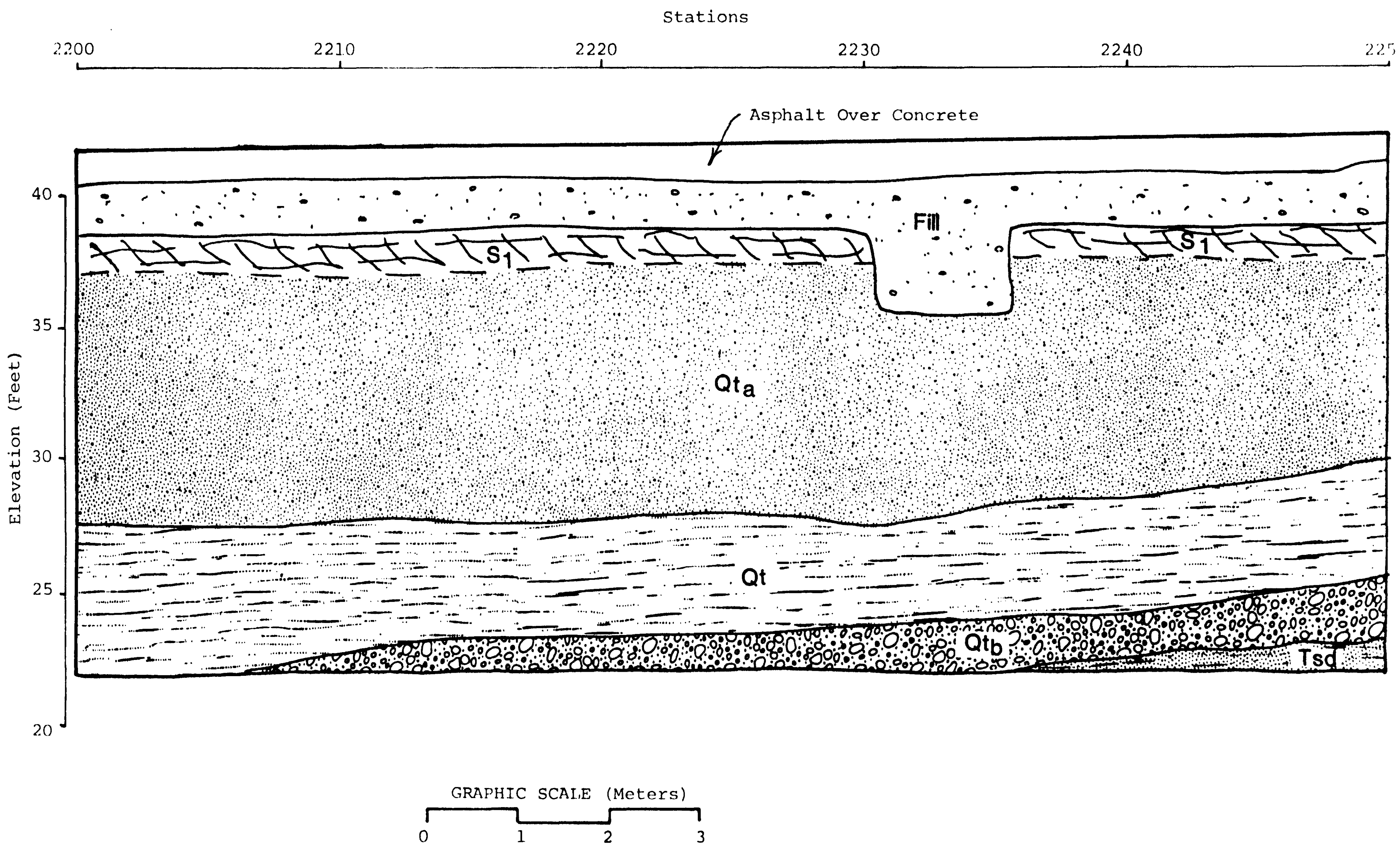


LOG OF TRENCH (NORTH WALL) STATIONS 2100 TO 2150				
DRAWN BY: mrk	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-47



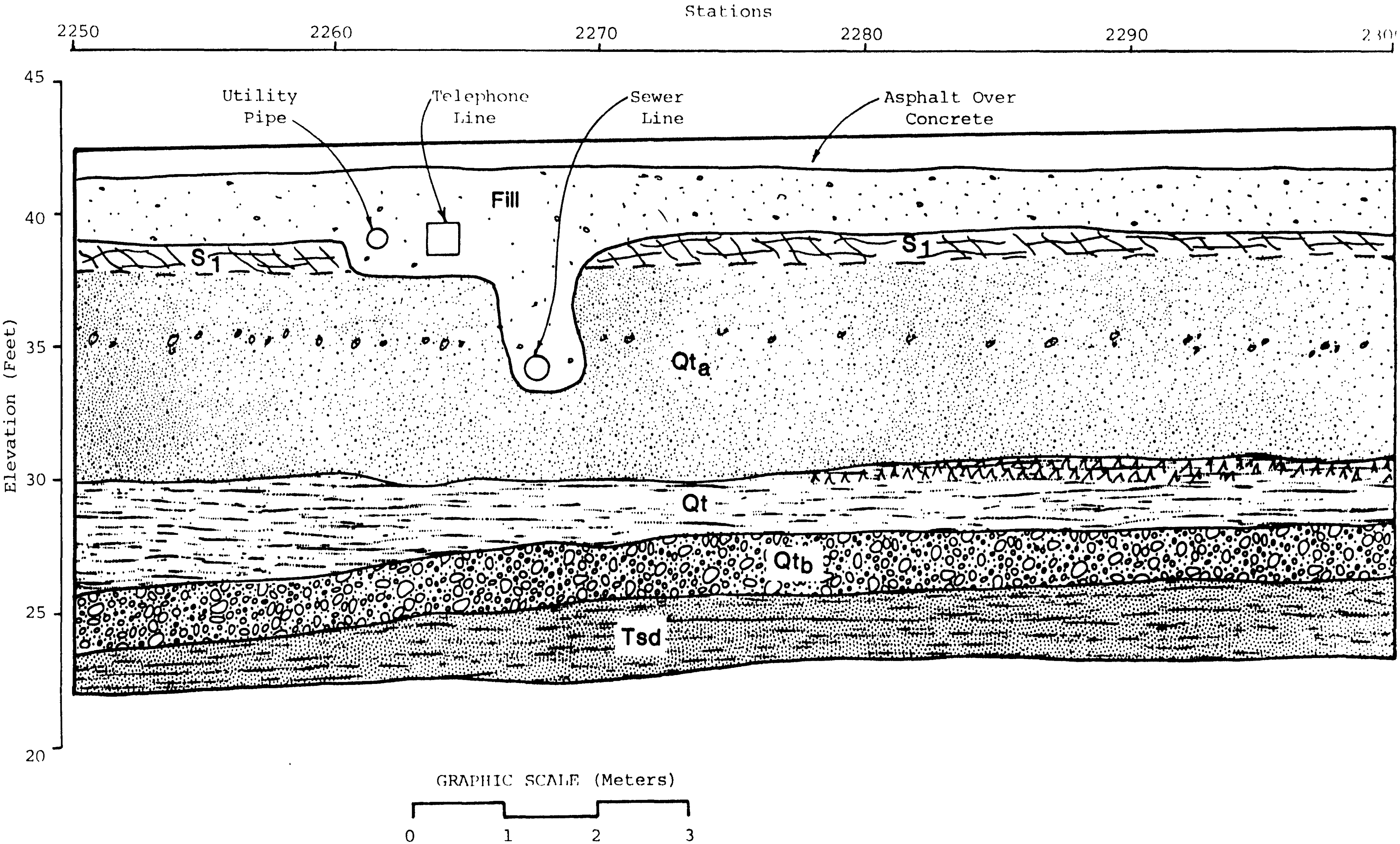
LOG OF TRENCH (NORTH WALL)
STATIONS 2150 TO 2200

DRAWN BY: mrk	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-48



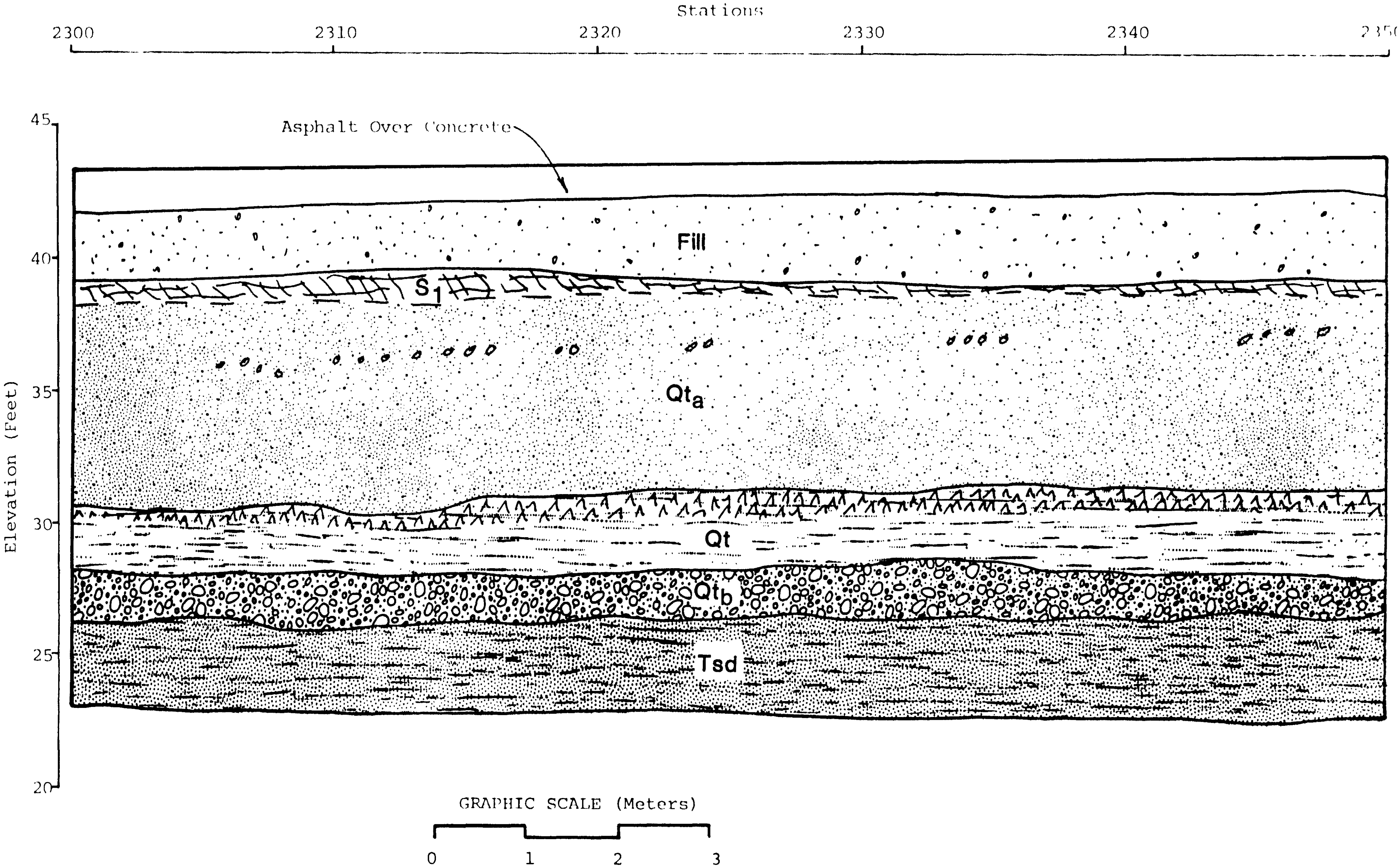
LOG OF TRENCH (NORTH WALL)
STATIONS 2200 TO 2250

DRAWN BY: mrk	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-49



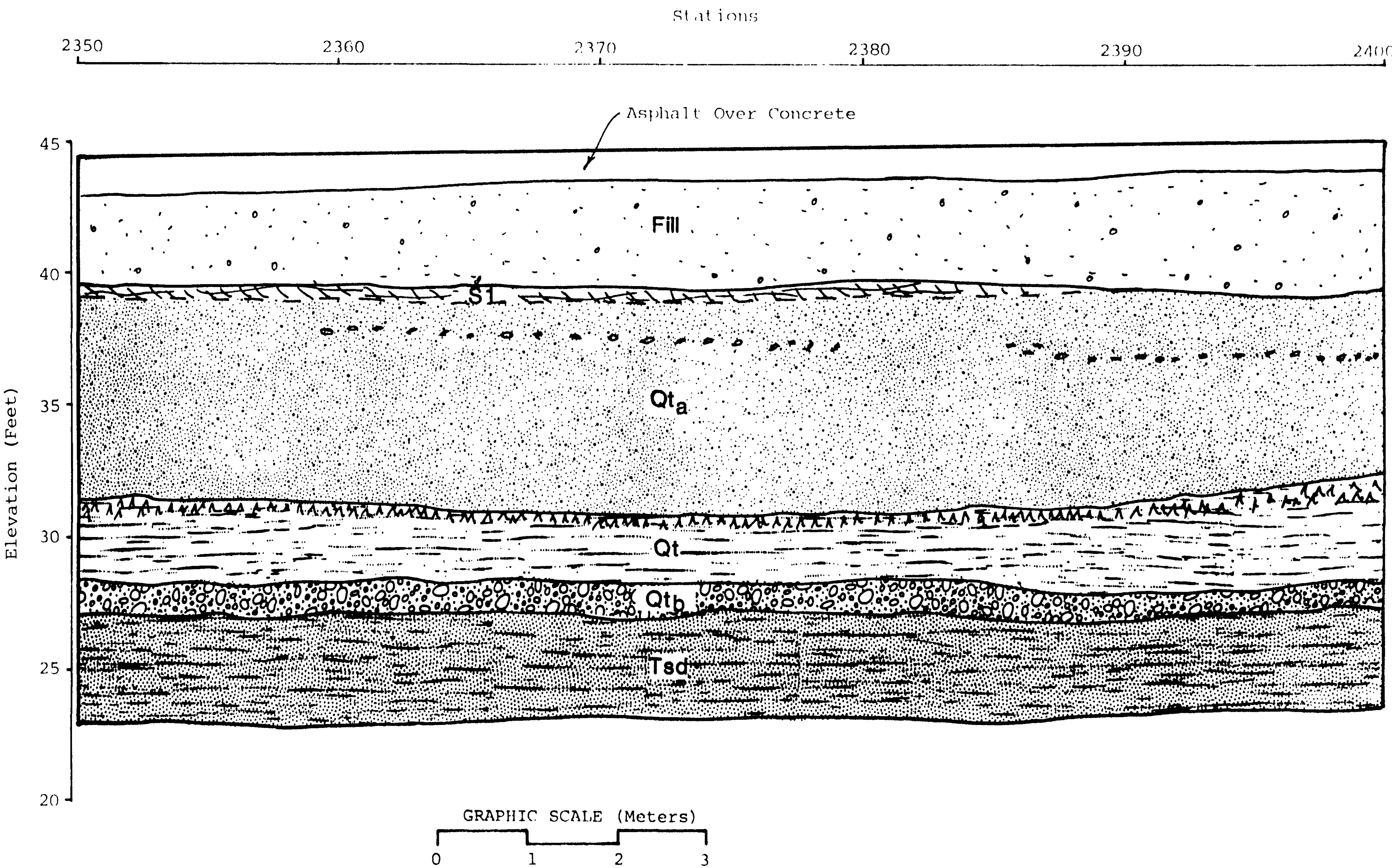
LOG OF TRENCH (NORTH WALL)
STATIONS 2250 TO 2300

DRAWN BY: mrk	CHECKED BY: ER	PROJECT NO: 50135H-GE01	DATE: 10-10-80	FIGURE NO: A-50



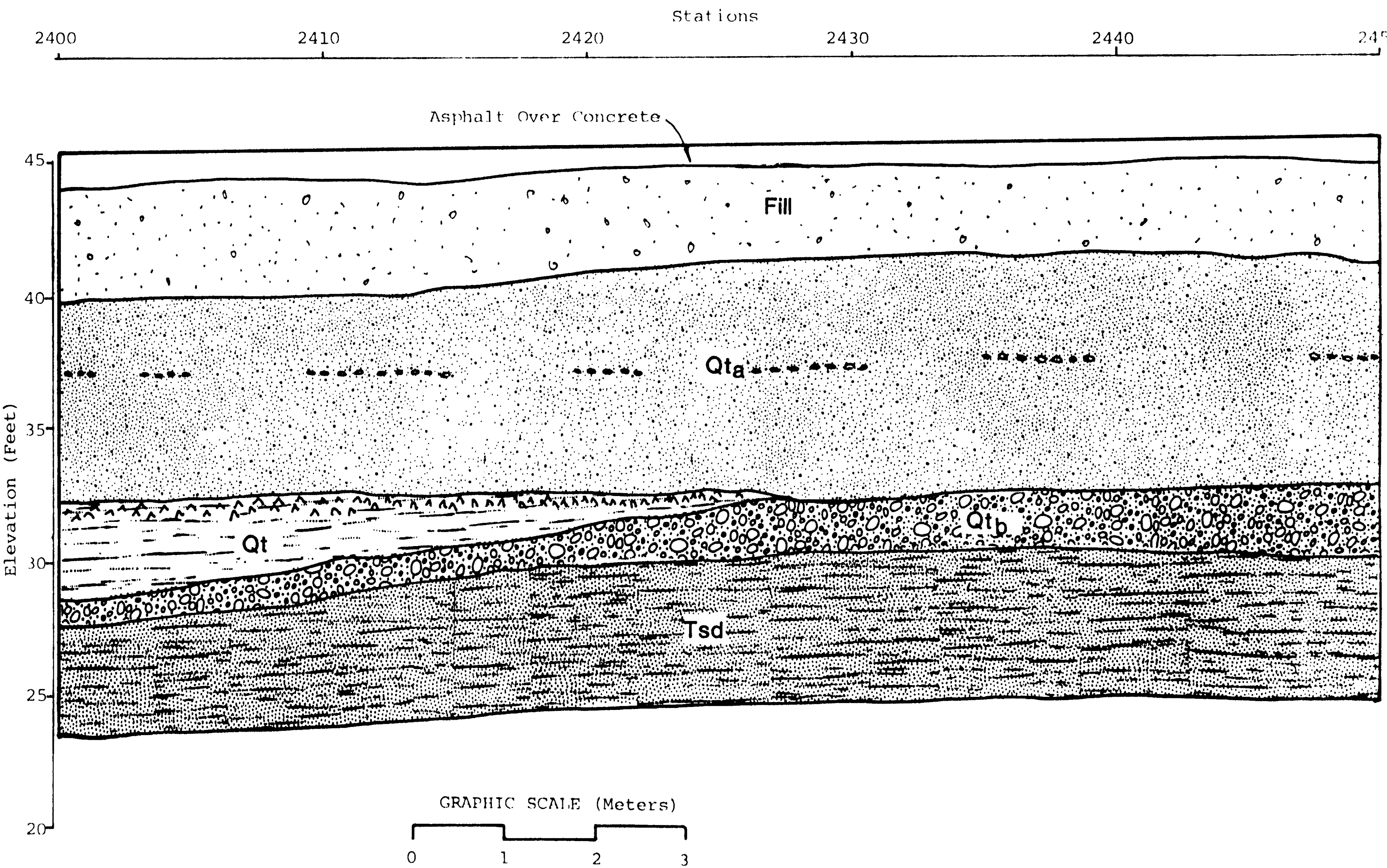
LOG OF TRENCH (NORTH WALL) . STATIONS 2300 TO 2350

DRAWN BY: mrk	**CHECKED BY:** EA	**PROJECT NO:** 50135H-GE01	**DATE:** 10-10-80	**FIGURE NO:** A-51



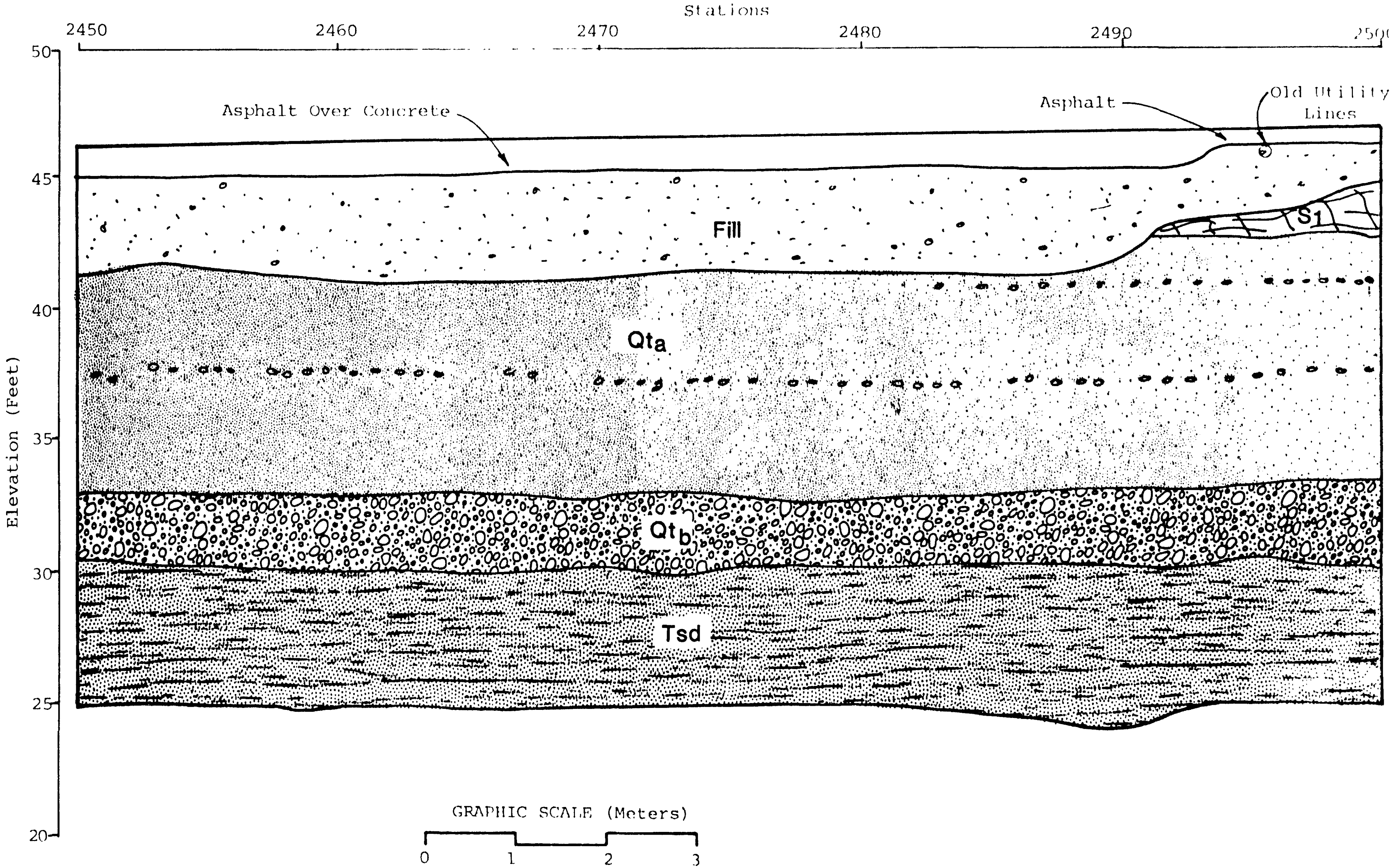
LOG OF TRENCH (NORTH WALL)
STATIONS 2350 TO 2400

DRAWN BY: mrk	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-10-80	FIGURE NO: A-52



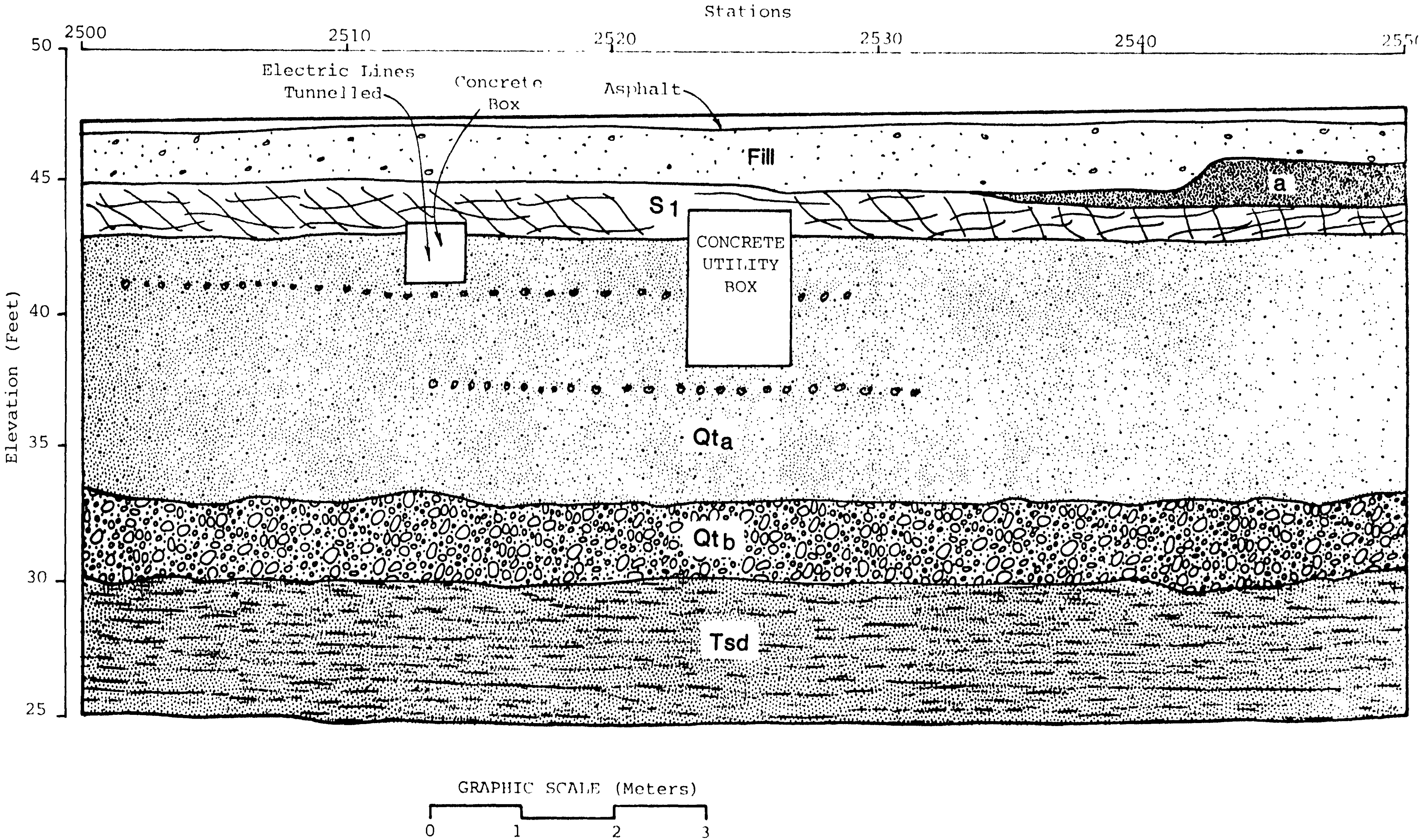
LOG OF TRENCH (NORTH WALL)
STATIONS 2400 TO 2450

DRAWN BY: mrk	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 10-10-80	FIGURE NO: A-53

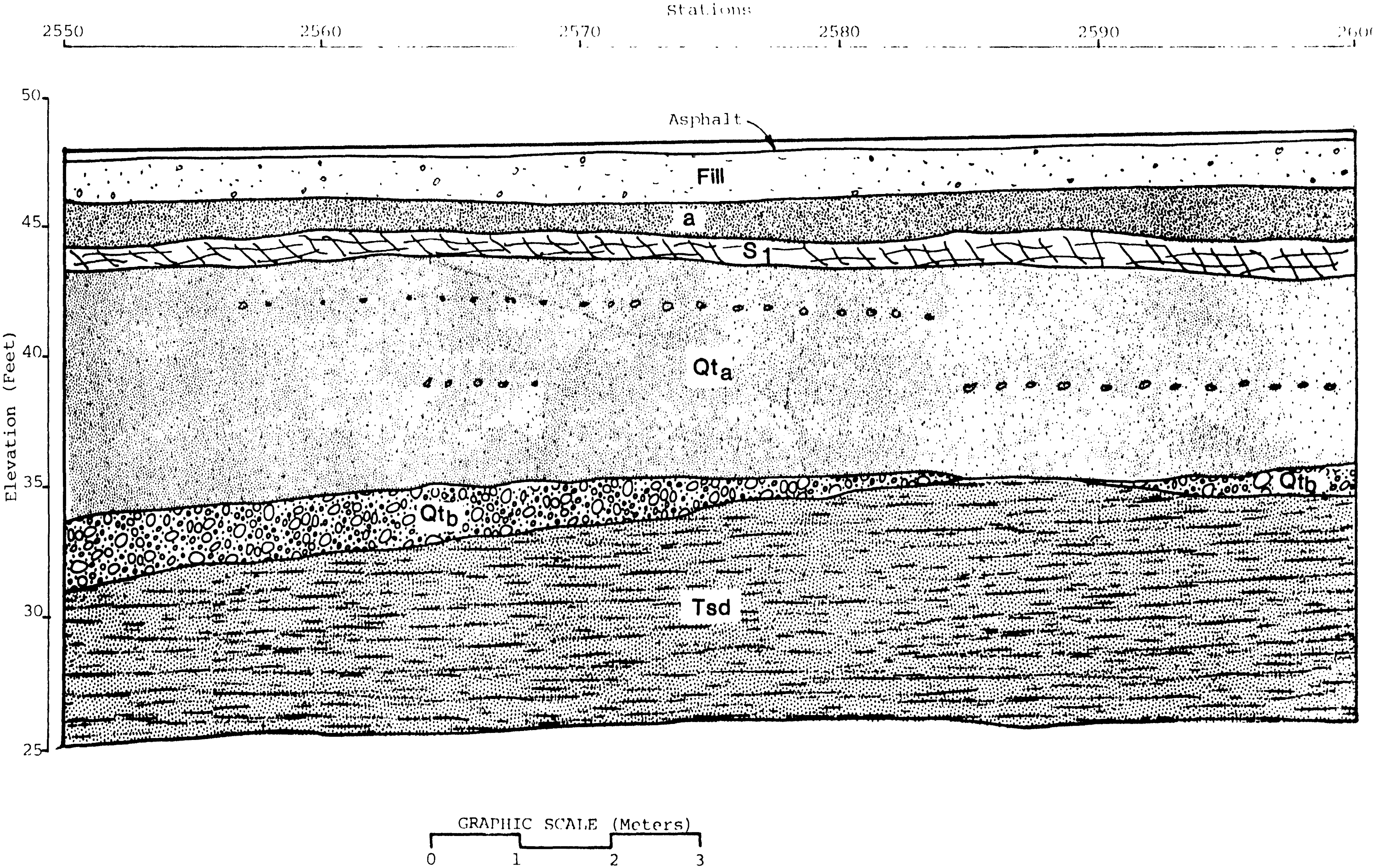


LOG OF TRENCH (NORTH WALL)
STATIONS 2550 TO 2600

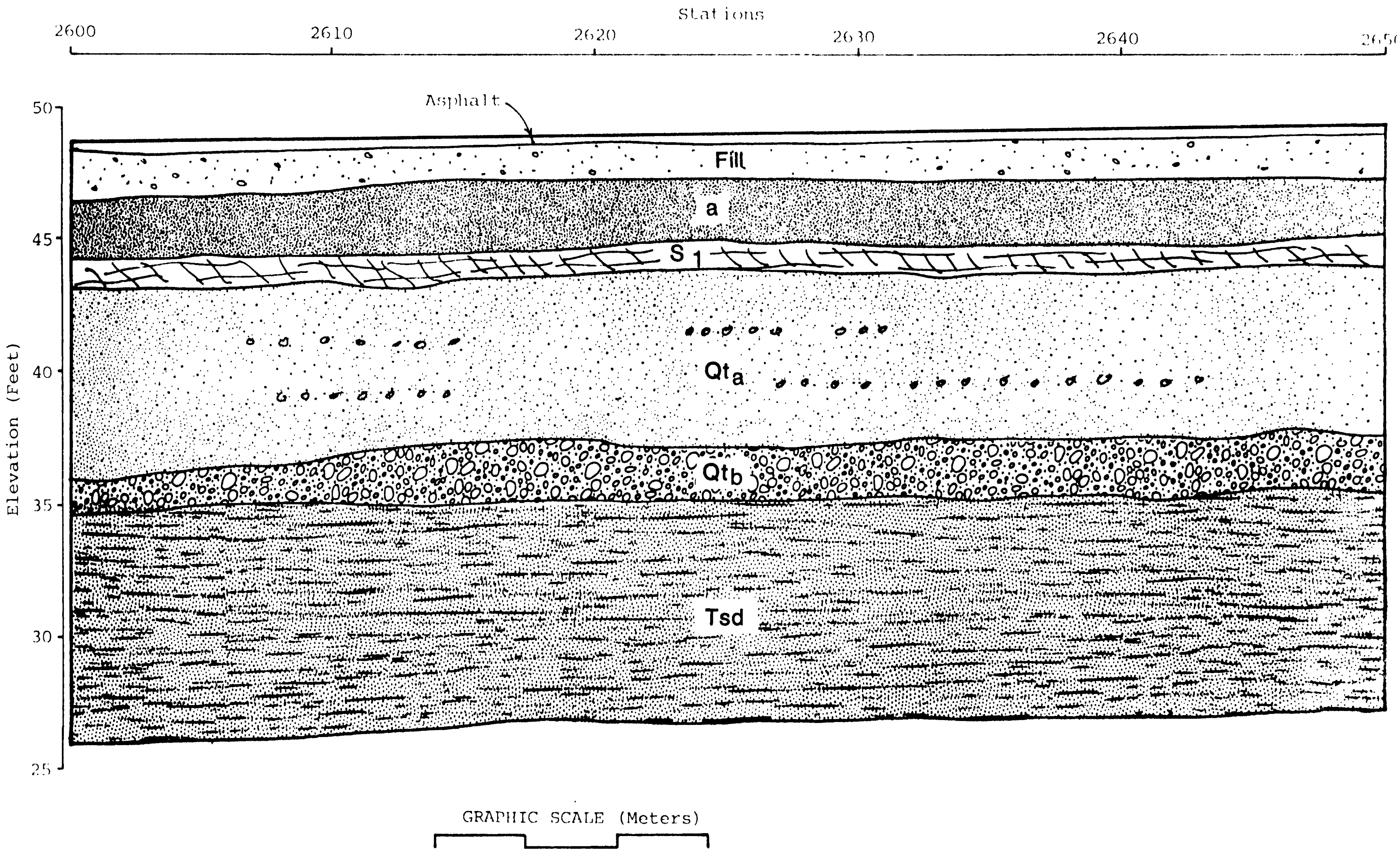
DRAWN BY: mrk	**CHECKED BY:** EA	**PROJECT NO:** 50135H-GE01	**DATE:** 10-8-80	**FIGURE NO:** A-54



LOG OF TRENCH (NORTH WALL) STATIONS 2500 TO 2550				
DRAWN BY: mrk	CHECKED BY: ED	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-55

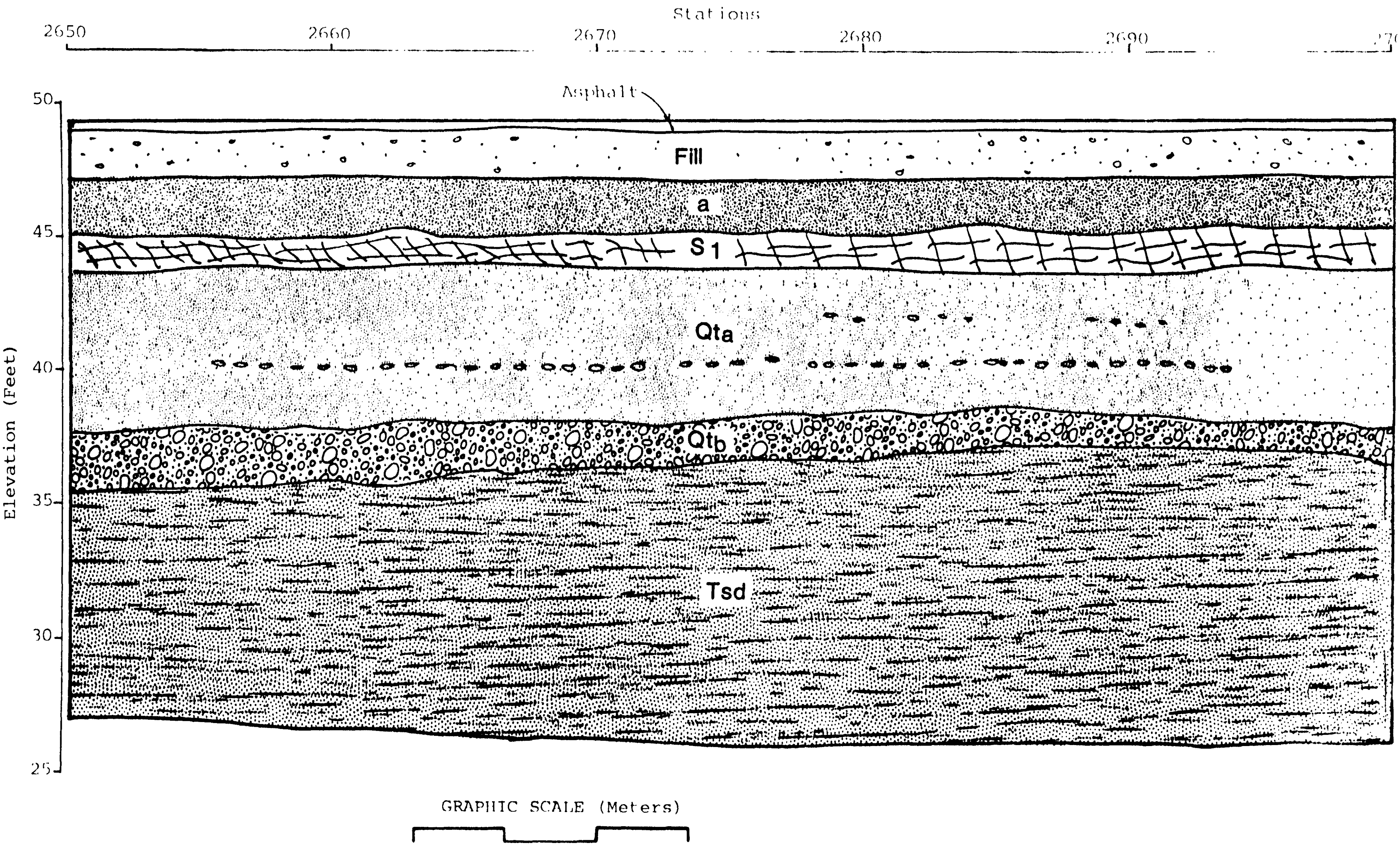


LOG OF TRENCH (NORTH WALL) STATIONS 2550 TO 2600				
DRAWN BY: mjk	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-56

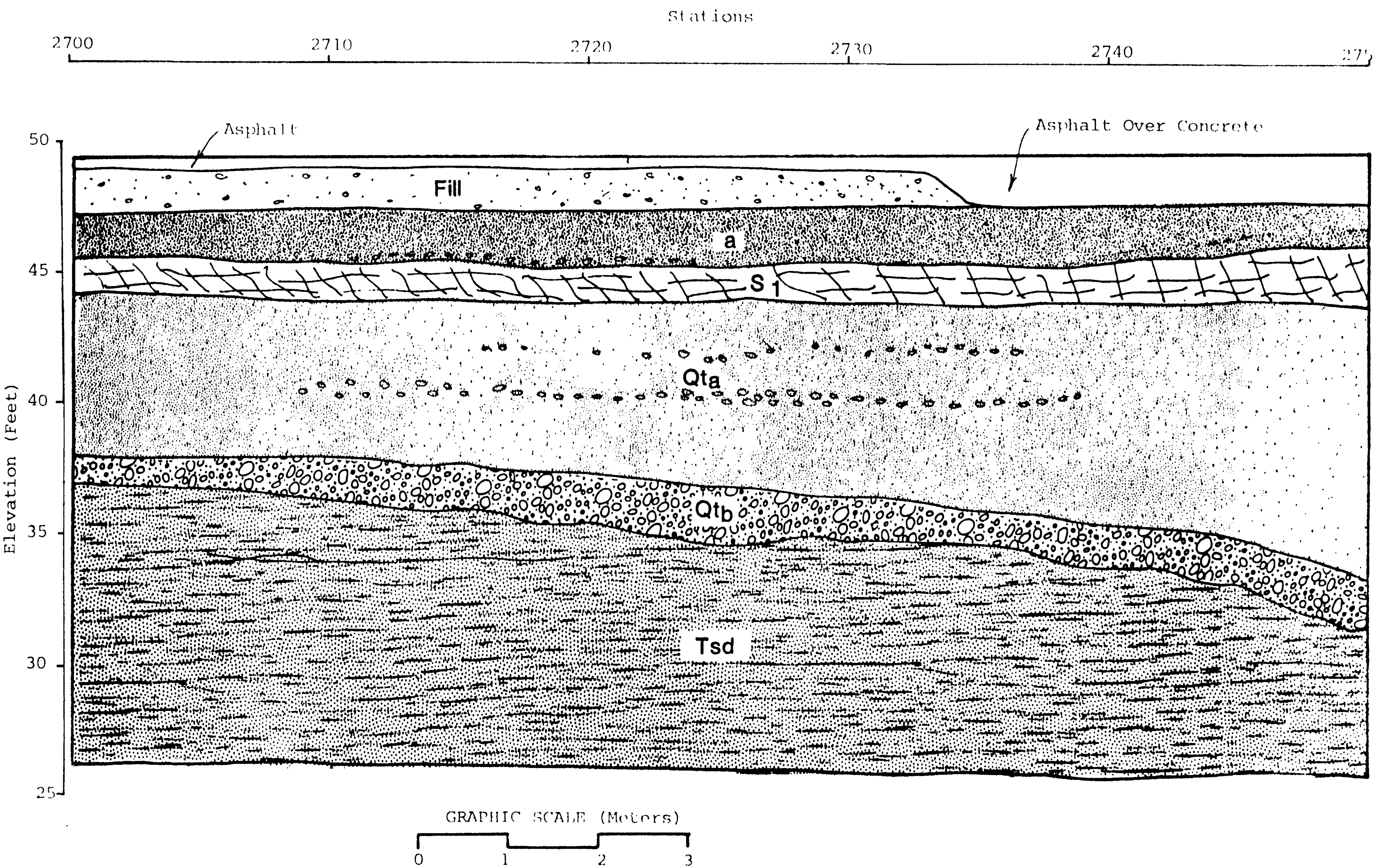


LOG OF TRENCH (NORTH WALL)
STATIONS 2600 TO 2650

DRAWN BY: mrk	**CHECKED BY:** EA	**PROJECT NO:** 50135H-GE01	**DATE:** 10-8-80	**FIGURE NO:** A-57

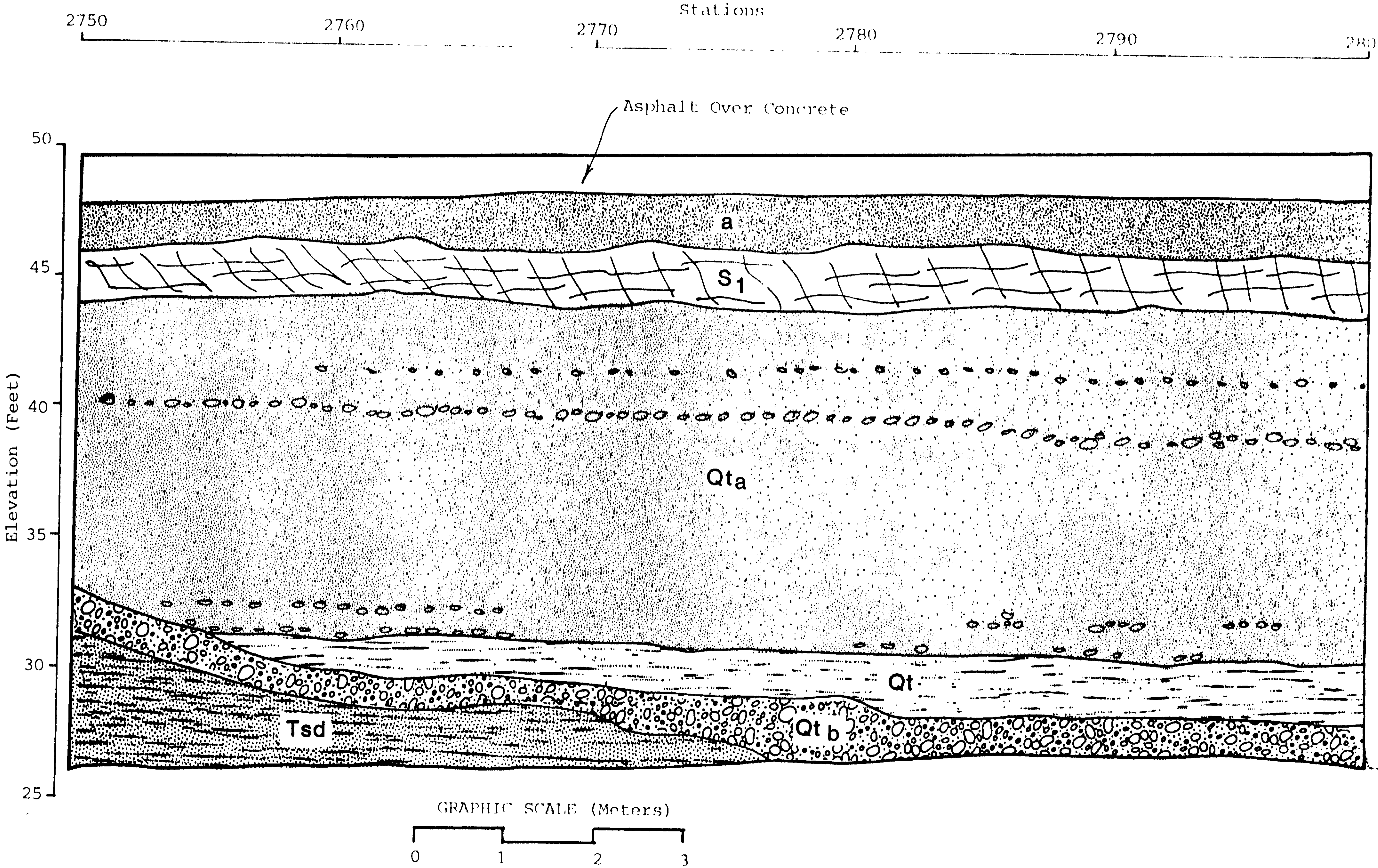


LOG OF TRENCH (NORTH WALL) STATIONS 2650 TO 2700				
DRAWN BY: mrk	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-58

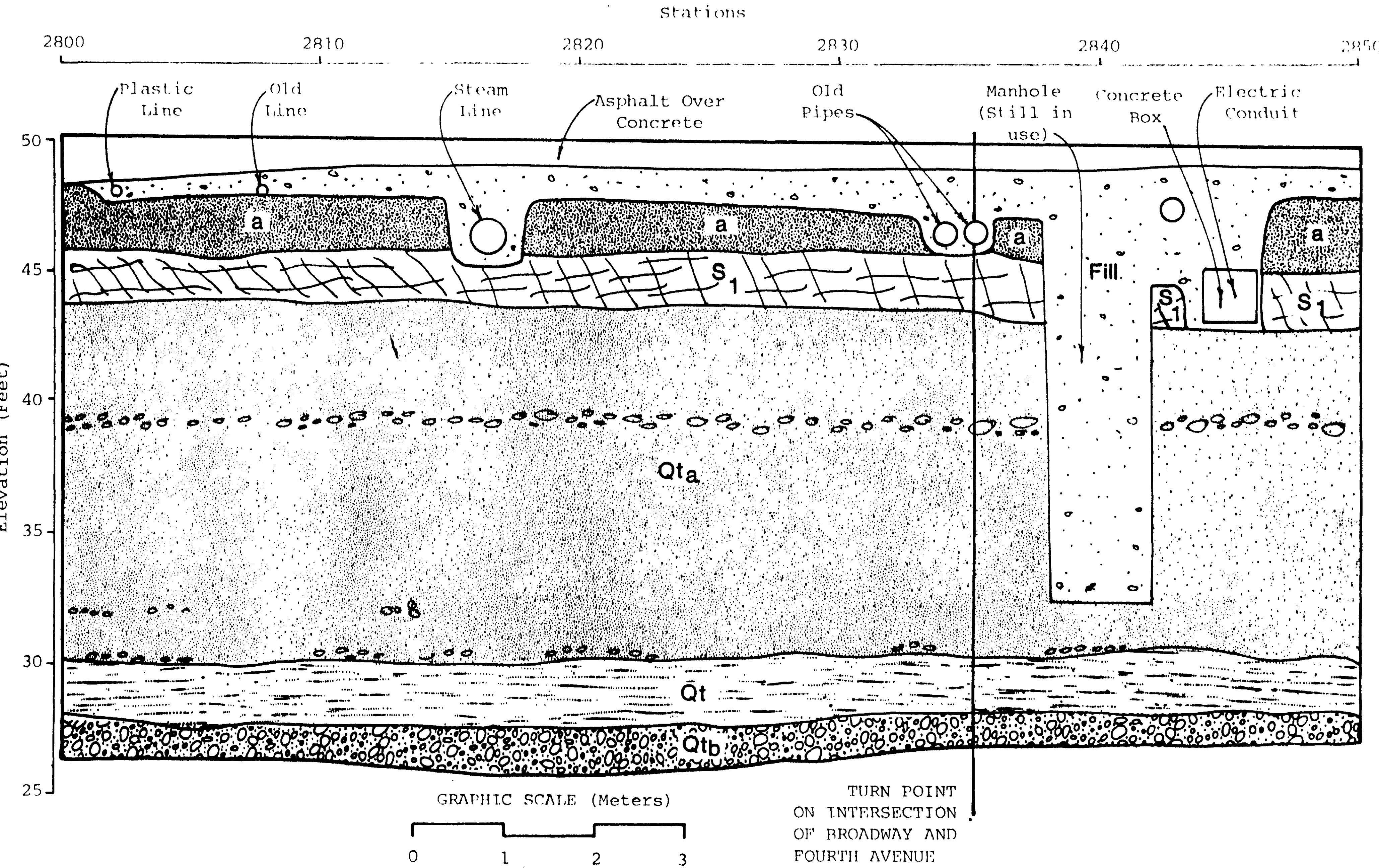


LOG OF TRENCH (NORTH WALL)
STATIONS 2700 TO 2750

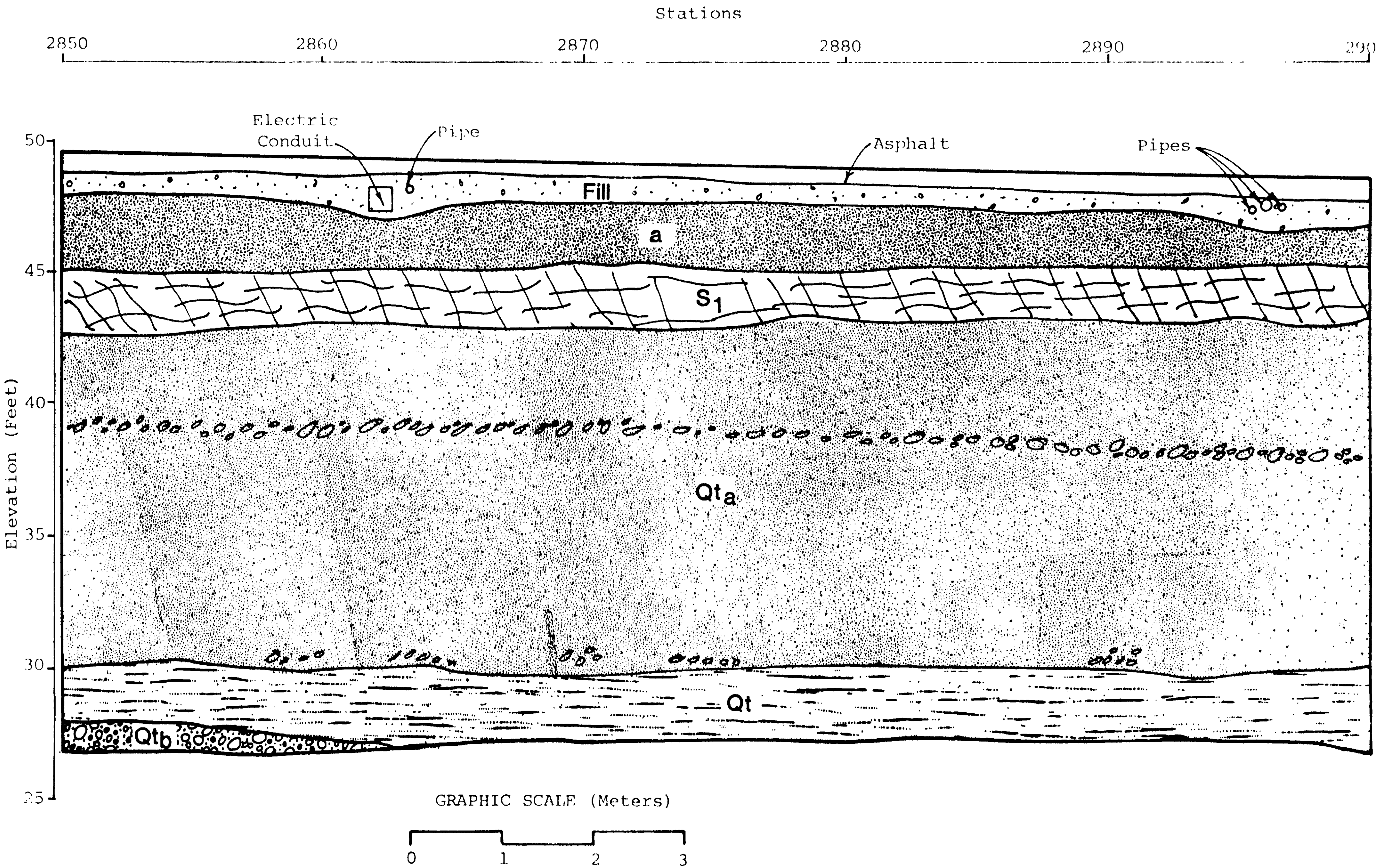
DRAWN BY: mrk	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-59



LOG OF TRENCH (NORTH WALL) STATIONS 2750 TO 2800				
DRAWN BY: mrk	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-60

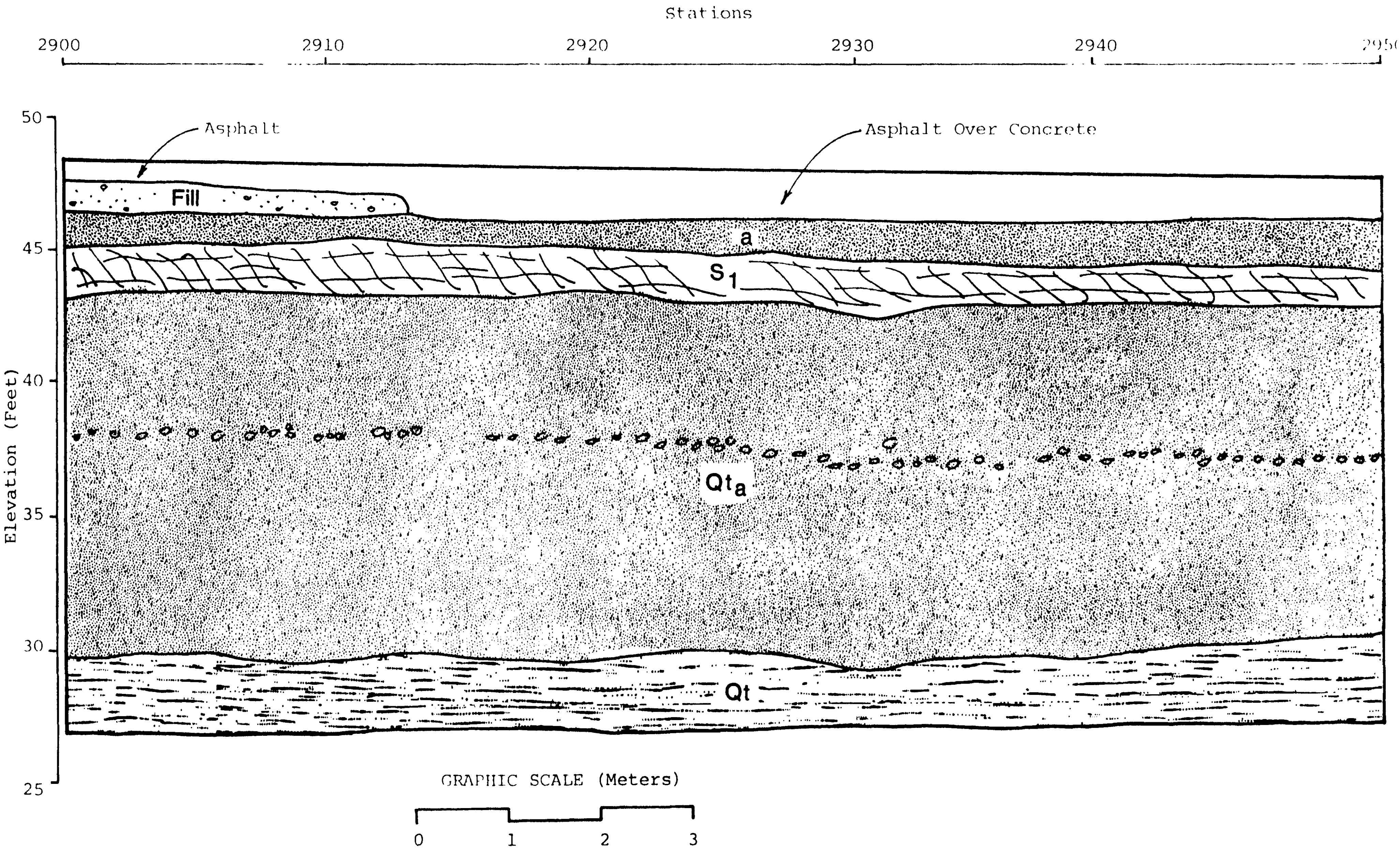


LOG OF TRENCH STATION 2800 TO 2850 NORTH WALL TO STATION 2036 - EAST WALL TO STATION 2850				
DRAWN BY: mrk	**CHECKED BY:** EA	**PROJECT NO:** 50135H-GE01	**DATE:** 10-8-80	**FIGURE NO:** A-61



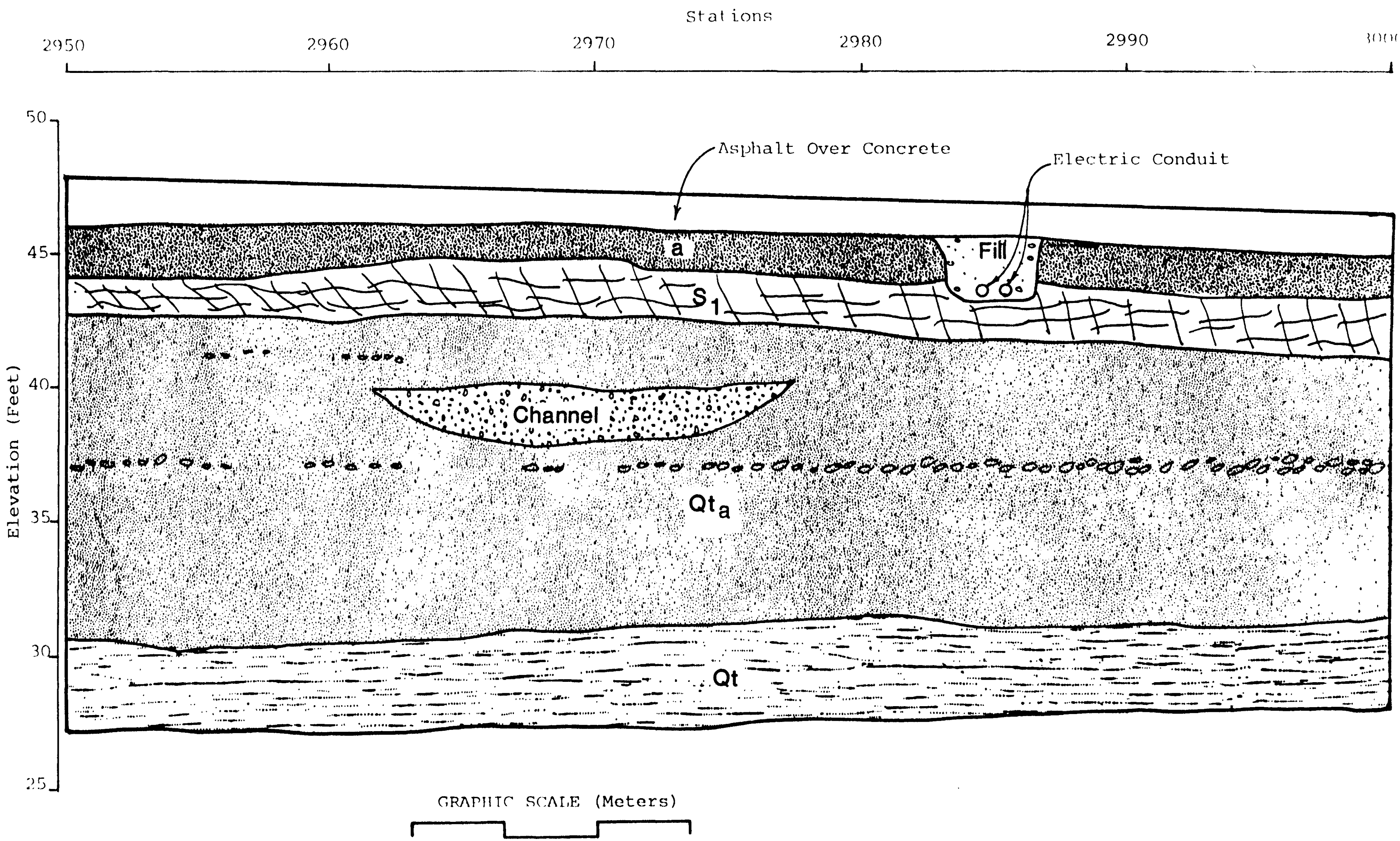
LOG OF TRENCH (EAST WALL)
STATIONS 2850 TO 2900

DRAWN BY: mrk	CHECKED BY:	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-62

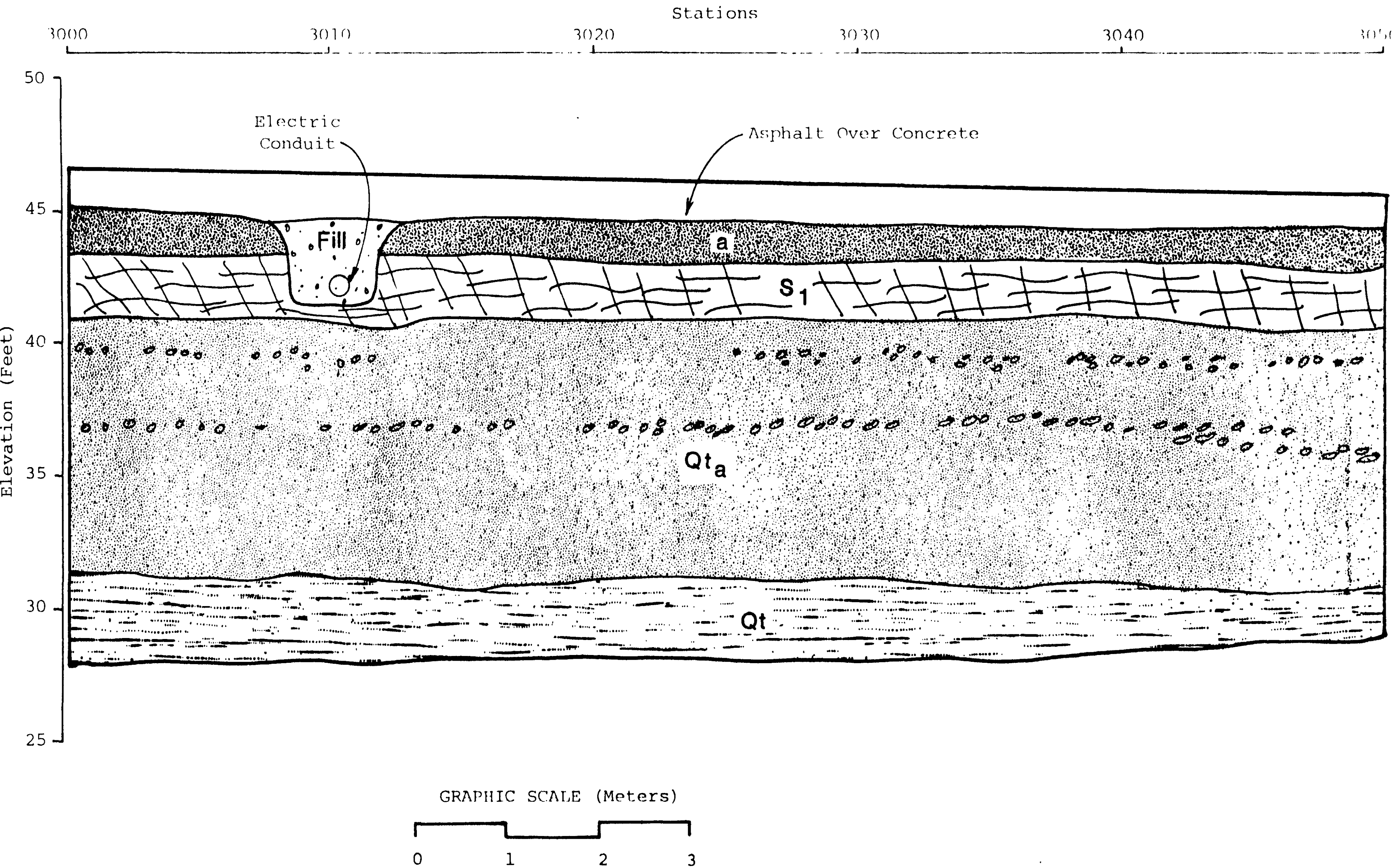


LOG OF TRENCH (EAST WALL)
STATIONS 2900 TO 2950

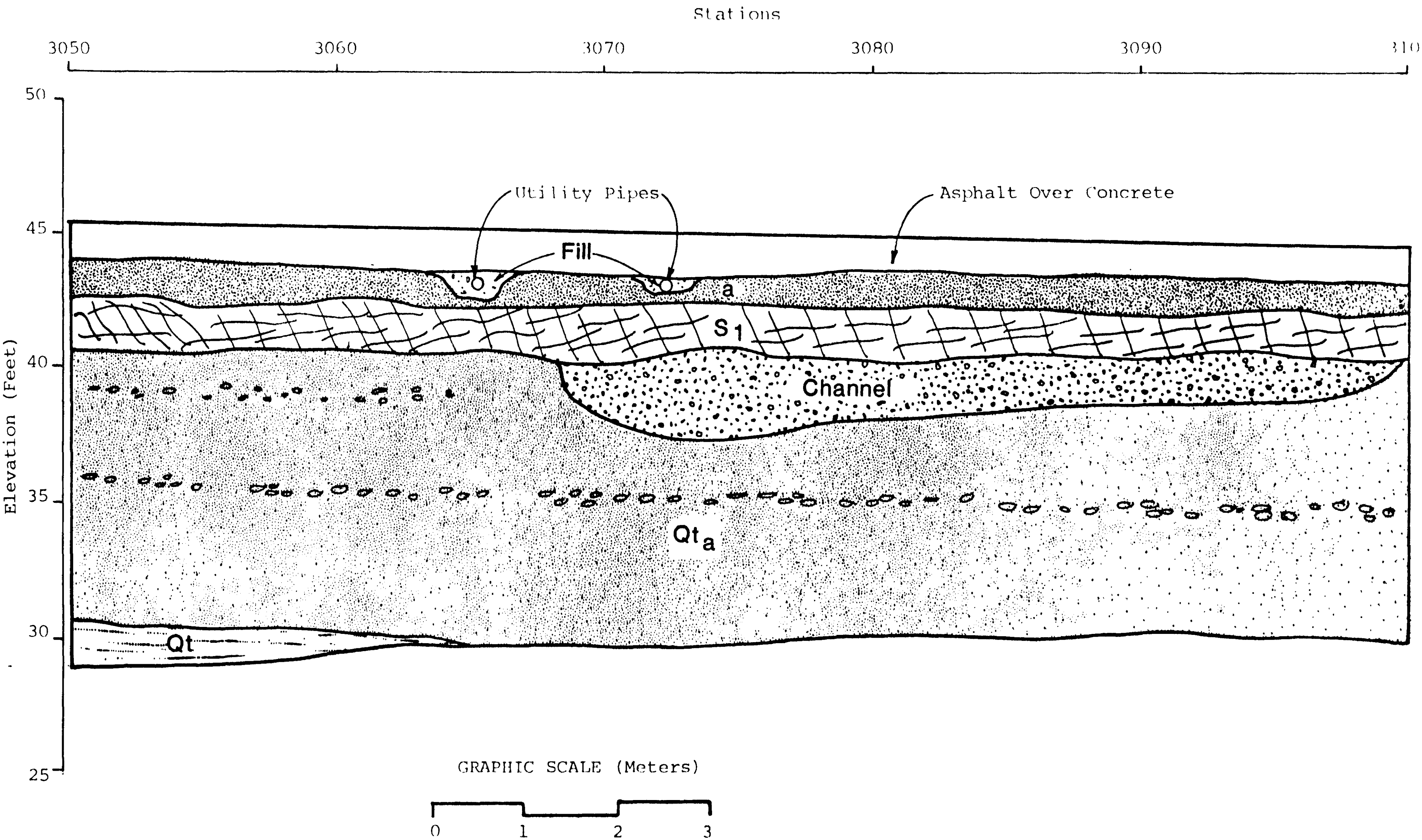
DRAWN BY: mrk	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-63



LOG OF TRENCH (EAST WALL) STATIONS 2950 TO 3000				
DRAWN BY: mrk	**CHECKED BY:** GA	**PROJECT NO:** 50135H-GE01	**DATE:** 10-8-80	**FIGURE NO:** A-64

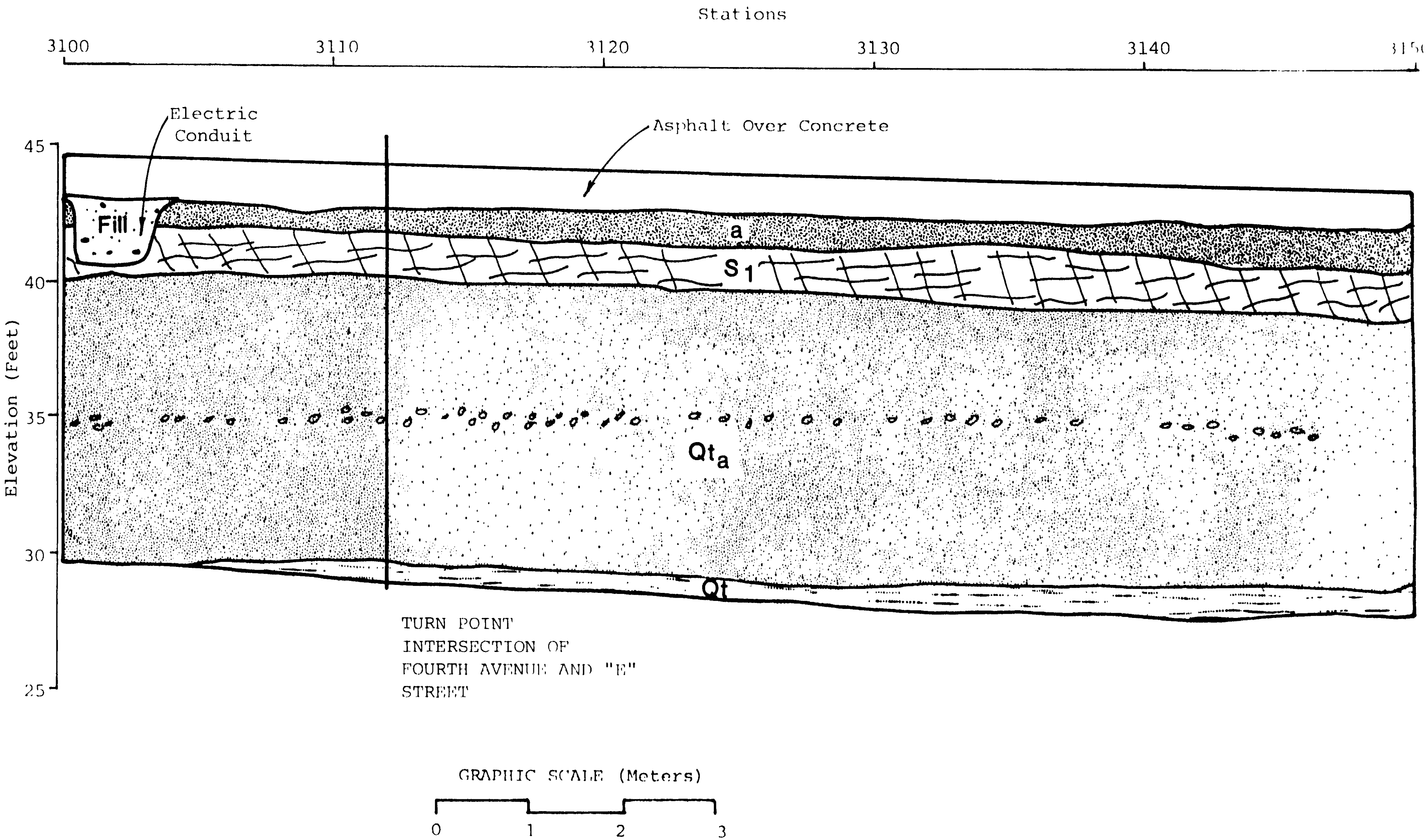


LOG OF TRENCH (EAST WALL) STATIONS 3000 TO 3050				
DRAWN BY: mrk	**CHECKED BY:** EA	**PROJECT NO:** 50135H-GE01	**DATE:** 10-8-80	**FIGURE NO:** A-65



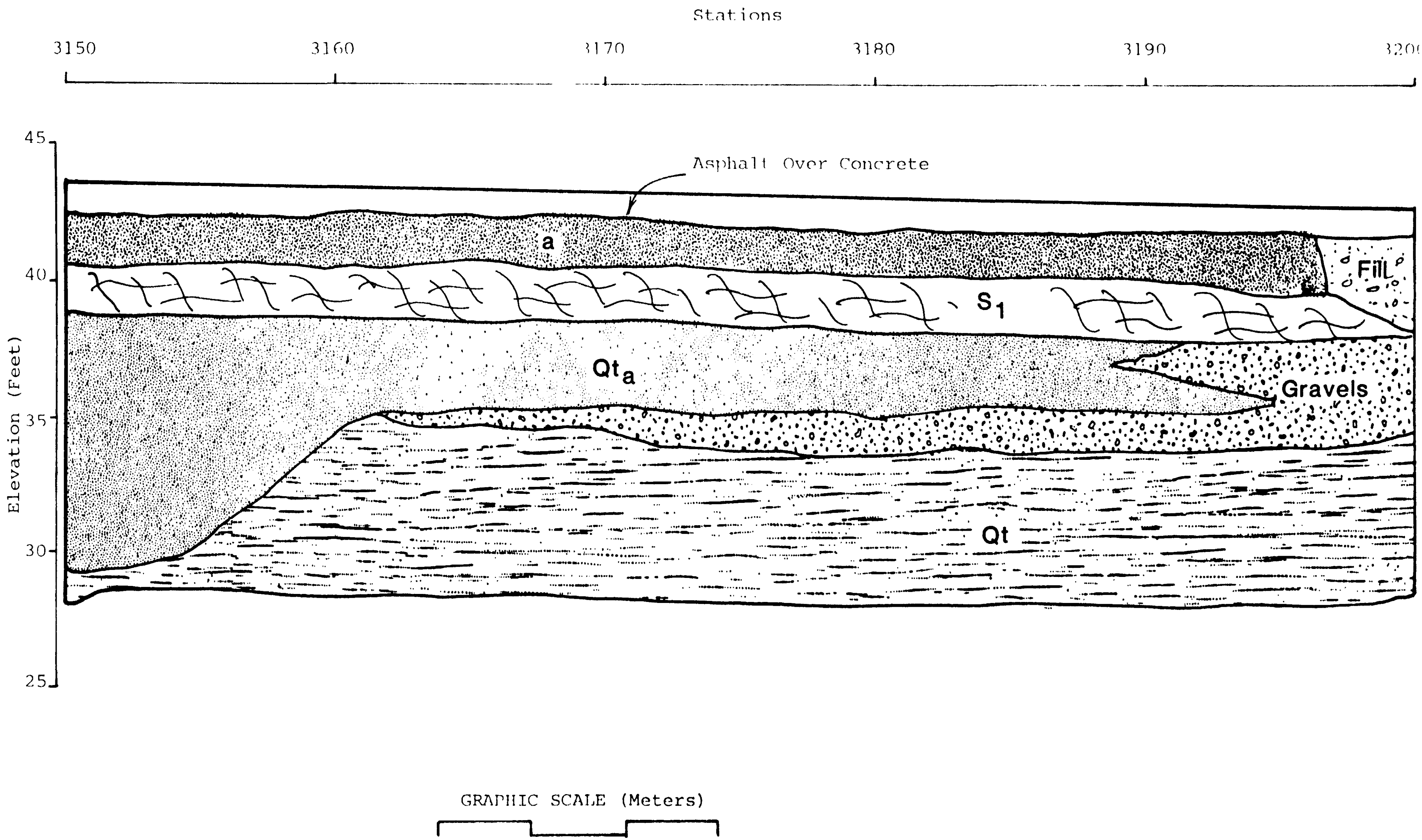
LOG OF TRENCH (EAST WALL)
STATIONS 3050 TO 3100

DRAWN BY: mrk	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-66

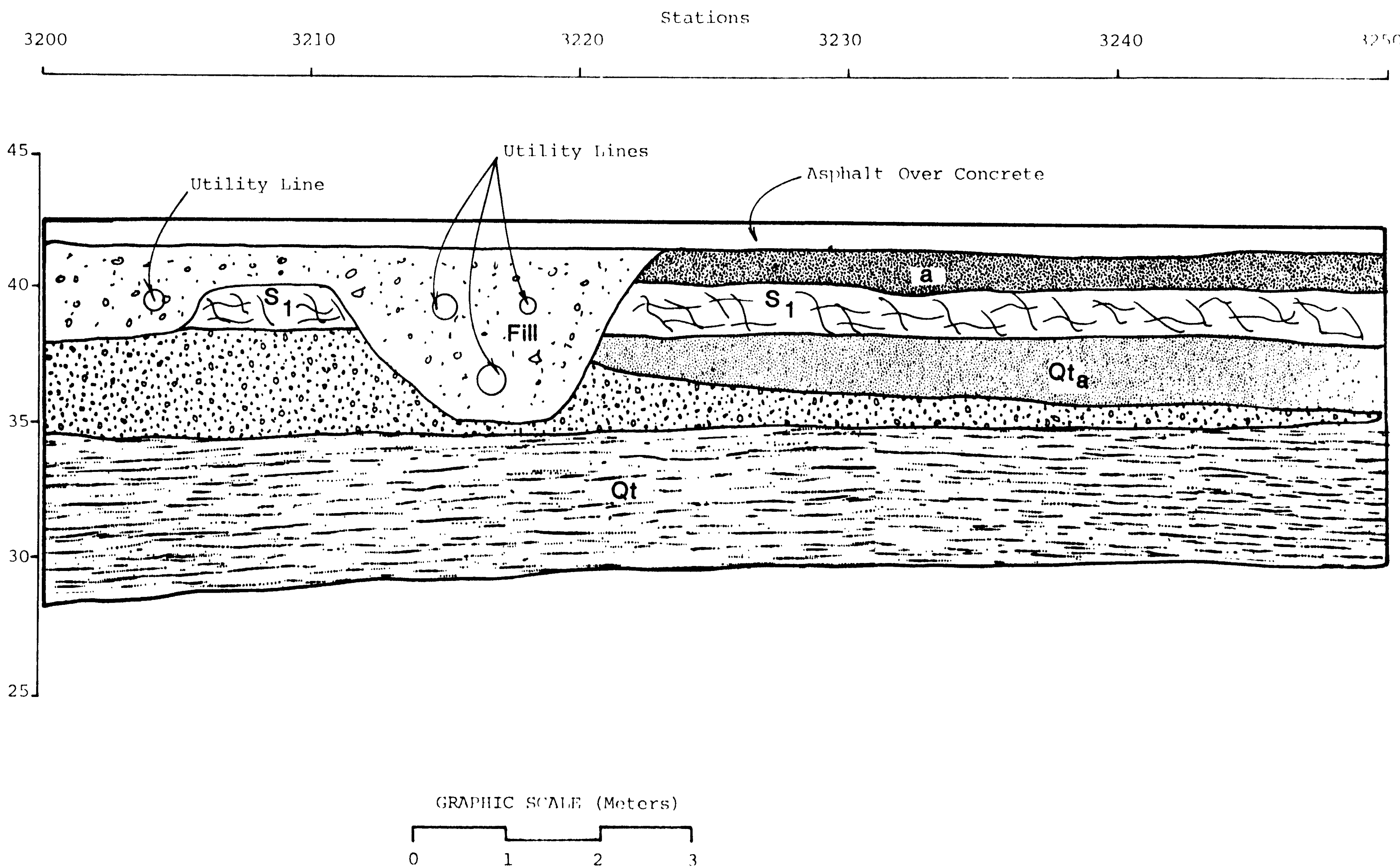


LOG OF TRENCH
STATIONS 3100 TO 3150
EAST WALL TO STATION 3112 - NORTH WALL TO STATION 3150

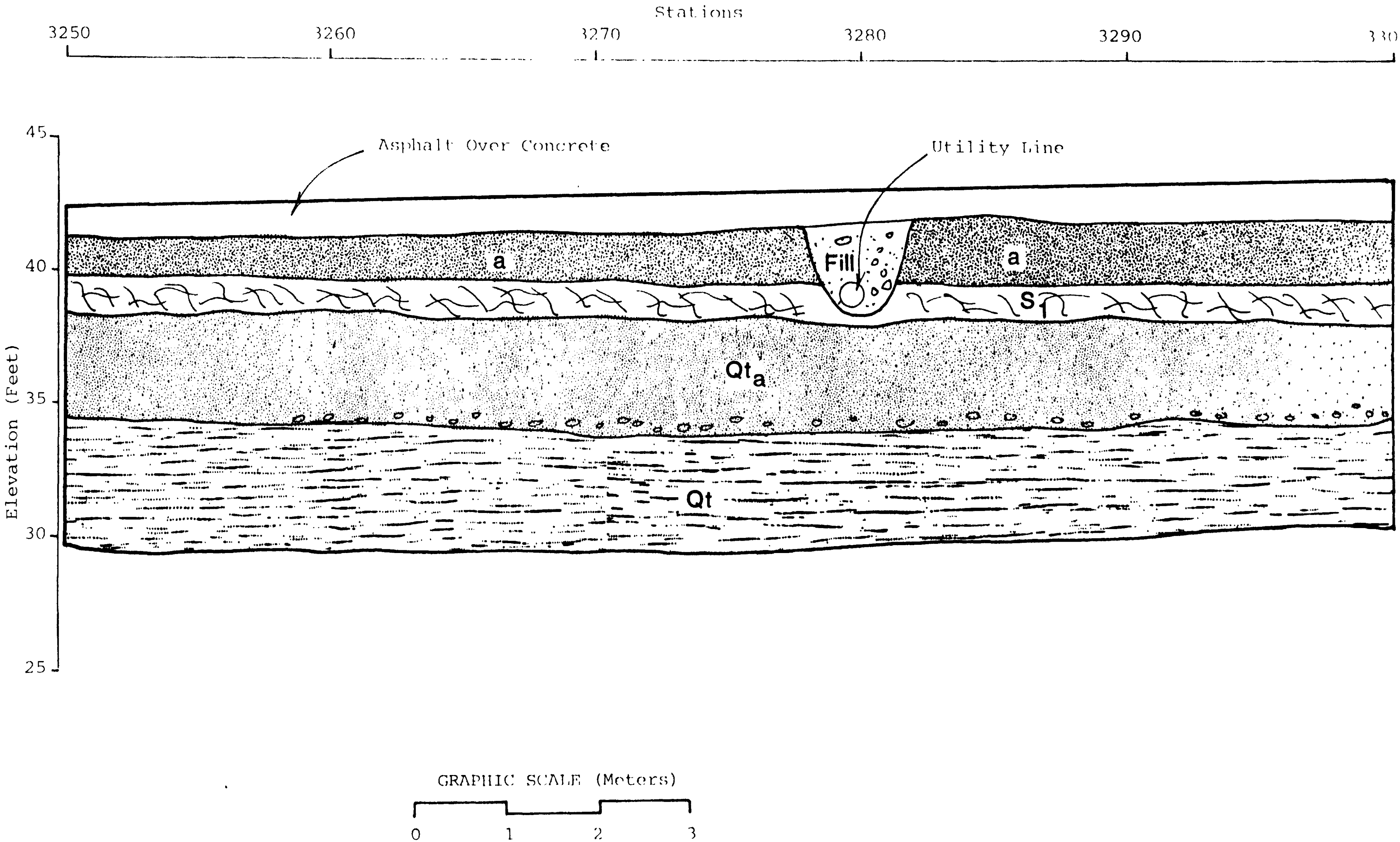
DRAWN BY: mrk	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-8-80	FIGURE NO: A-67



LOG OF TRENCH (EAST WALL) STATIONS 3150 TO 3200				
DRAWN BY: ch	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 10-28-80	FIGURE NO: A-68

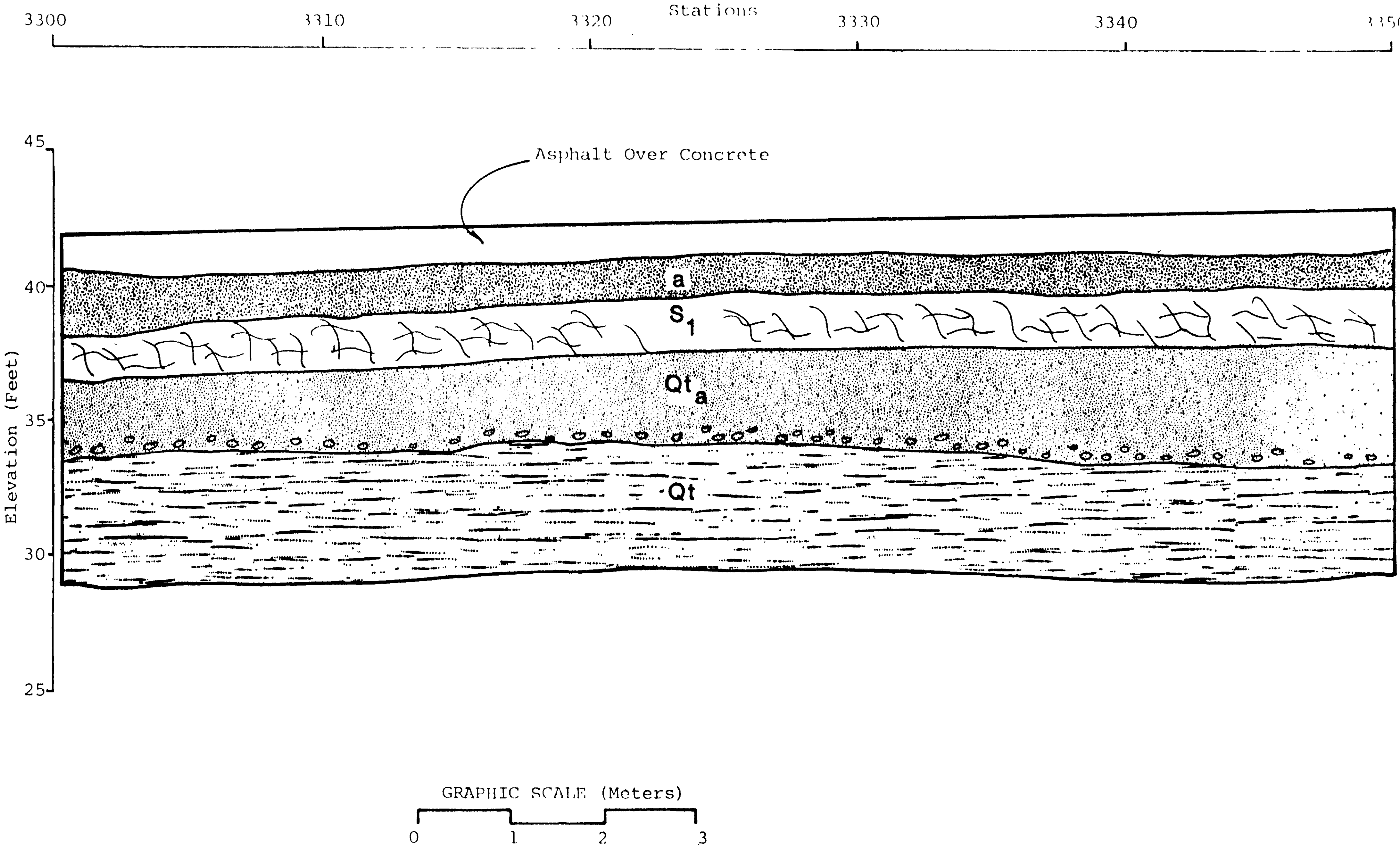


LOG OF TRENCH (NORTH WALL) STATIONS 3200 TO 3250				
DRAWN BY: ch	**CHECKED BY:** GA	**PROJECT NO:** 50135H-GE01	**DATE:** 10-28-80	**FIGURE NO:** A-69



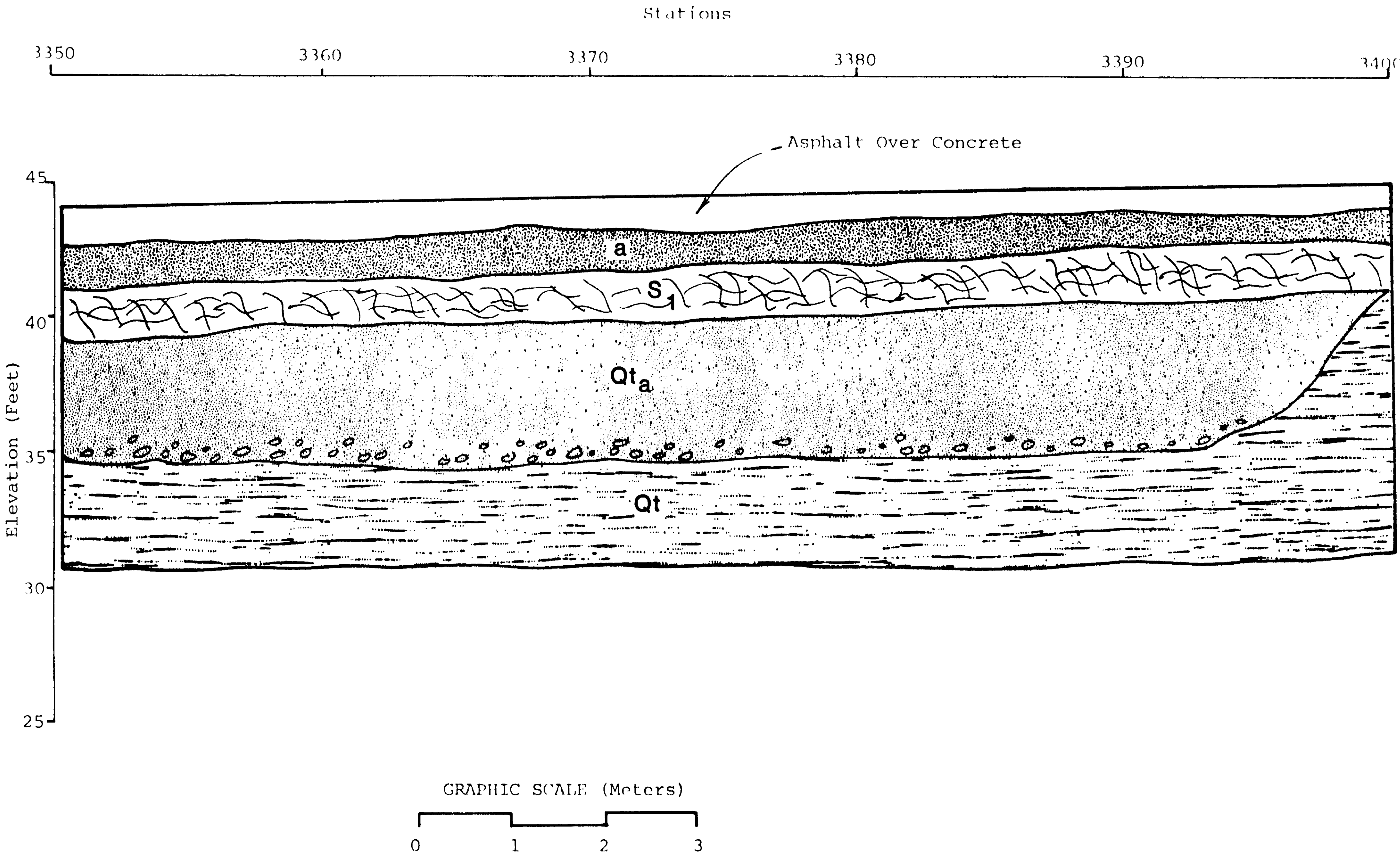
LOG OF TRENCH (NORTH WALL)
STATIONS 3250 TO 3300

DRAWN BY: ch	CHECKED BY:	PROJECT NO: 50135H-GE01	DATE: 10-28-80	FIGURE NO: A-70



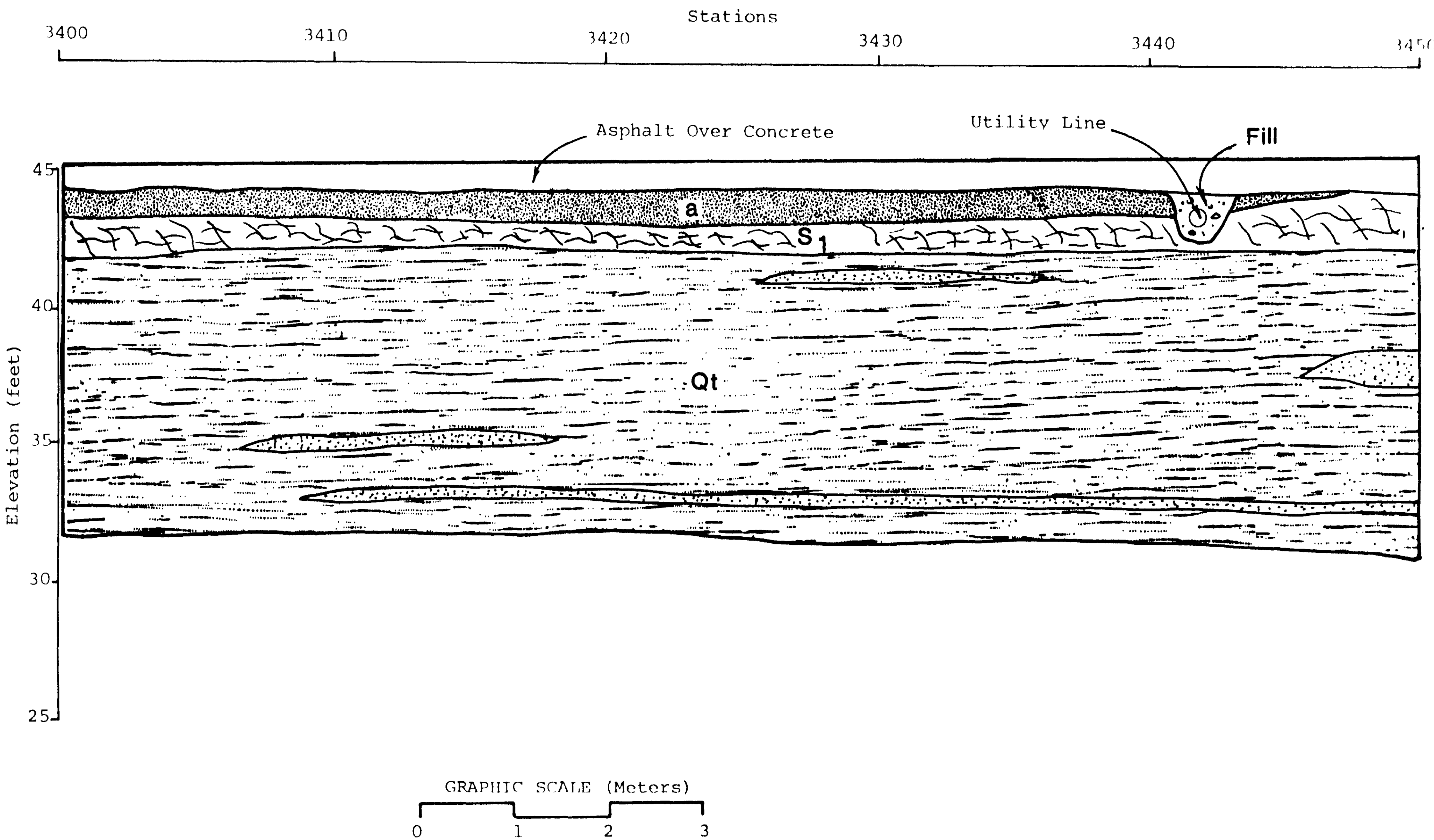
LOG OF TRENCH (NORTH WALL)
STATIONS 3300 TO 3350

DRAWN BY: ch	CHECKED BY: GR	PROJECT NO: 50135H-GE01	DATE: 10-28-80	FIGURE NO: A-71



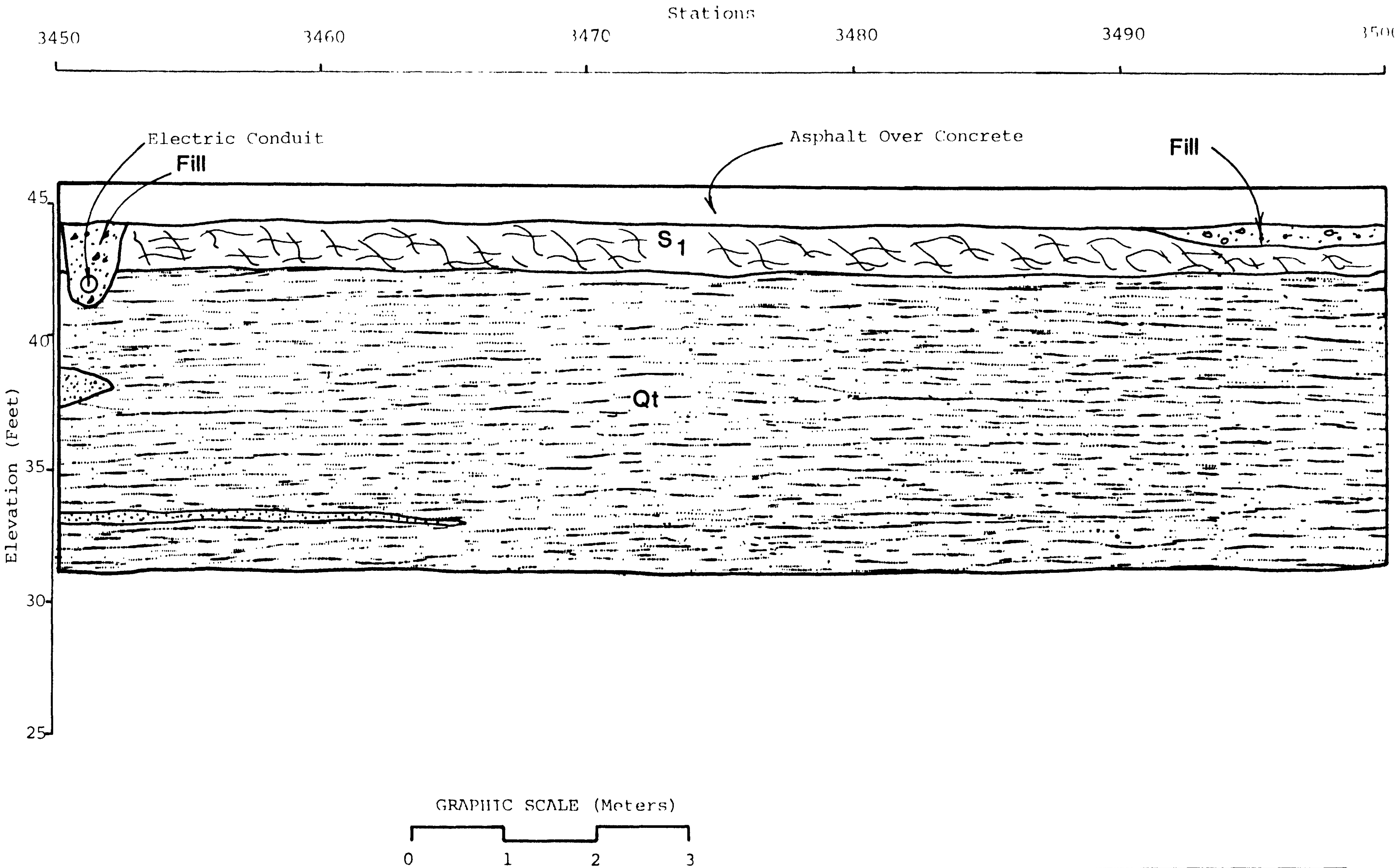
LOG OF TRENCH (NORTH WALL)
STATIONS 3350 TO 3400

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GEO1	DATE: 10-29-80	FIGURE NO: A-72



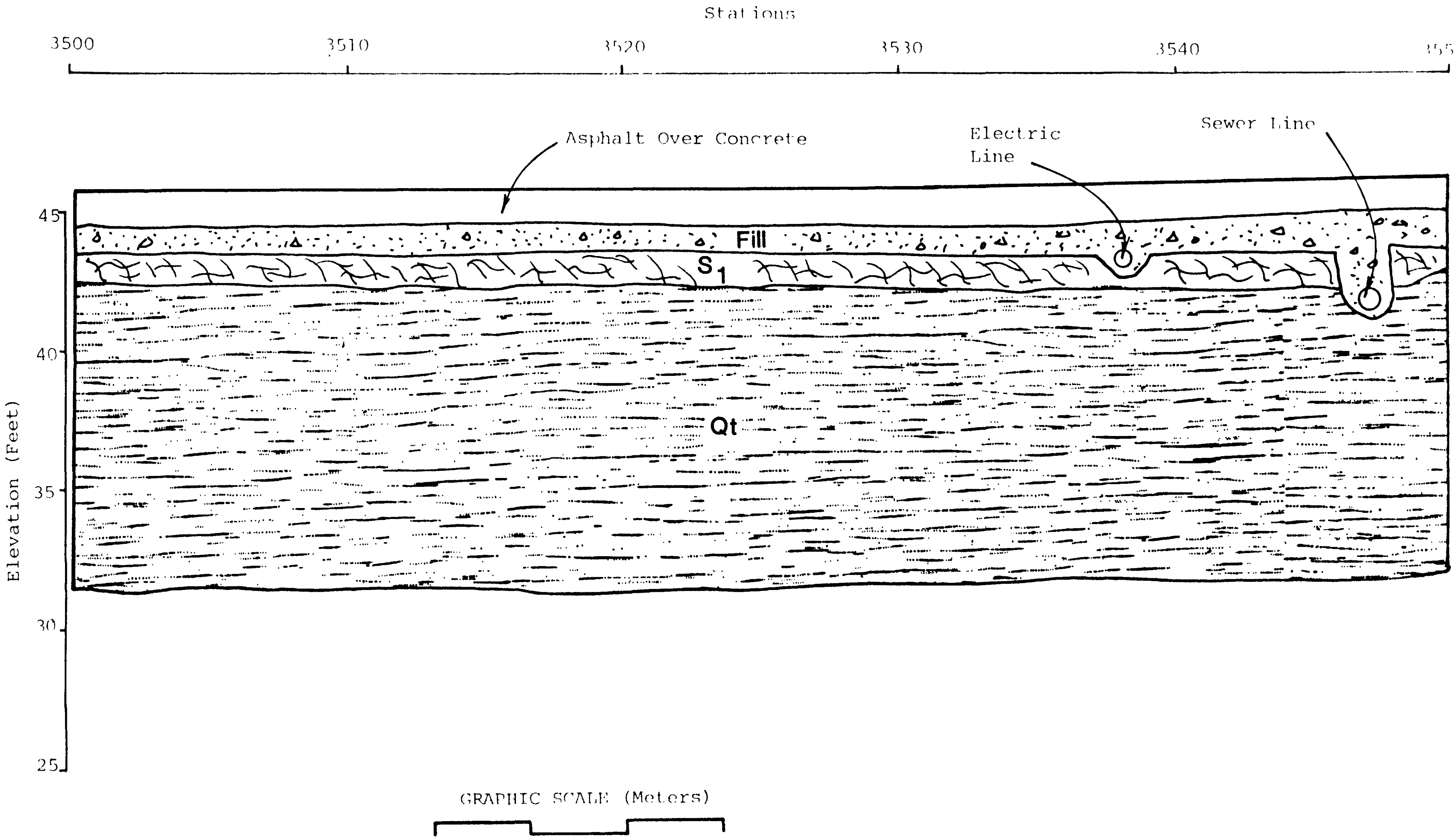
LOG OF TRENCH (NORTH WALL)
STATIONS 3400 TO 3450

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-29-80	FIGURE NO: A-73



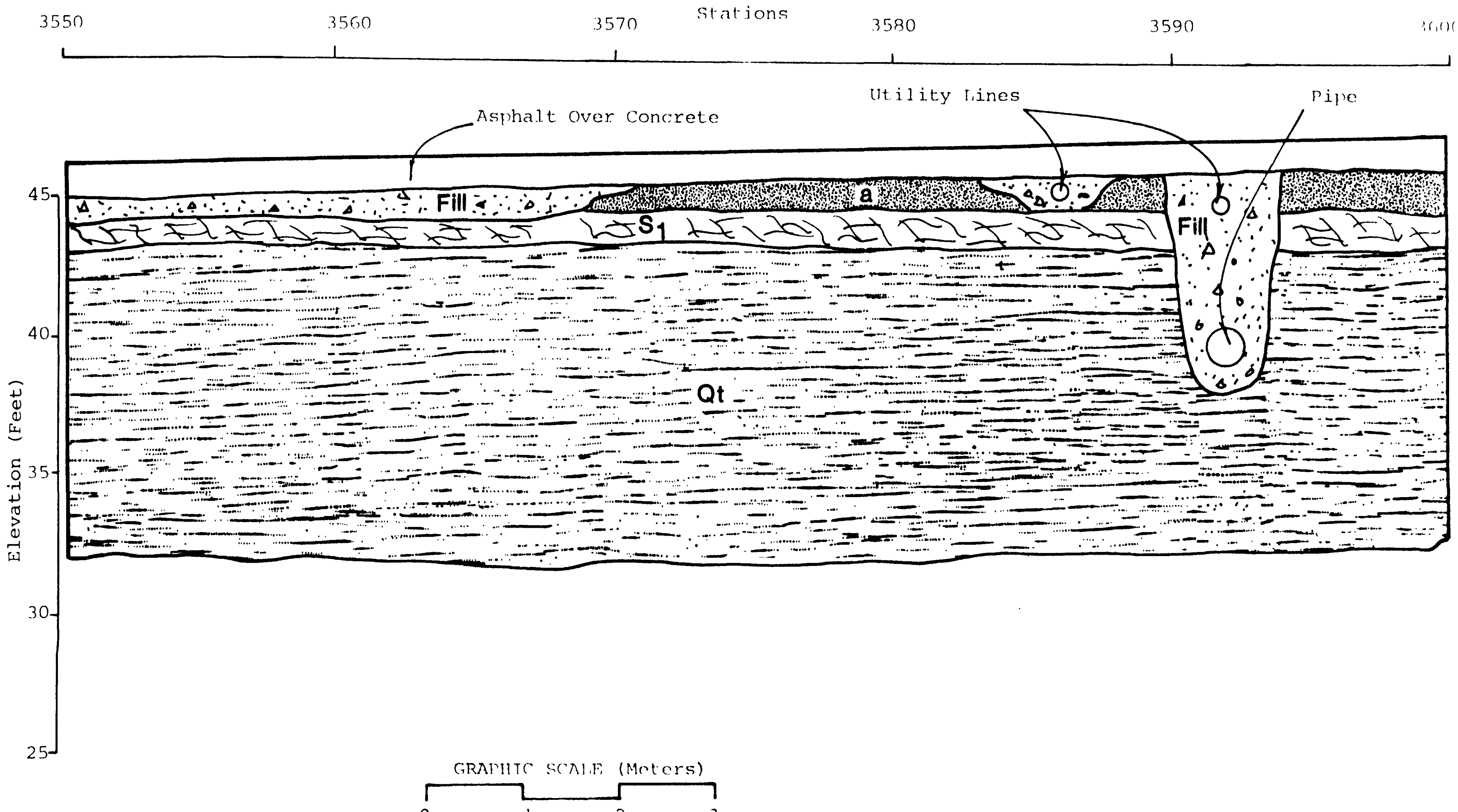
LOG OF TRENCH (NORTH WALL)
STATIONS 3450 TO 3500

DRAWN BY: ch	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 10-29-80	FIGURE NO: A-74

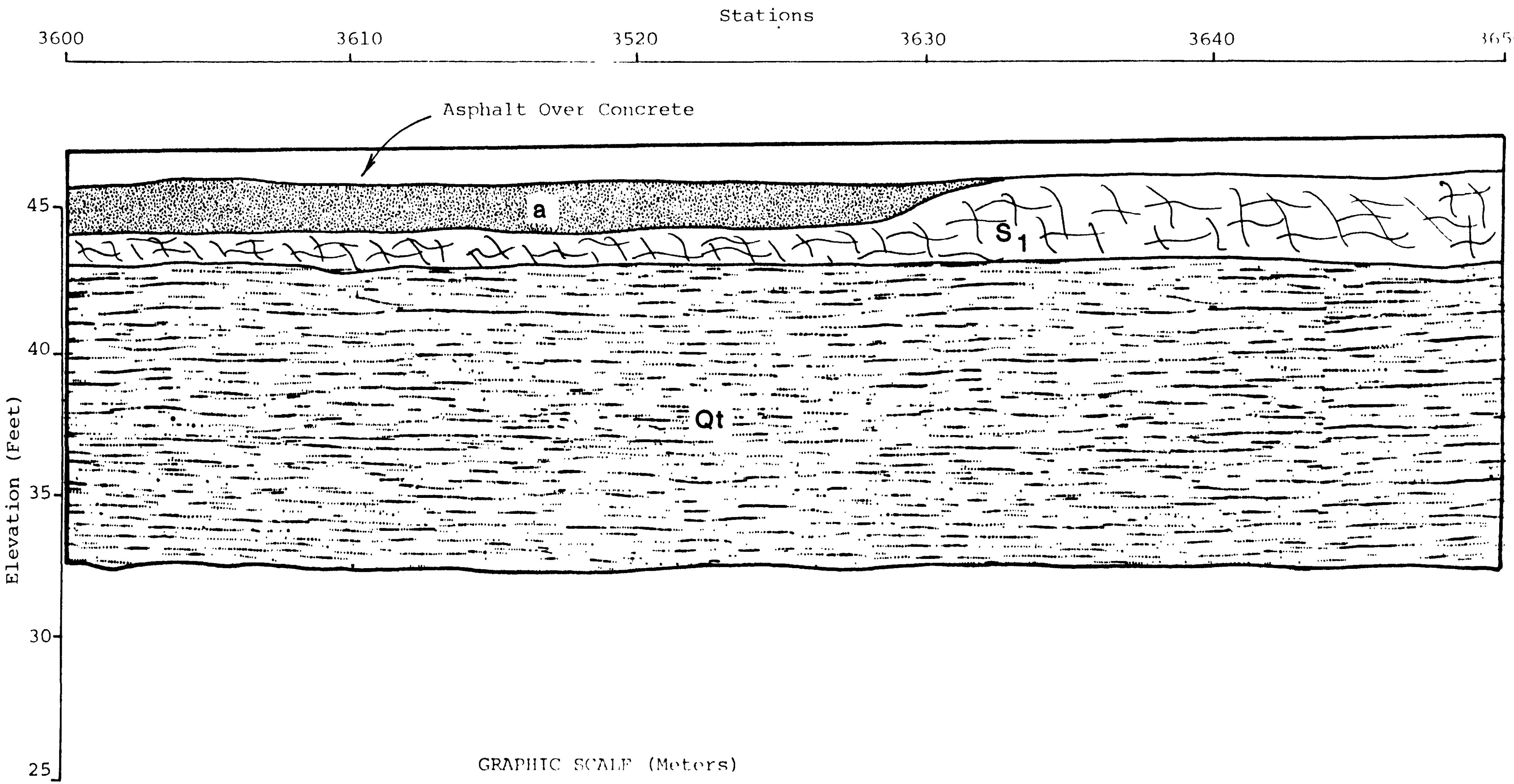


LOG OF TRENCH (NORTH WALL)
STATIONS 3500 TO 3550

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GEO1	DATE: 10-29-80	FIGURE NO: A-75



LOG OF TRENCH (NORTH WALL) STATIONS 3550 TO 3600				
DRAWN BY: ch	CHECKED BY: ER	PROJECT NO: 50135H-GE01	DATE: 10-29-80	FIGURE NO: A-76

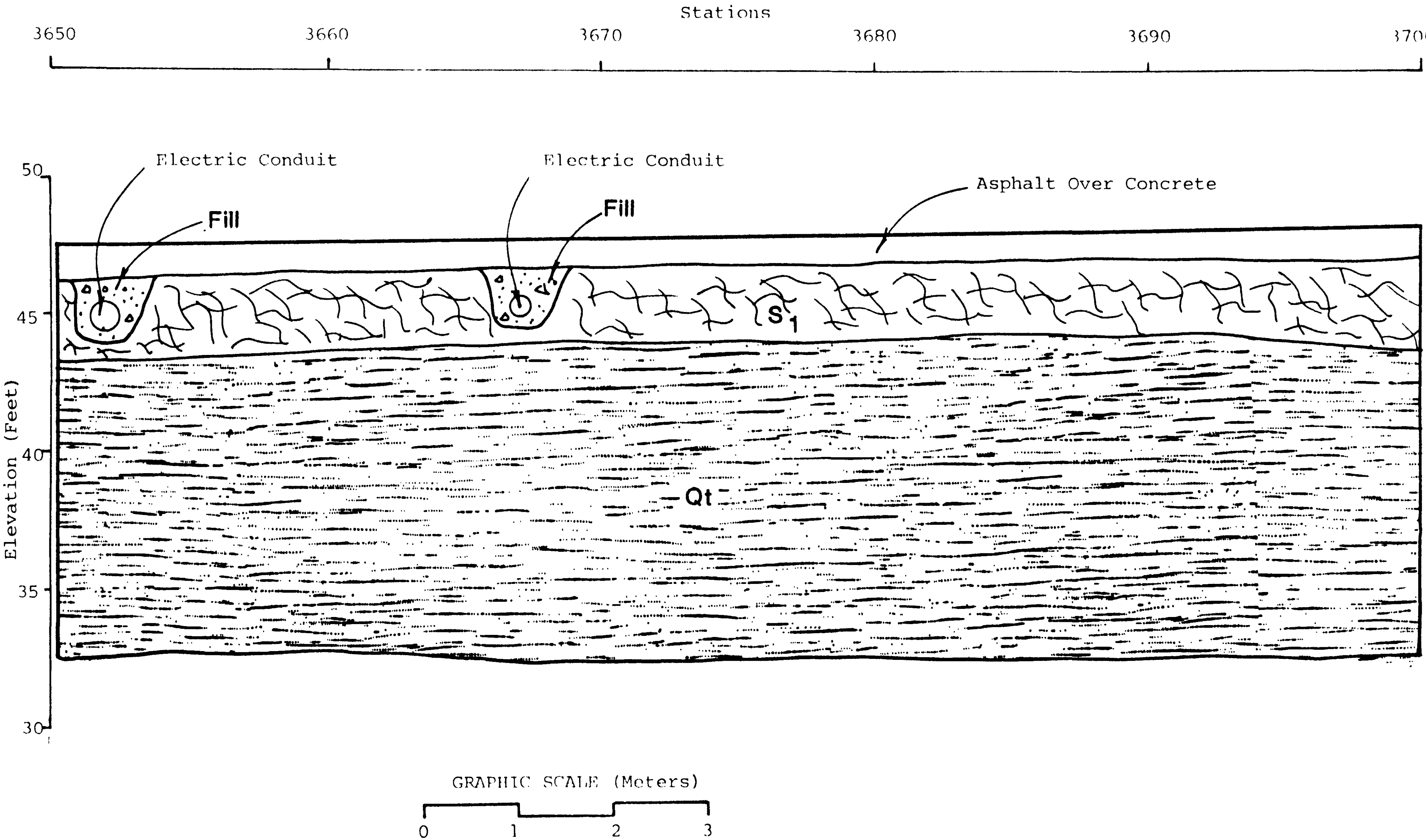


GRAPHIC SCALE (Meters)

0 1 2 3

LOG OF TRENCH (NORTH WALL)
STATIONS 3600 TO 3650

DRAWN BY: ch	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 10-29-80	FIGURE NO: A-77



LOG OF TRENCH (NORTH WALL) STATIONS 3650 TO 3700				
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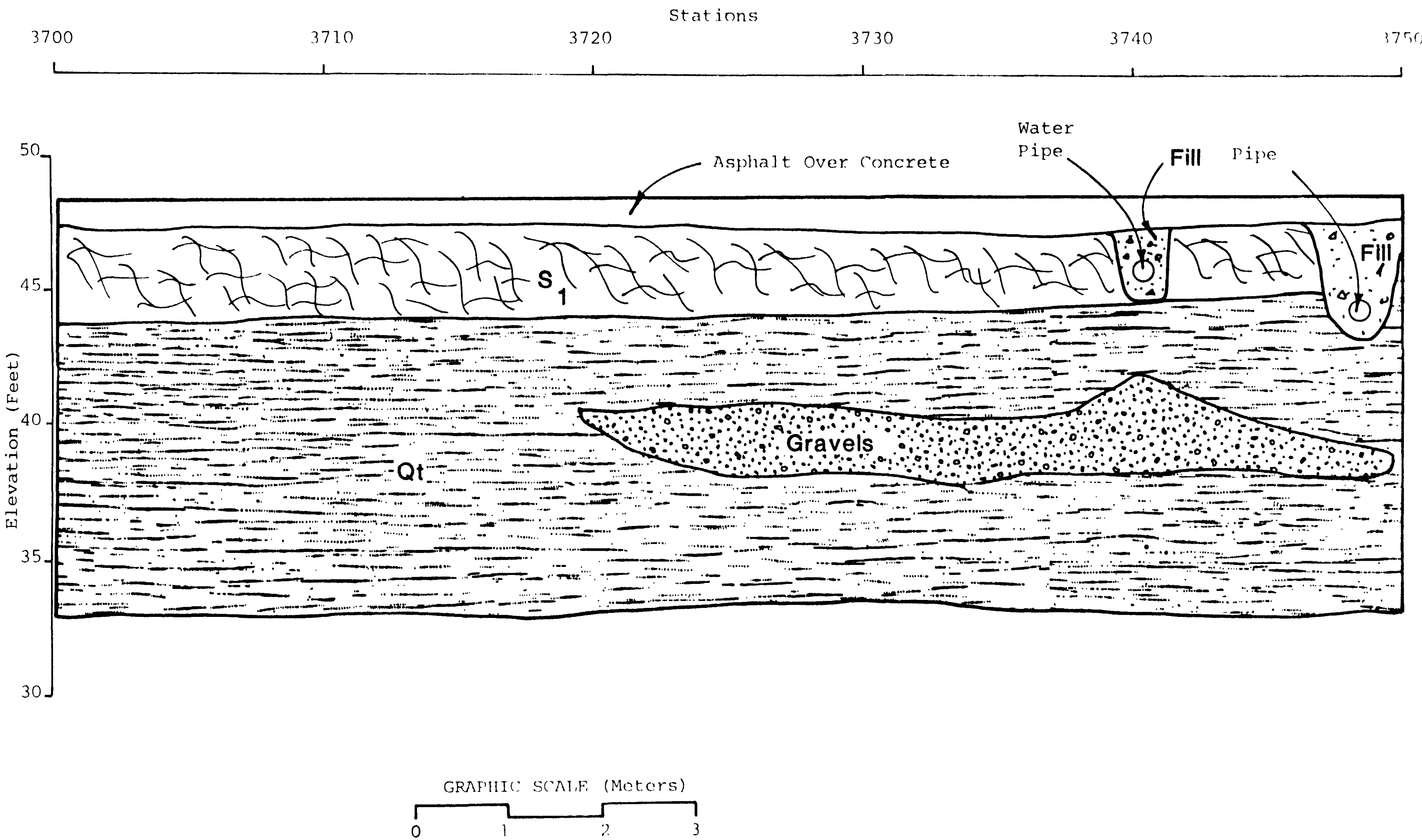

LOG OF TRENCH (NORTH WALL) STATIONS 3700 TO 3750				
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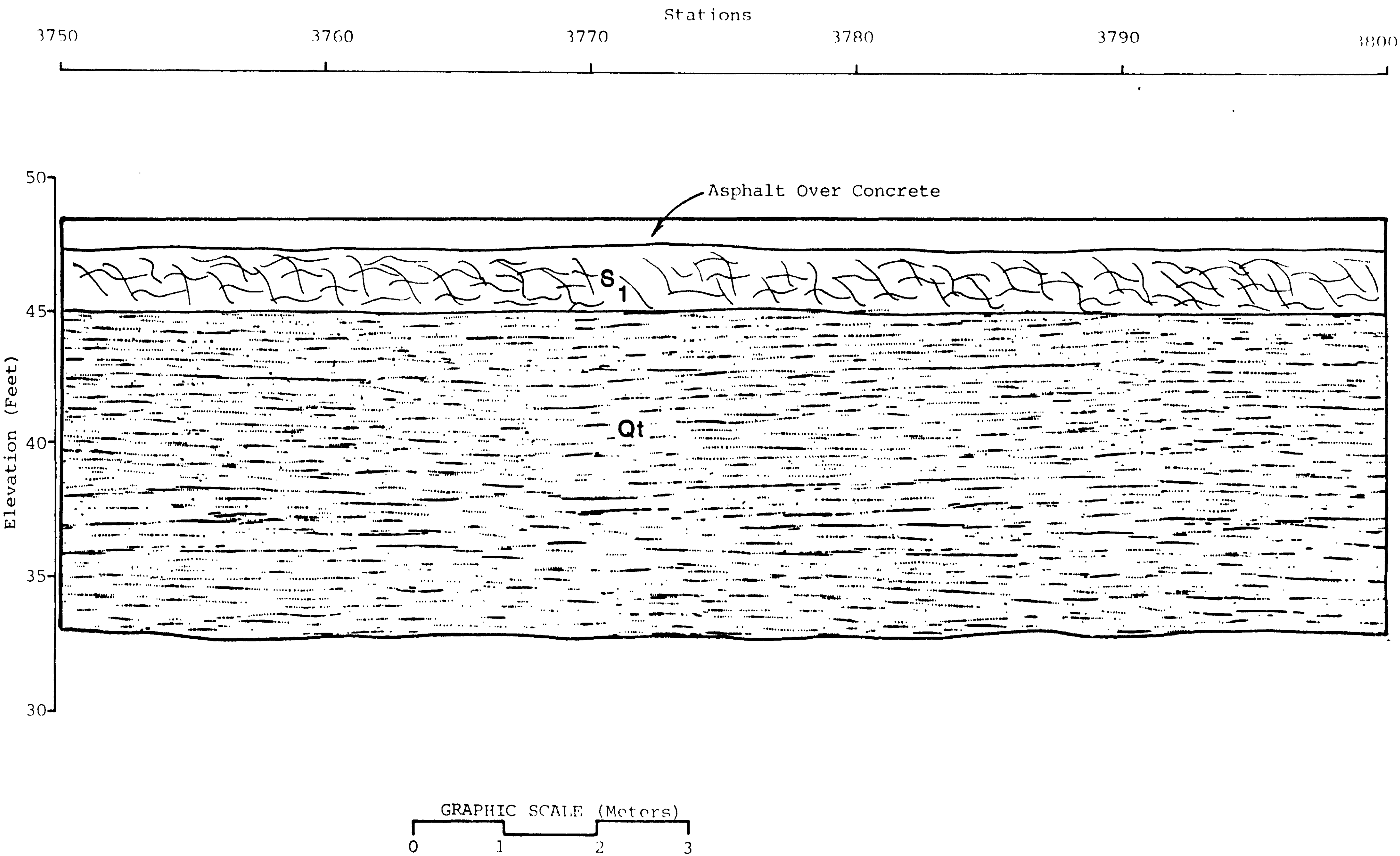

LOG OF TRENCH (NORTH WALL)
STATIONS 3750 TO 3800

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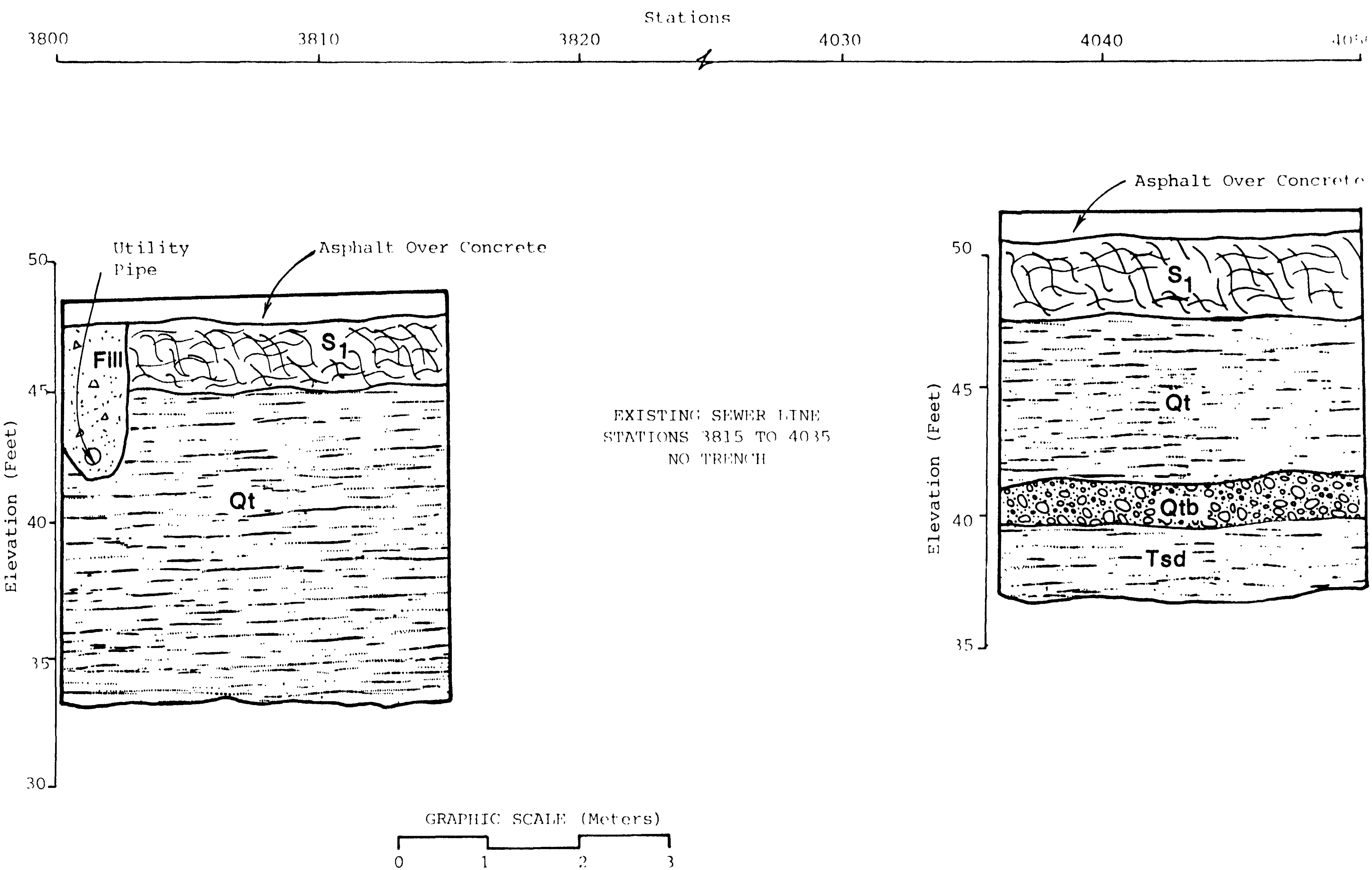

LOG OF TRENCH (NORTH WALL)
STATIONS 3800 TO 4050

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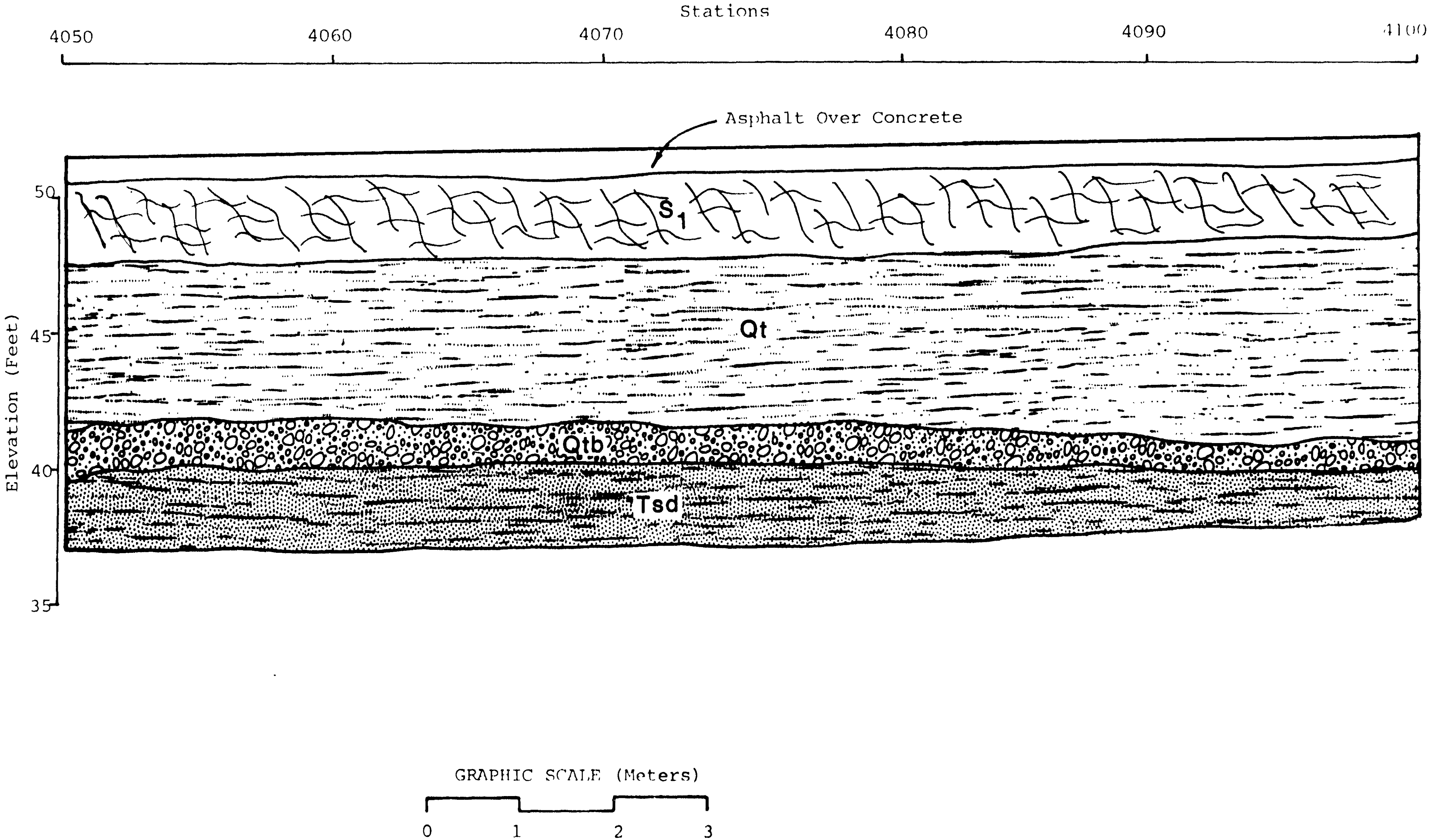

LOG OF TRENCH (NORTH WALL)
STATIONS 4050 TO 4100

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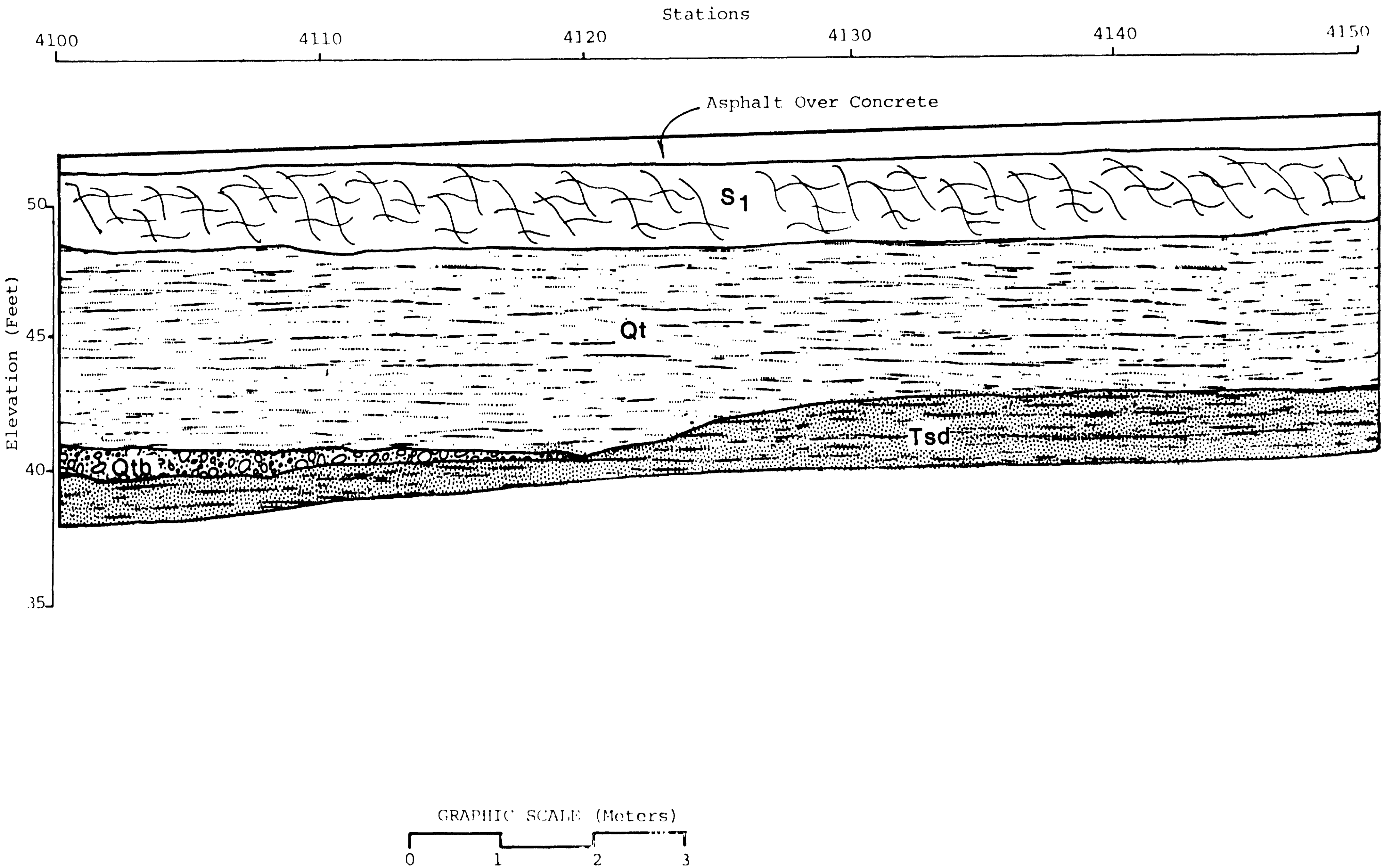
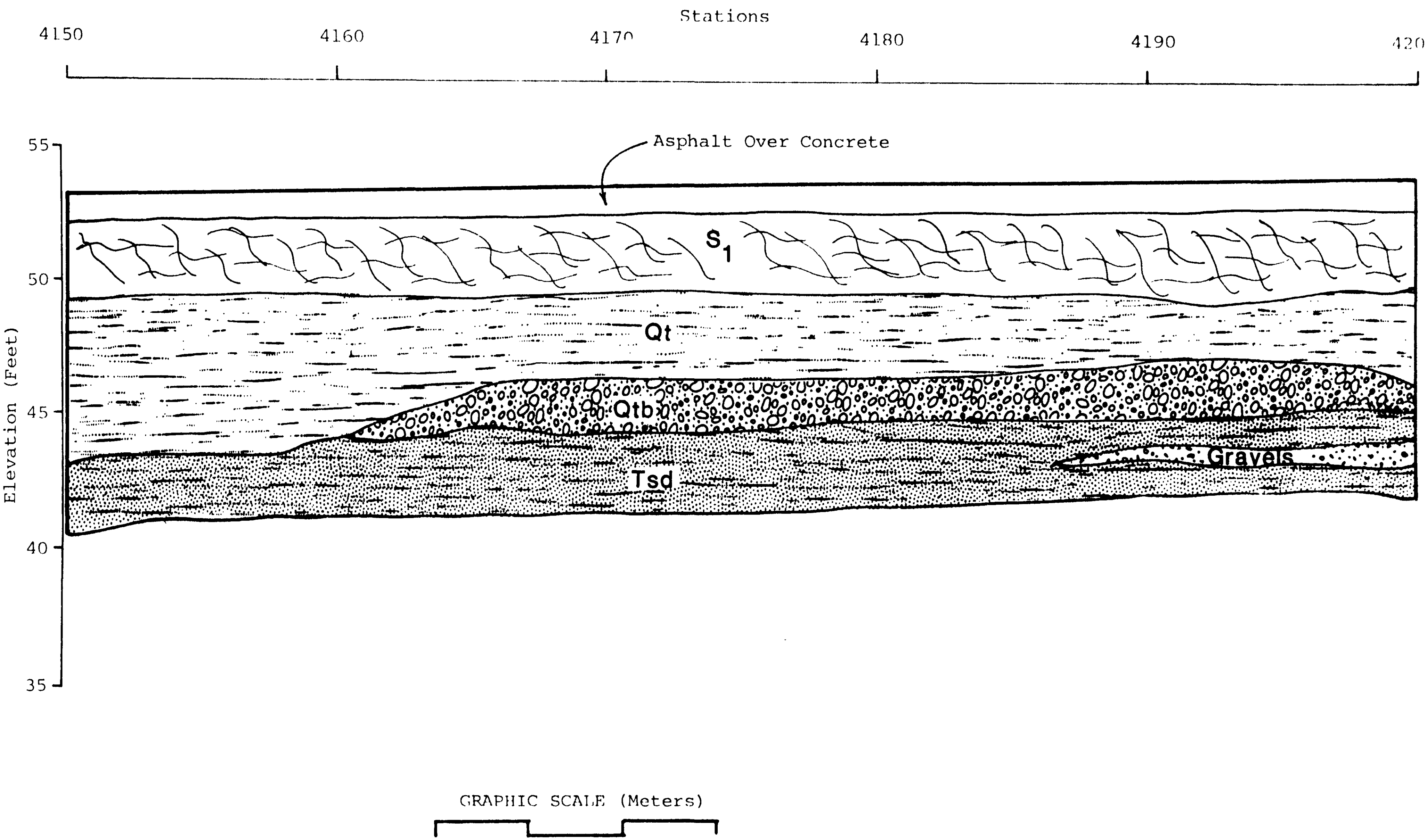
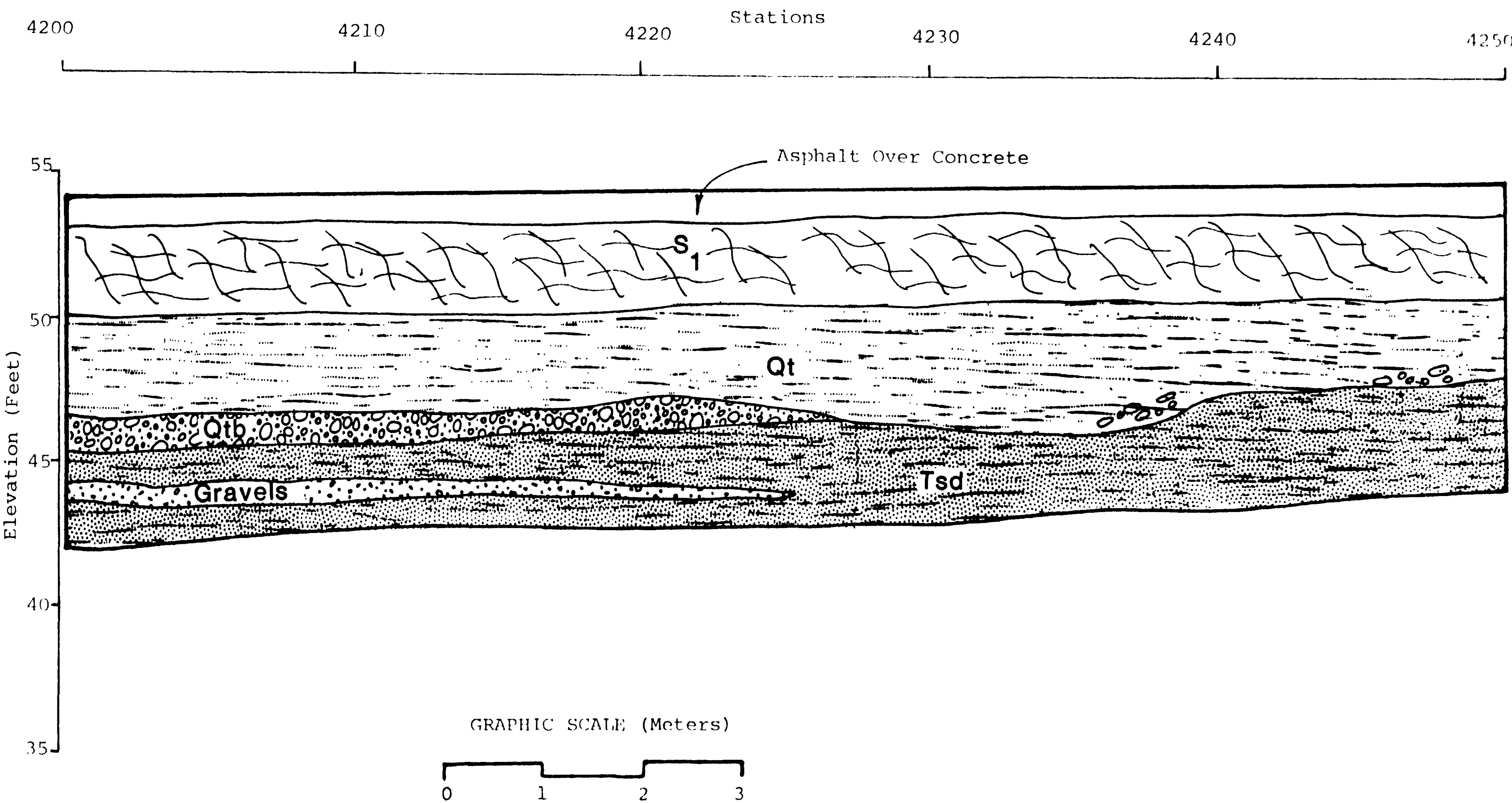


LOG OF TRENCH (NORTH WALL) STATIONS 4100 TO 4150				
DRAWN BY: ch	CHECKED BY: CR	PROJECT NO: 50135H-GEO1	DATE: 10-29-80	FIGURE NO: A-83



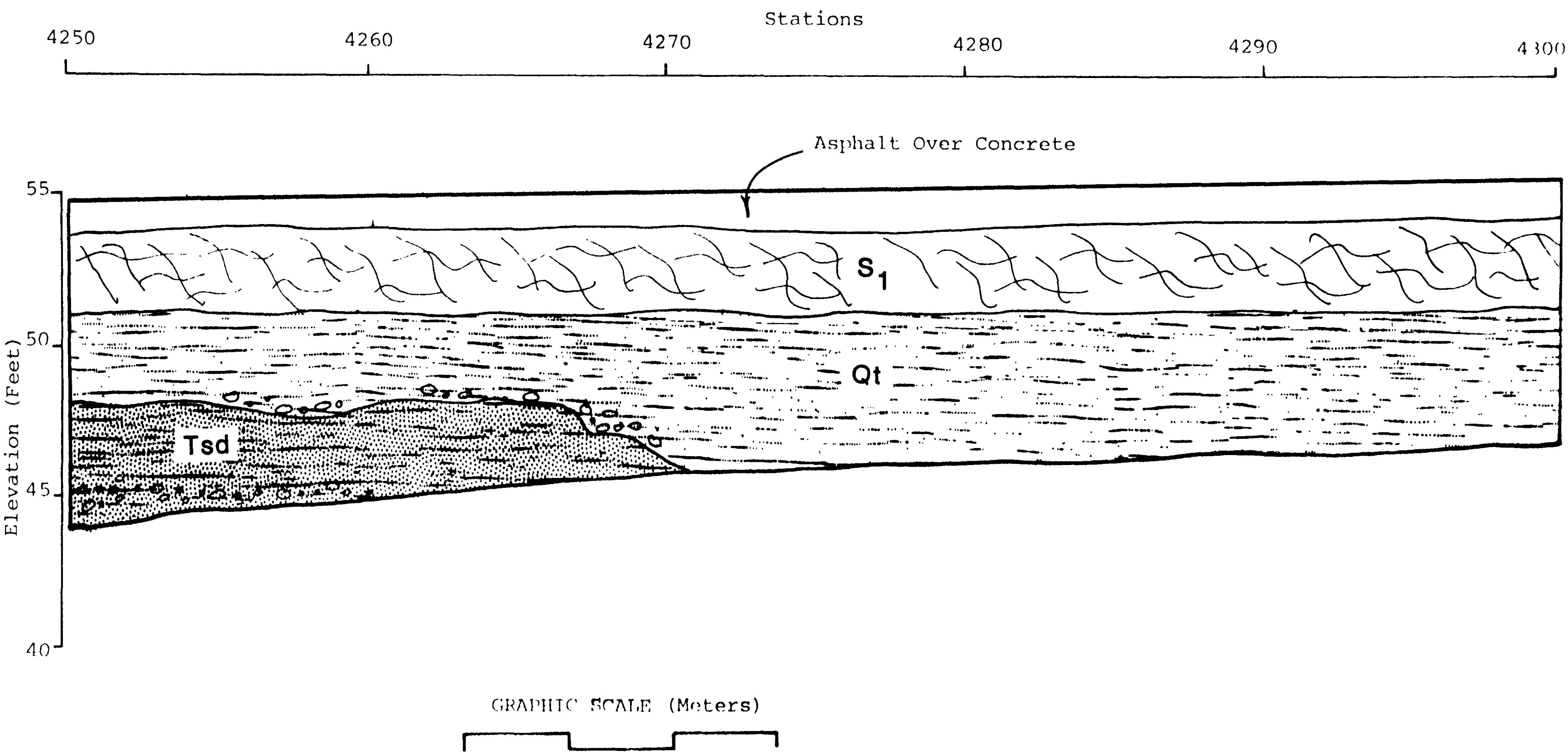
LOG OF TRENCH (NORTH WALL)
STATIONS 4150 TO 4200

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GEO1	DATE: 10-30-80	FIGURE NO: A-84



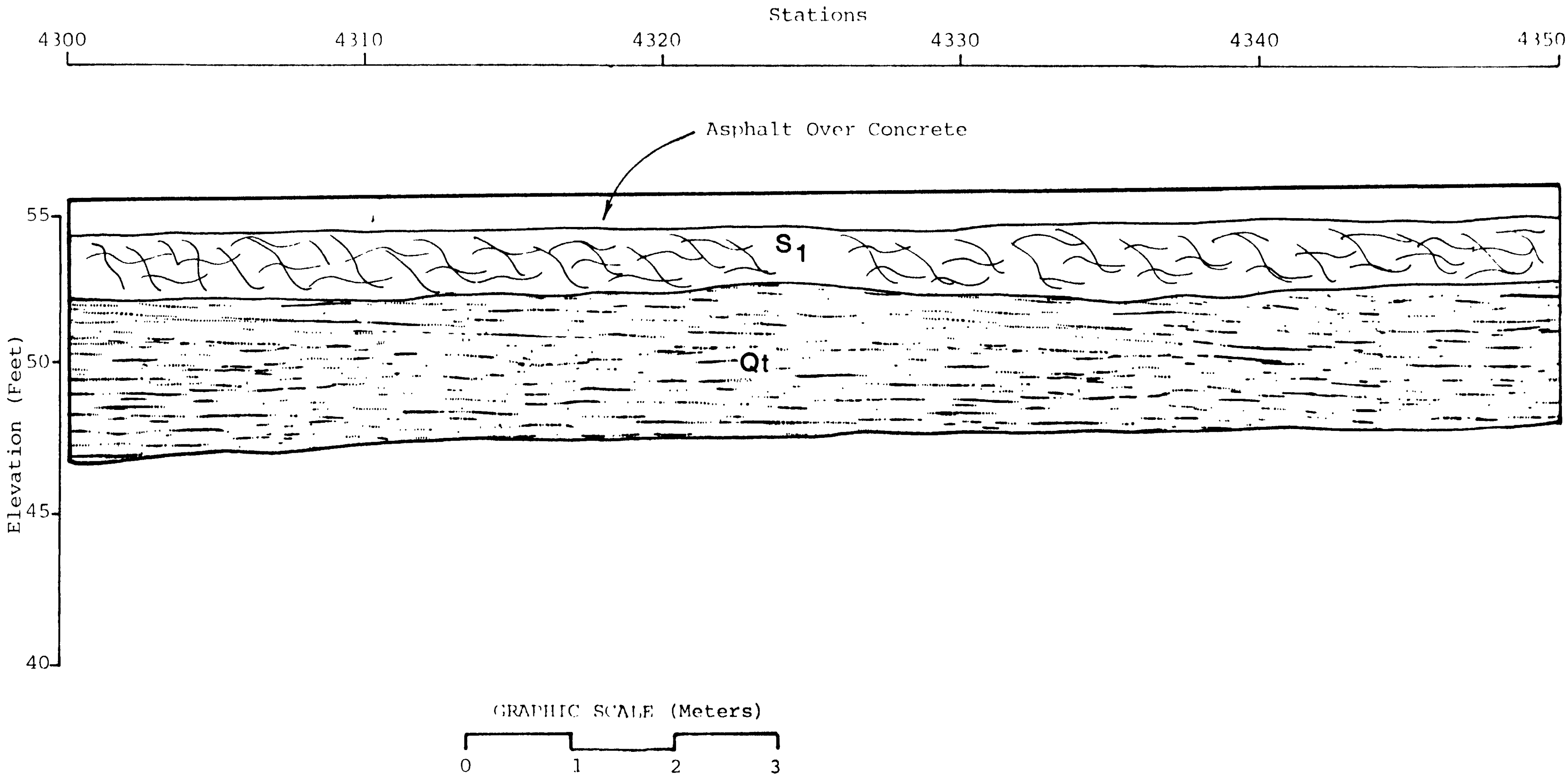
LOG OF TRENCH (NORTH WALL)
STATIONS 4200 TO 4250

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-30-80	FIGURE NO: A-[illegible]



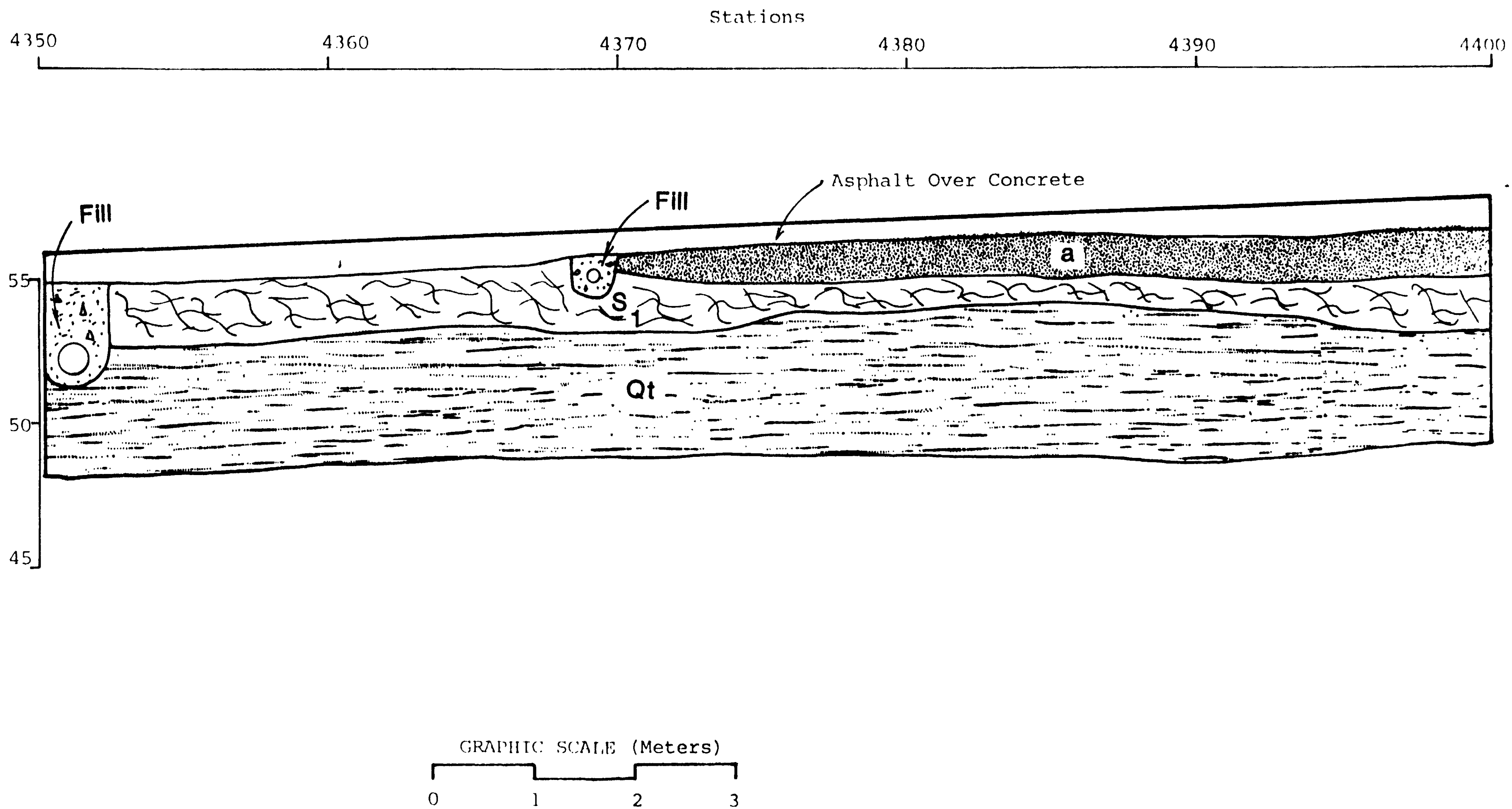
LOG OF TRENCH (NORTH WALL)
STATIONS 4250 TO 4300

DRAWN BY:	CHECKED BY:	PROJECT NO:	DATE:	FIGURE NO:
ch	EH	5Q135H-GEO1	10-30-80	A-[illegible]



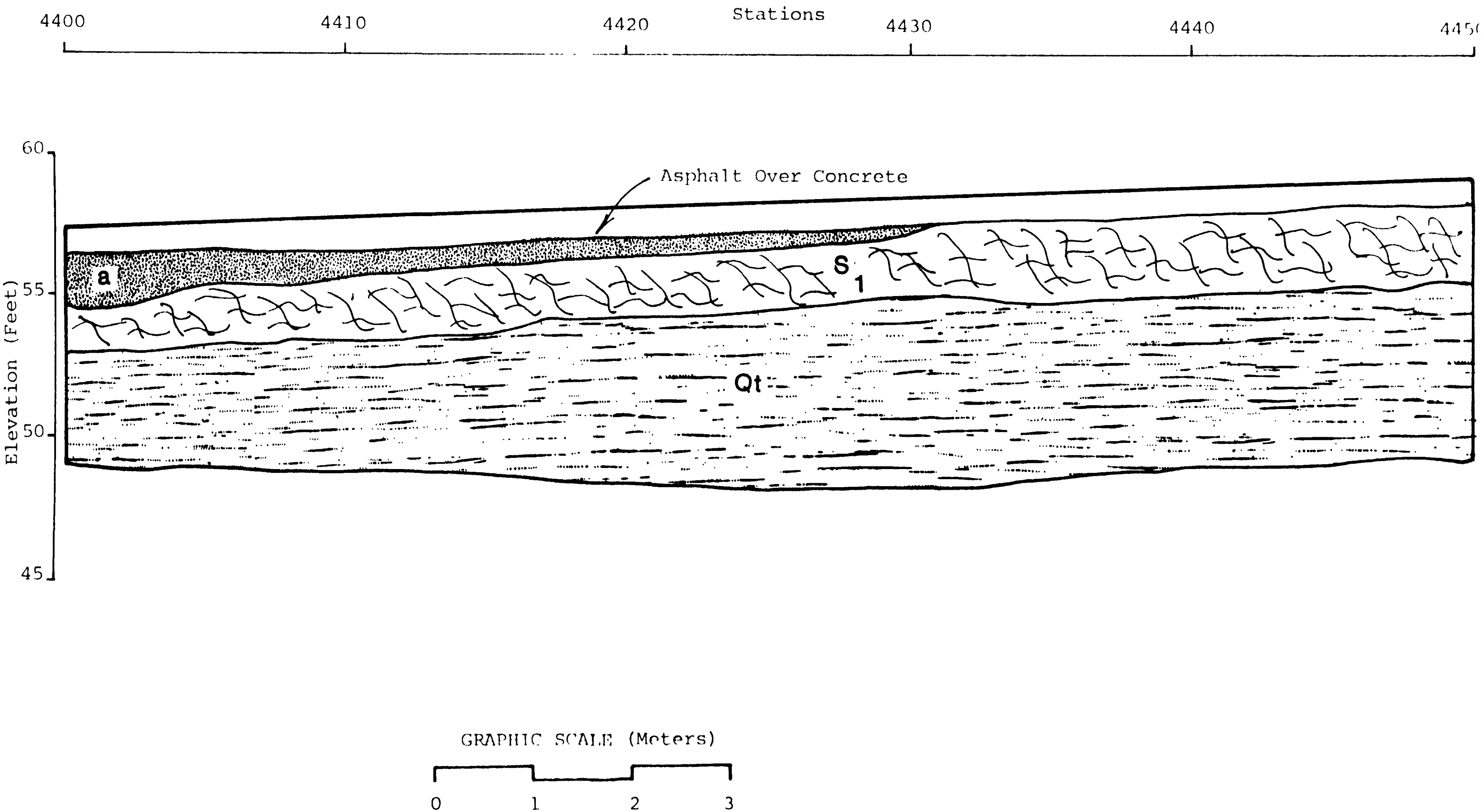
LOG OF TRENCH (NORTH WALL)
STATIONS 4300 TO 4350

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-30-80	FIGURE NO: A-87



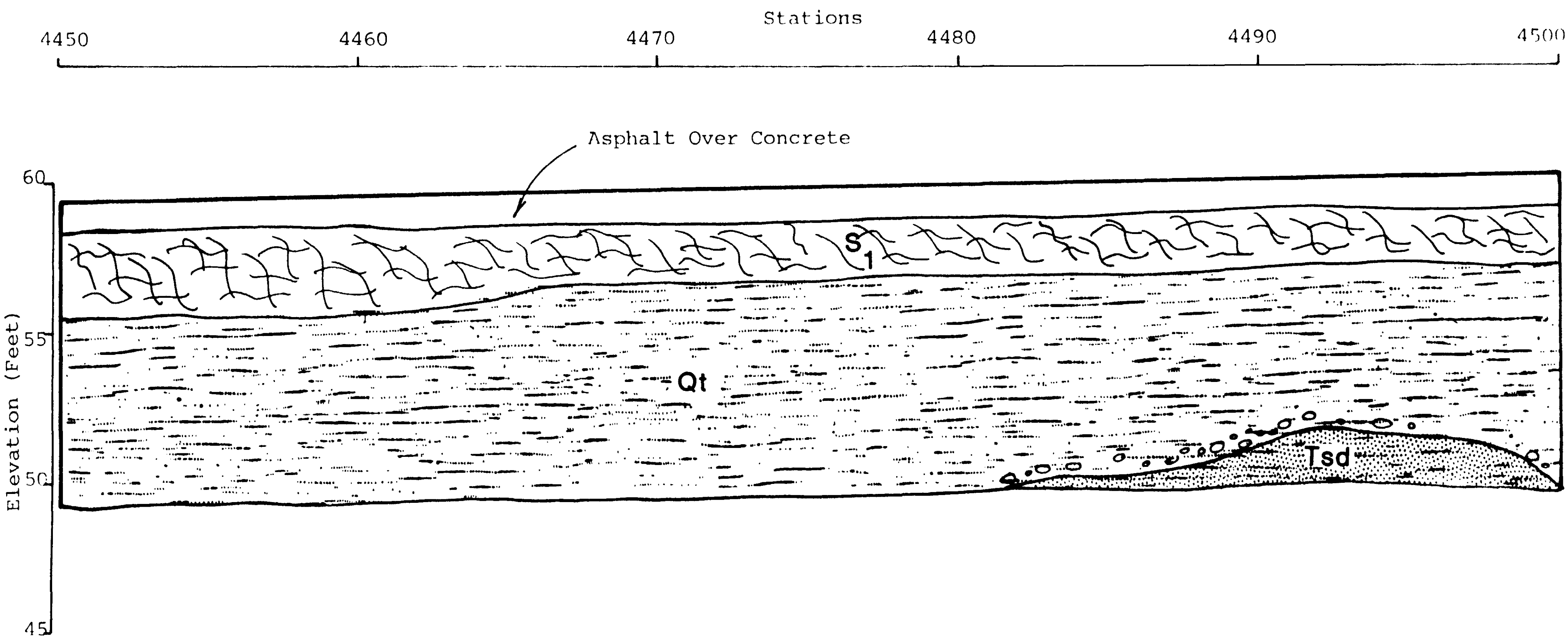
LOG OF TRENCH (NORTH WALL)
STATIONS 4350 TO 4400

DRAWN BY: ch	CHECKED BY: [illegible]	PROJECT NO: 501341I-GE01	DATE: 10-30-80	FIGURE NO: A-88



LOG OF TRENCH (NORTH WALL)
STATIONS 4400 TO 4450

DRAWN BY: ch	CHECKED BY: GA	PROJECT NO: 50135H-GEO1	DATE: 10-30-80	FIGURE NO: A-89

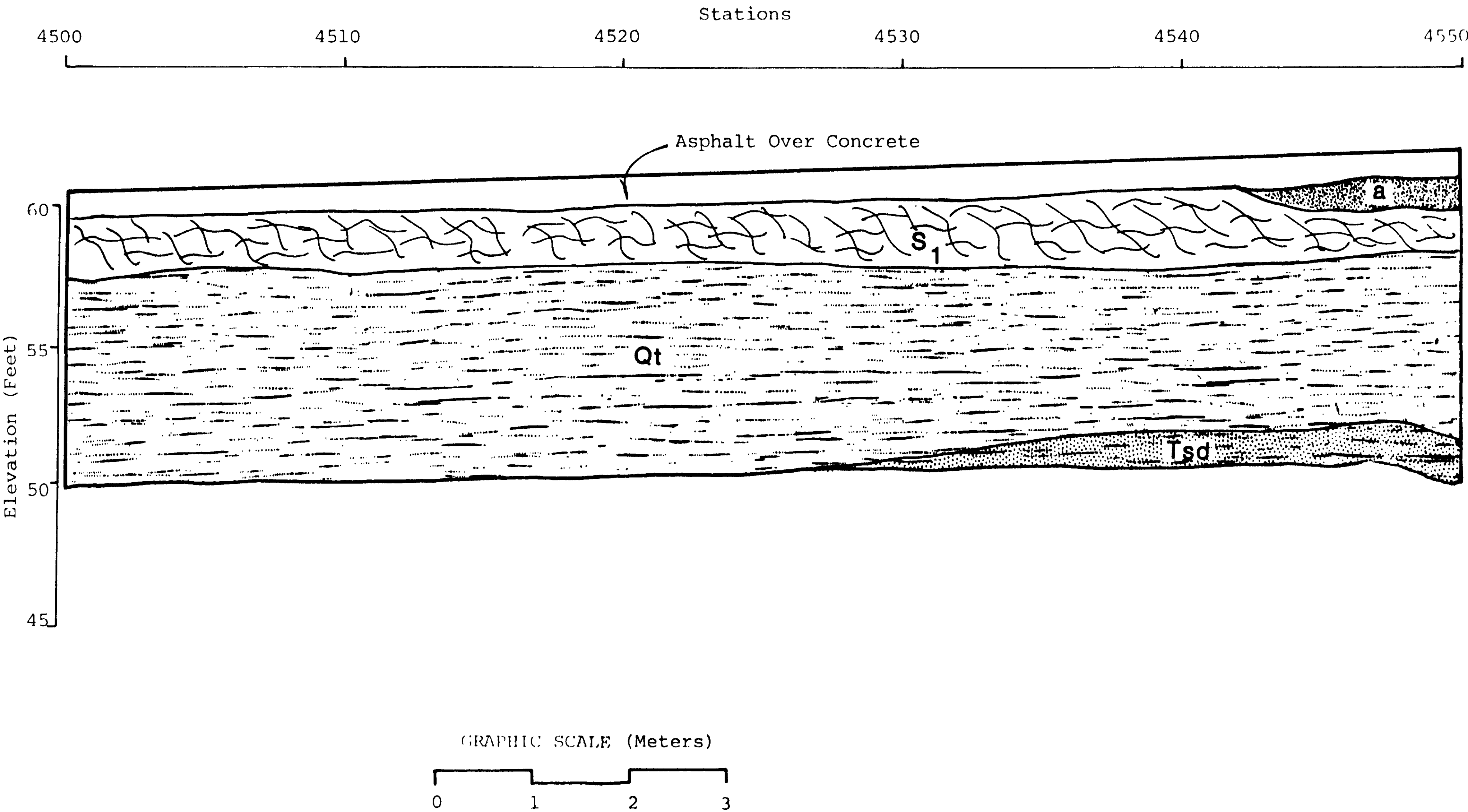


GRAPHIC SCALE (Meters)

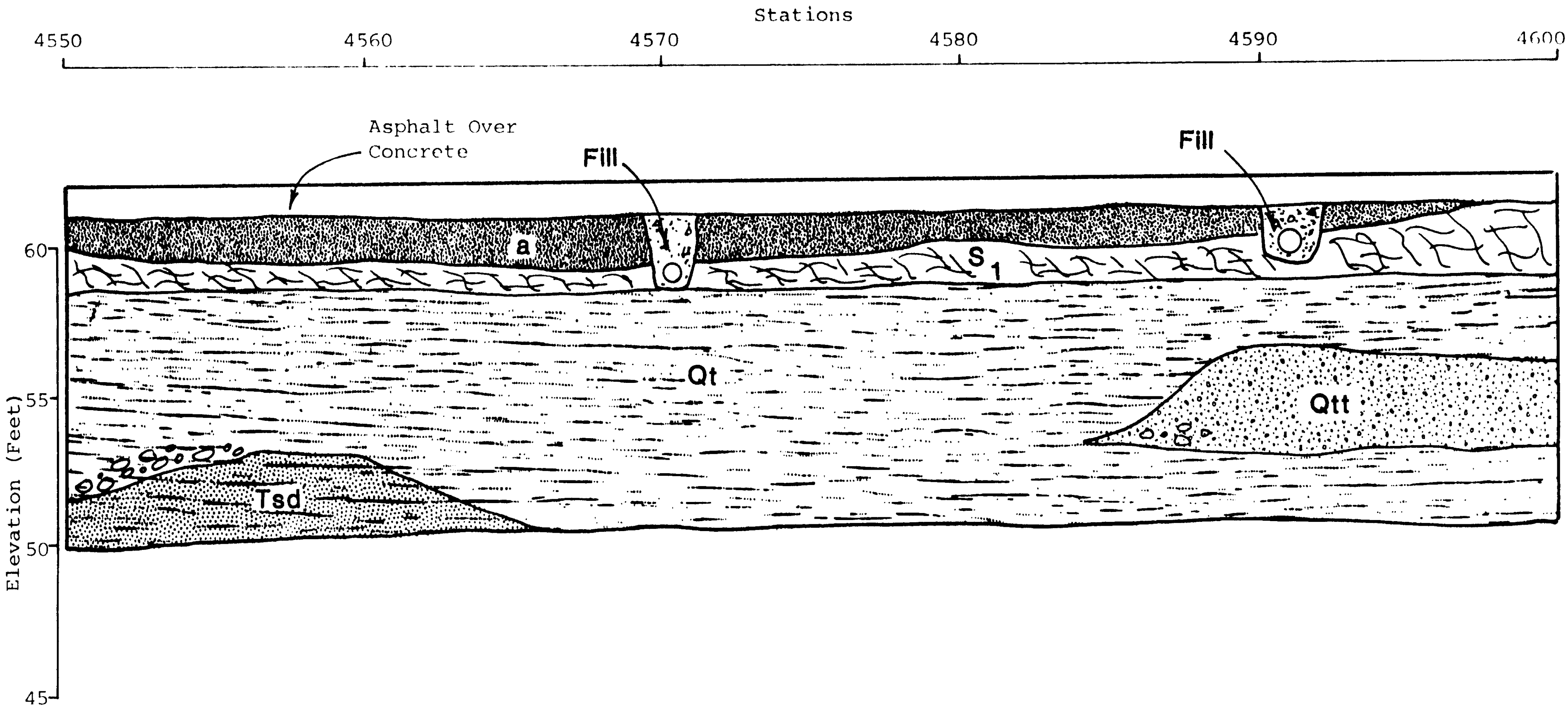
0 1 2 3

LOG OF TRENCH (NORTH WALL)
STATIONS 4450 TO 4500

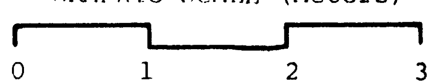
DRAWN BY: ch	CHECKED BY: GA	PROJECT NO: 50135H-GE01	DATE: 10-30-80	FIGURE NO: A-90



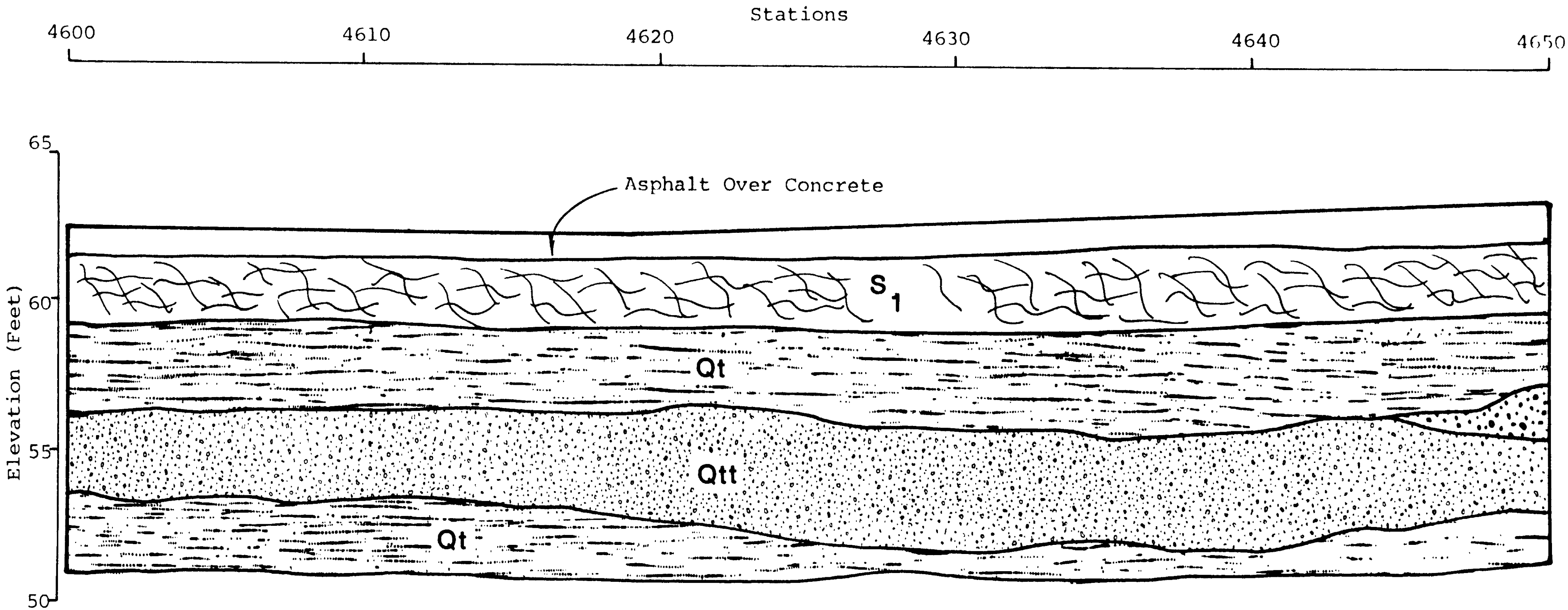
LOG OF TRENCH (NORTH WALL) STATIONS 4500 TO 4550				
DRAWN BY: ch	**CHECKED BY:** GA	**PROJECT NO:** 50135H-GE01	**DATE:** 10-31-80	**FIGURE NO:** A-91



GRAPHIC SCALE (Meters)

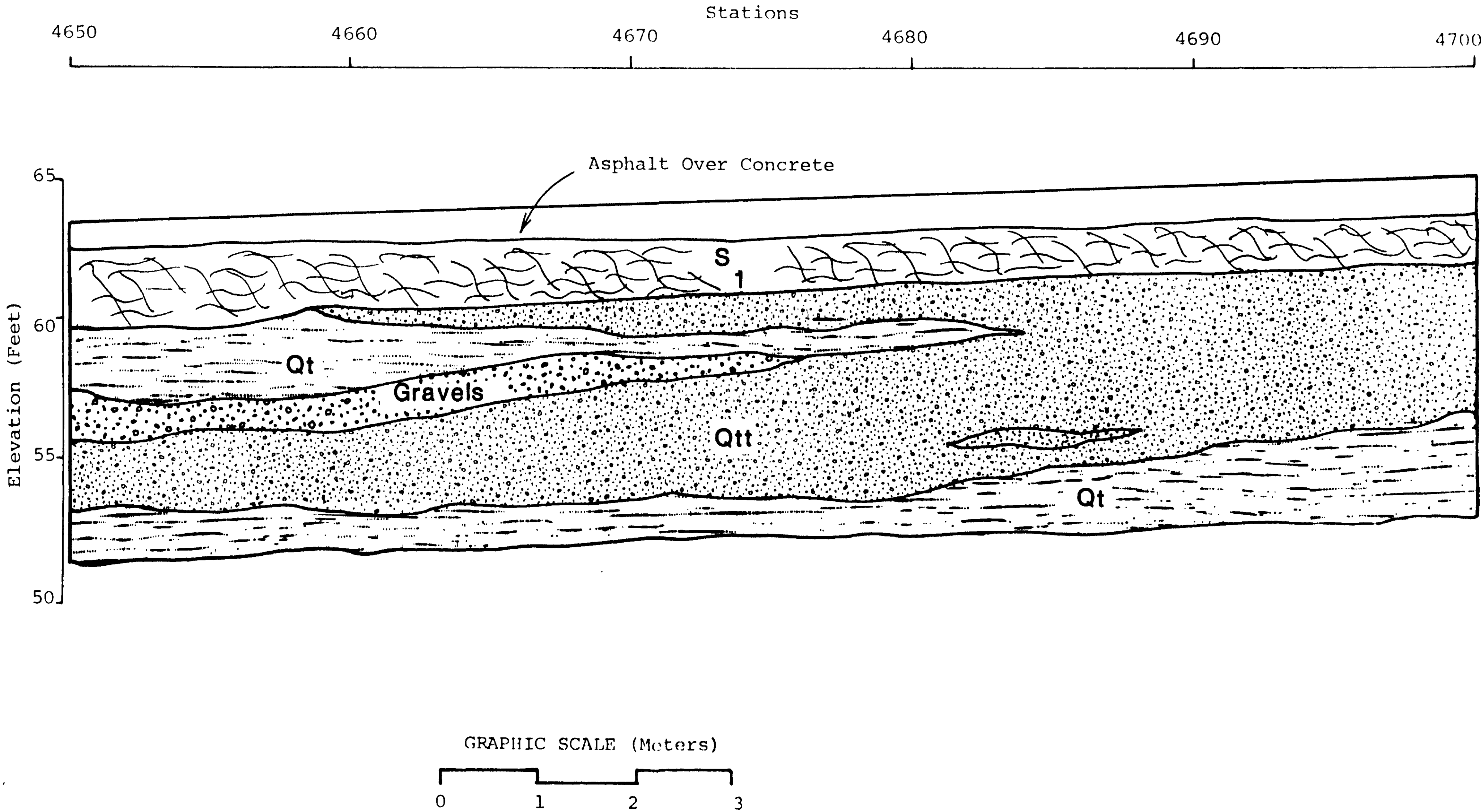


LOG OF TRENCH (NORTH WALL) STATIONS 4550 TO 4600				
DRAWN BY: ch	**CHECKED BY:**	**PROJECT NO:** 50135H-GE01	**DATE:** 10-31-80	**FIGURE NO:** A-92

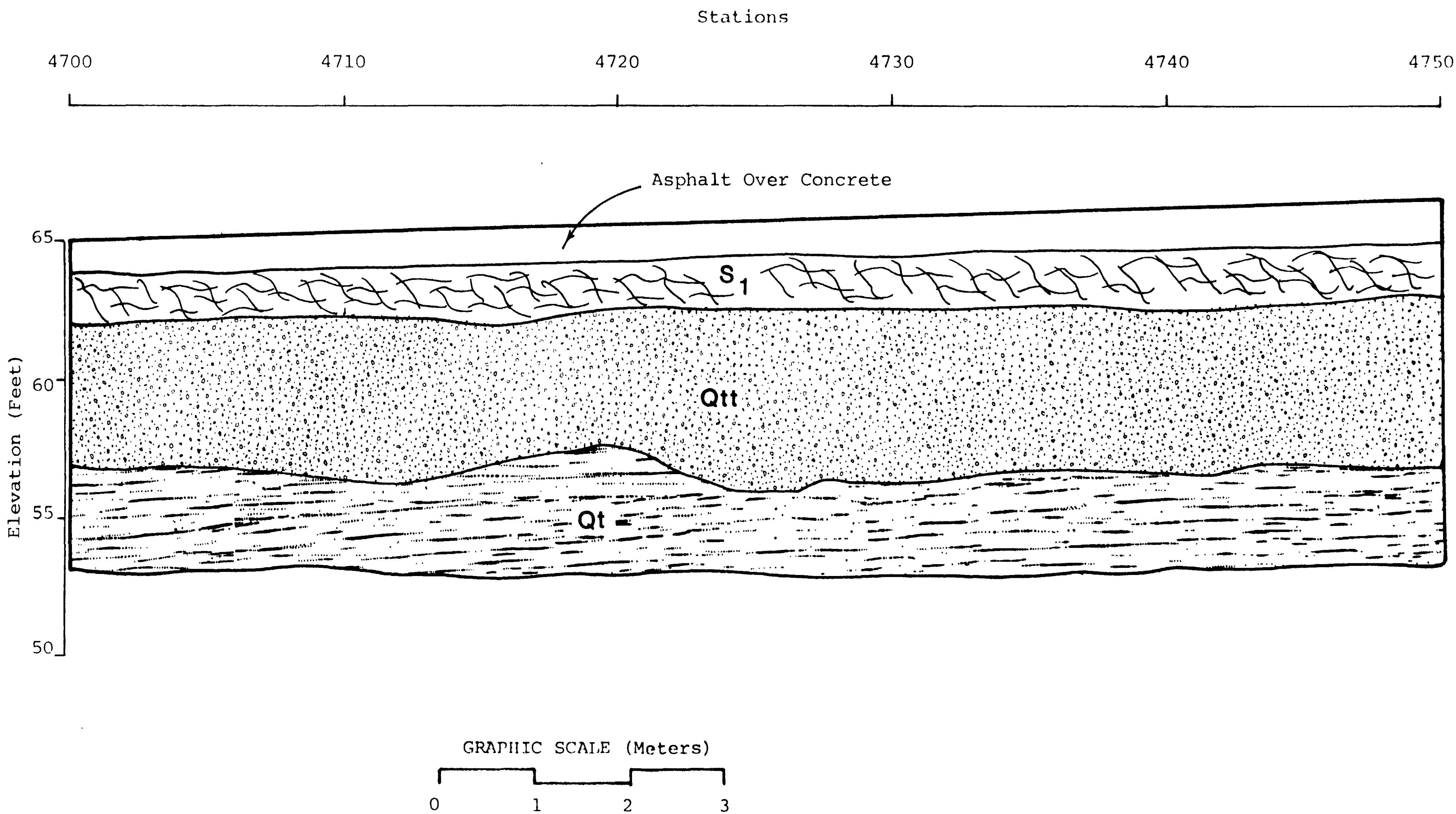


LOG OF TRENCH (NORTH WALL)
STATIONS 4600 TO 4650

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 10-31-80	FIGURE NO: A-93



LOG OF TRENCH (NORTH WALL) STATIONS 4650 TO 4700				
DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50125H-GEO1	DATE: 10-31-80	FIGURE NO: A-94



LOG OF TRENCH (NORTH WALL) STATIONS 4700 TO 4750				
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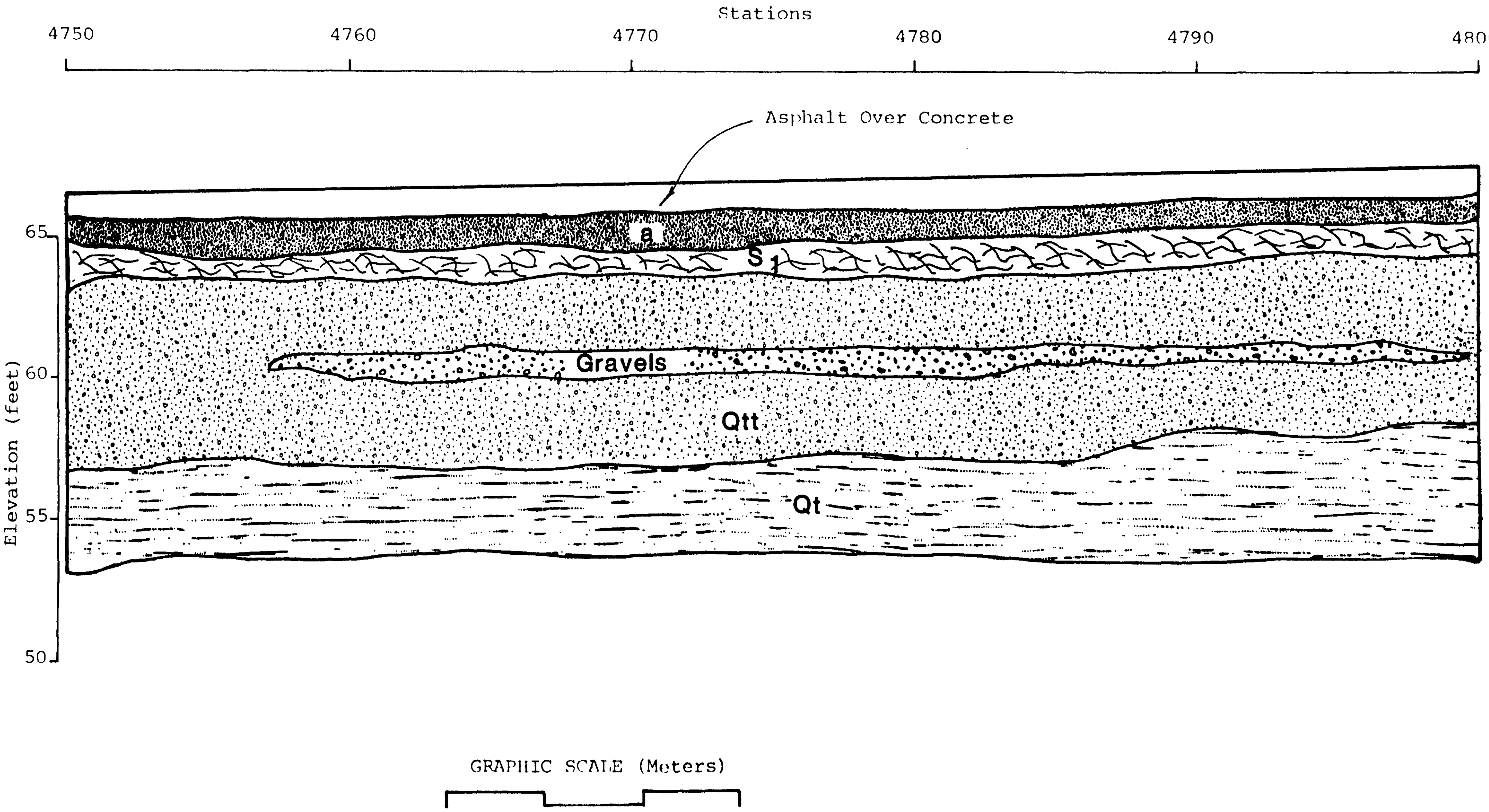
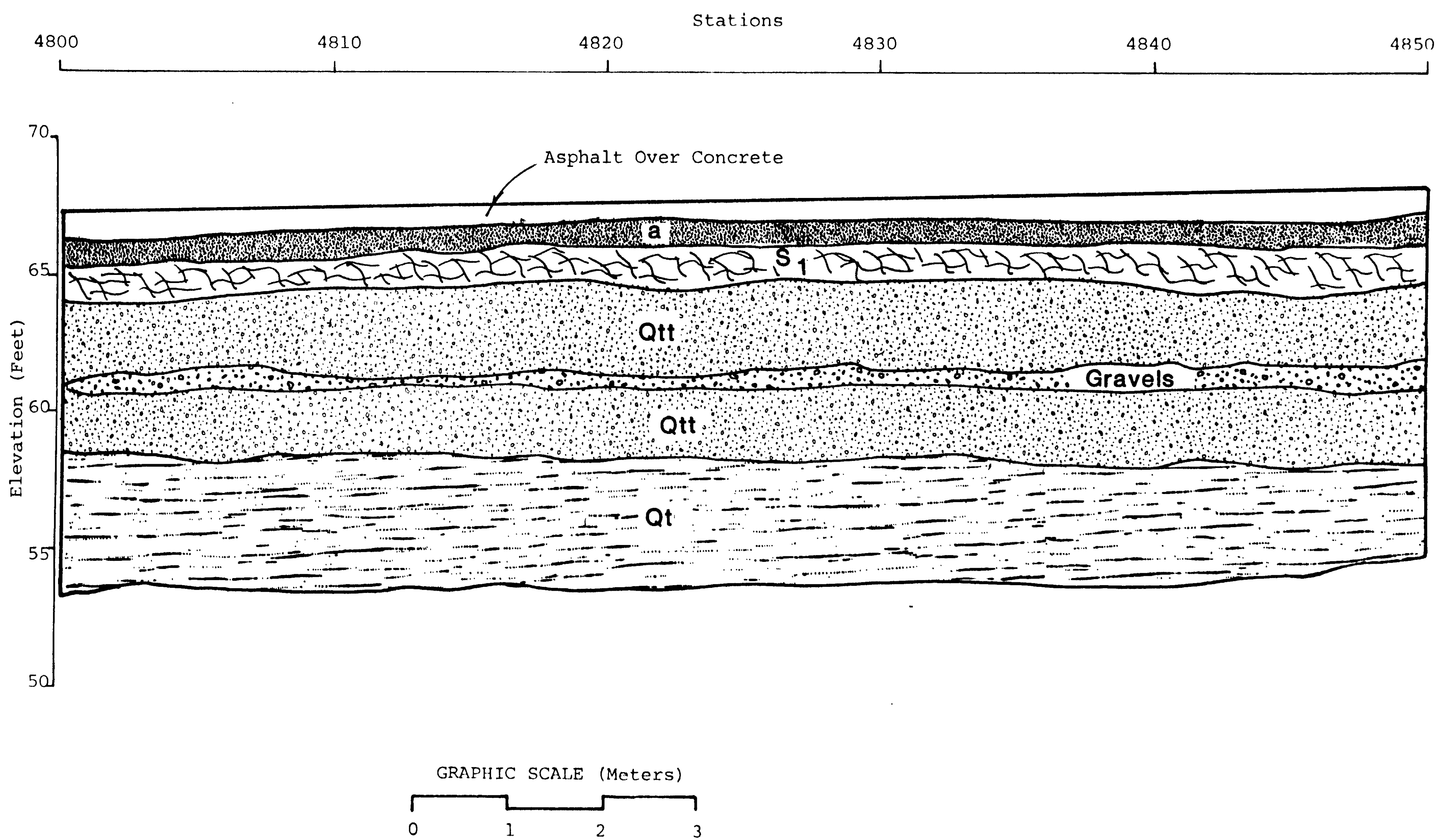


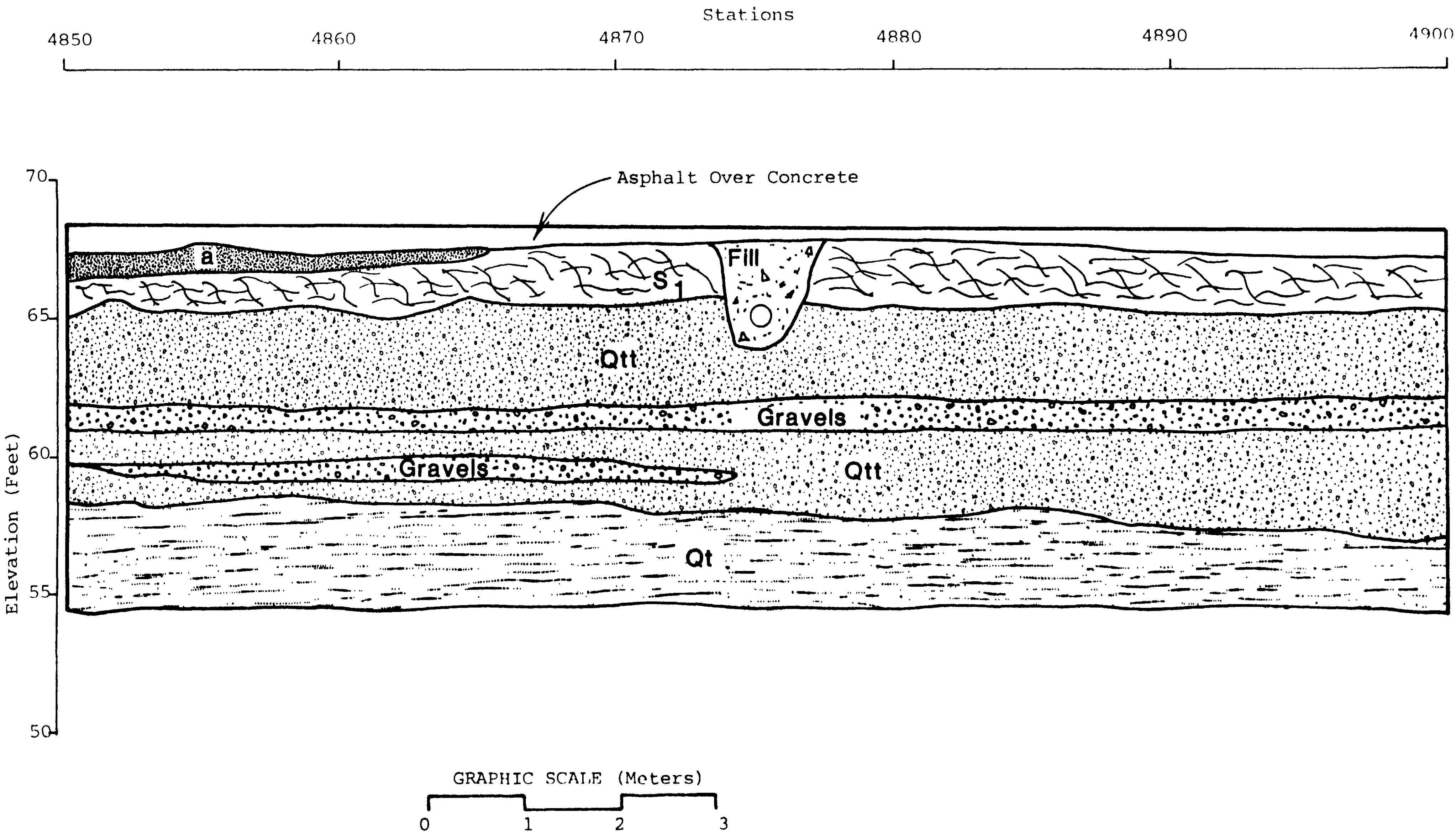
LOG OF TRENCH (NORTH WALL)
STATIONS 4750 TO 4800

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GEO1	DATE: 10-31-80	FIGURE NO: A-96



LOG OF TRENCH (NORTH WALL)
STATIONS 4800 TO 4850

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GEO1	DATE: 10-31-80	FIGURE NO: A-97



LOG OF TRENCH (NORTH WALL) STATIONS 4850 TO 4900				
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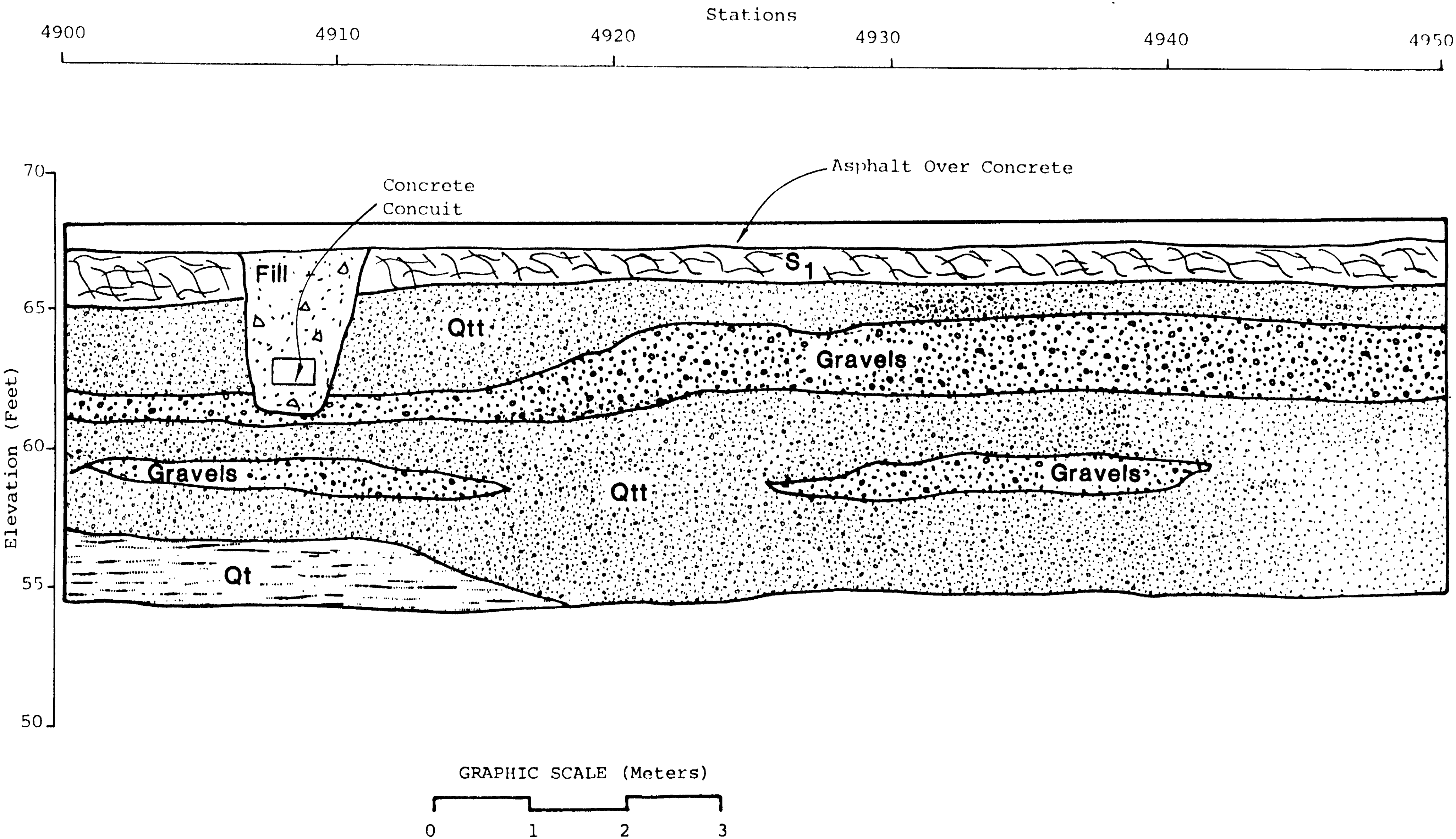
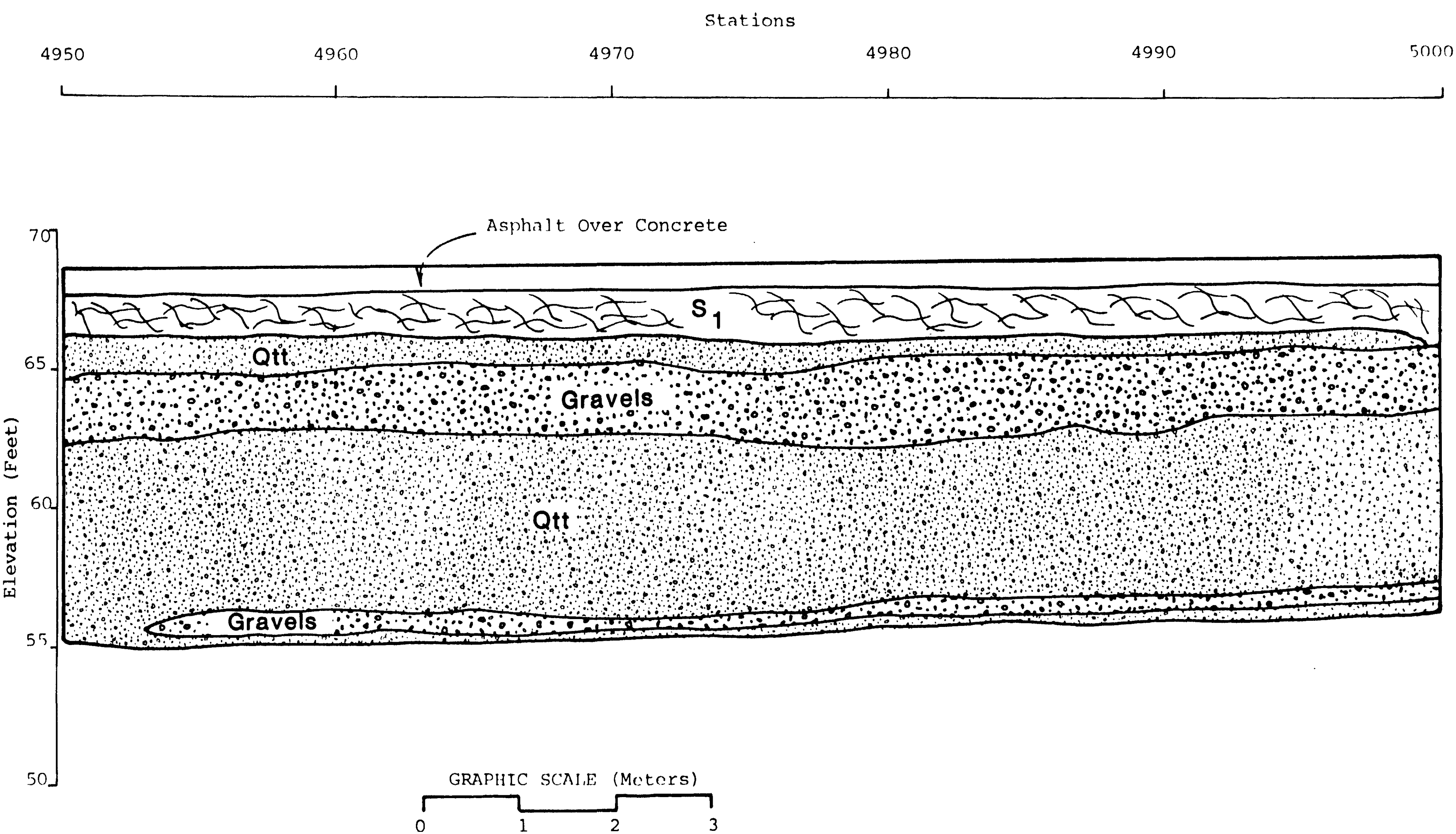


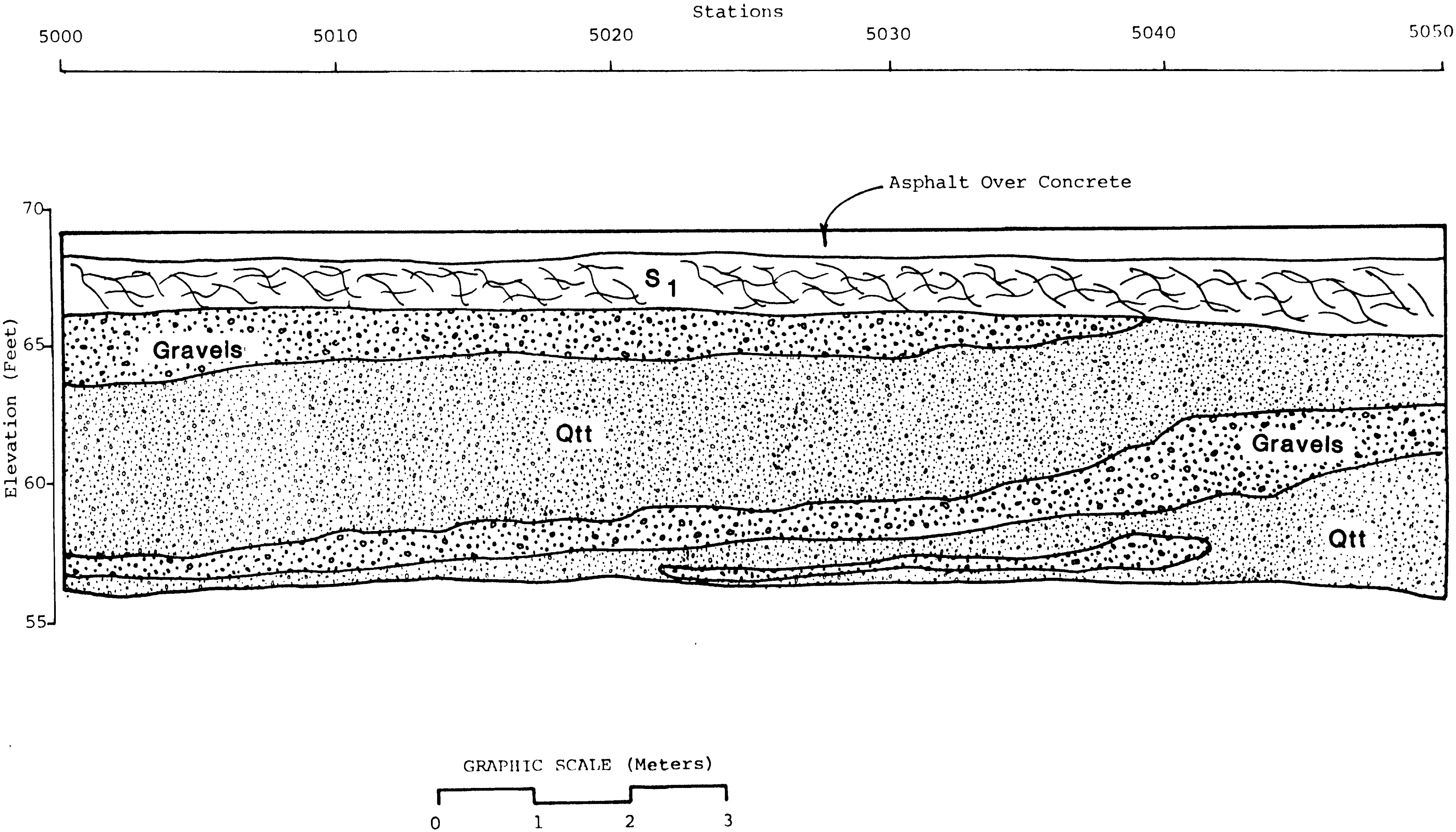
LOG OF TRENCH (NORTH WALL)
STATIONS 4900 TO 4950

DRAWN BY: ch	**CHECKED BY:** EA	**PROJECT NO:** 50135H-GEO1	**DATE:** 11-3-80	**FIGURE NO:** A-99



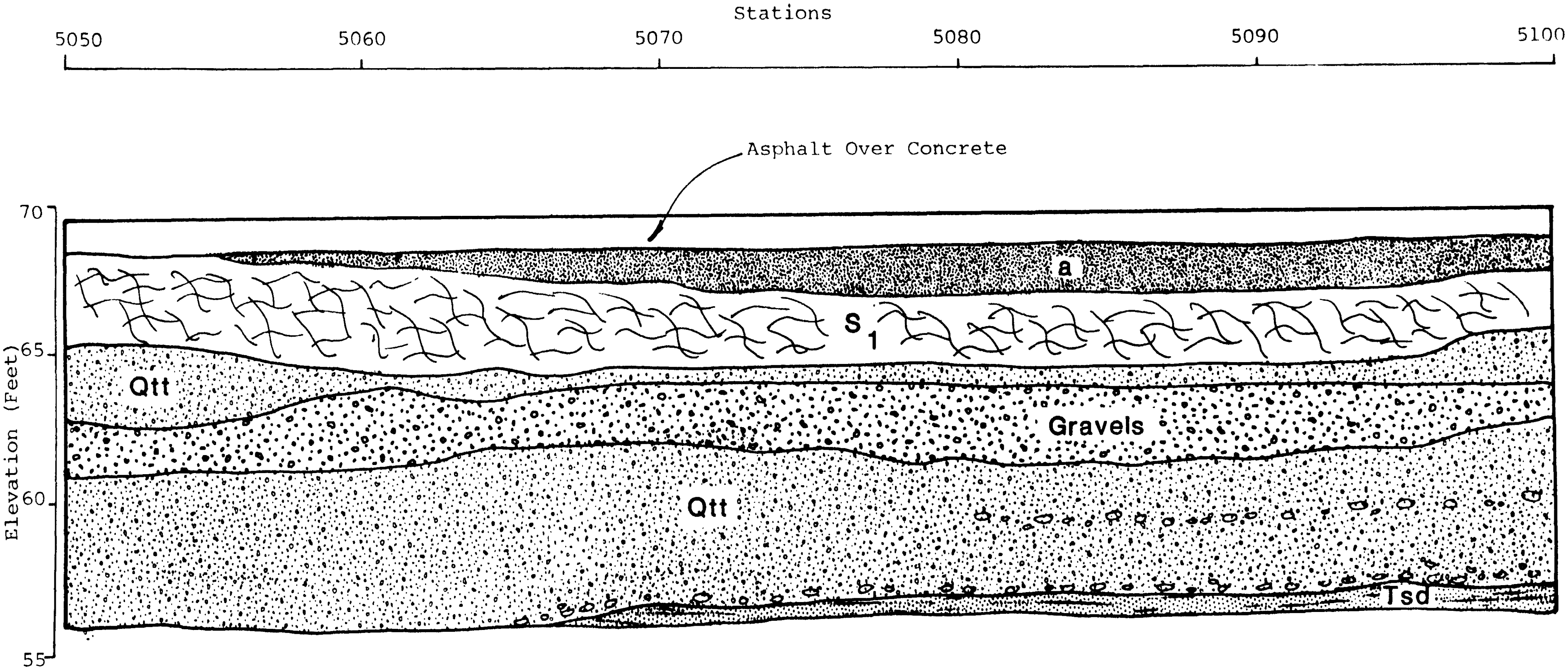
LOG OF TRENCH (NORTH WALL)
STATIONS 4950 TO 5000

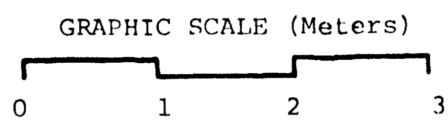
DRAWN BY: ch	CHECKED BY: GA	PROJECT NO: 50135H-GEO1	DATE: 11-3-80	FIGURE NO: A-100



LOG OF TRENCH (NORTH WALL)
STATIONS 5000 TO 5050

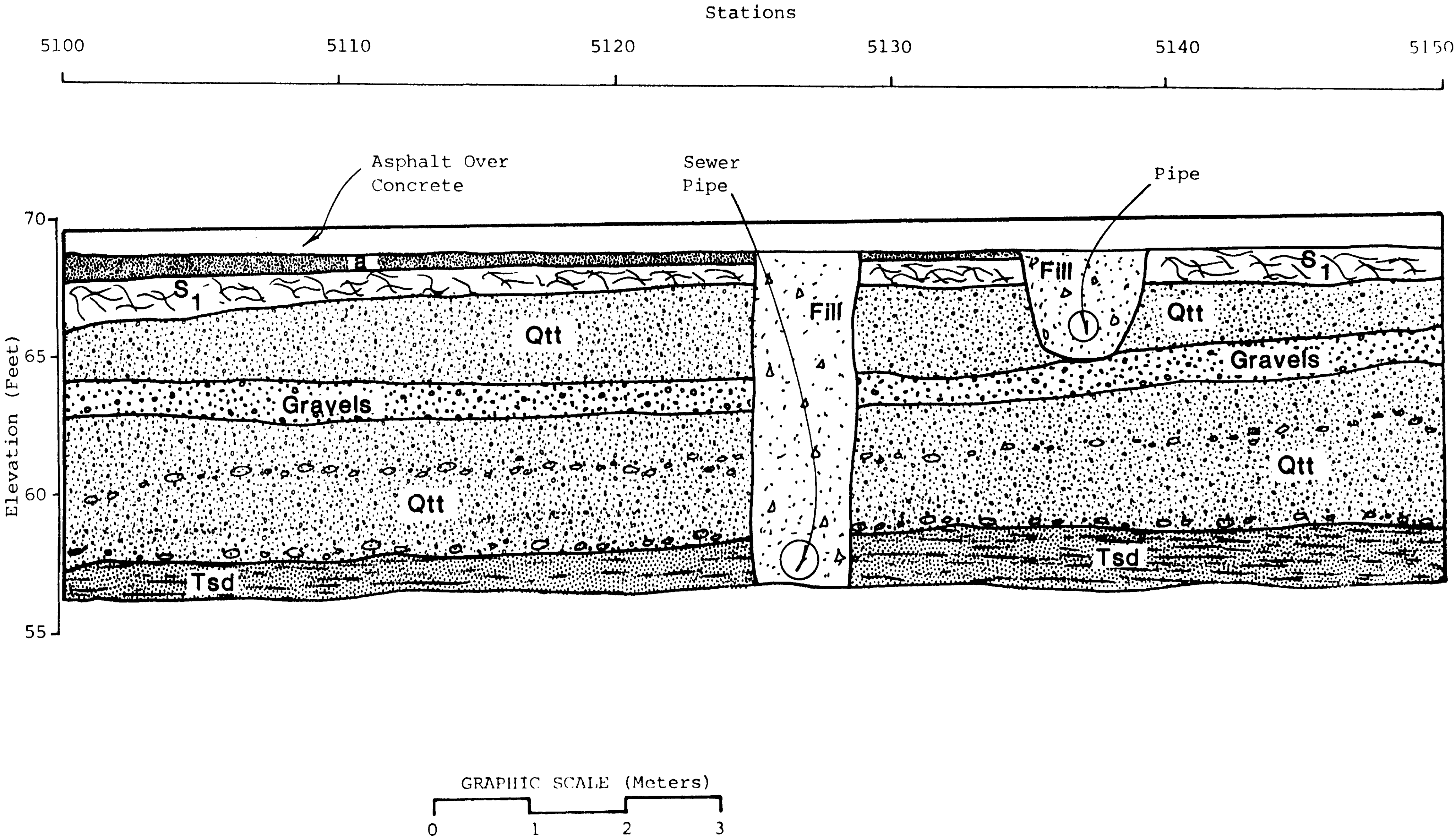
DRAWN BY: ch	**CHECKED BY:**	**PROJECT NO:** 50135H-GE01	**DATE:** 11-3-80	**FIGURE NO:** A-101





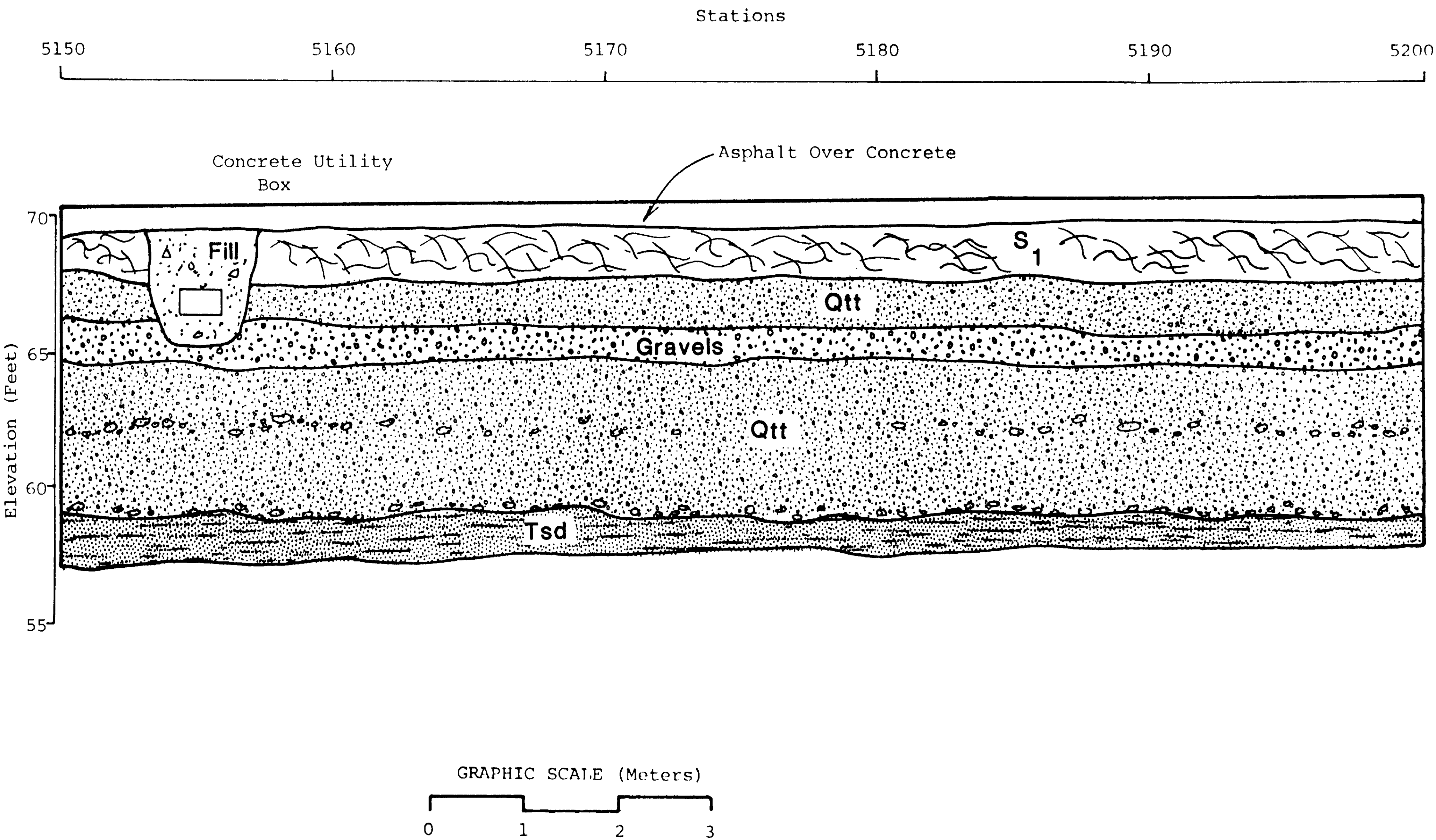
LOG OF TRENCH (NORTH WALL)
STATIONS 5050 TO 5100

DRAWN BY: ch	CHECKED BY: ER	PROJECT NO: 50135H-GE01	DATE: 11-3-80	FIGURE NO: A-102



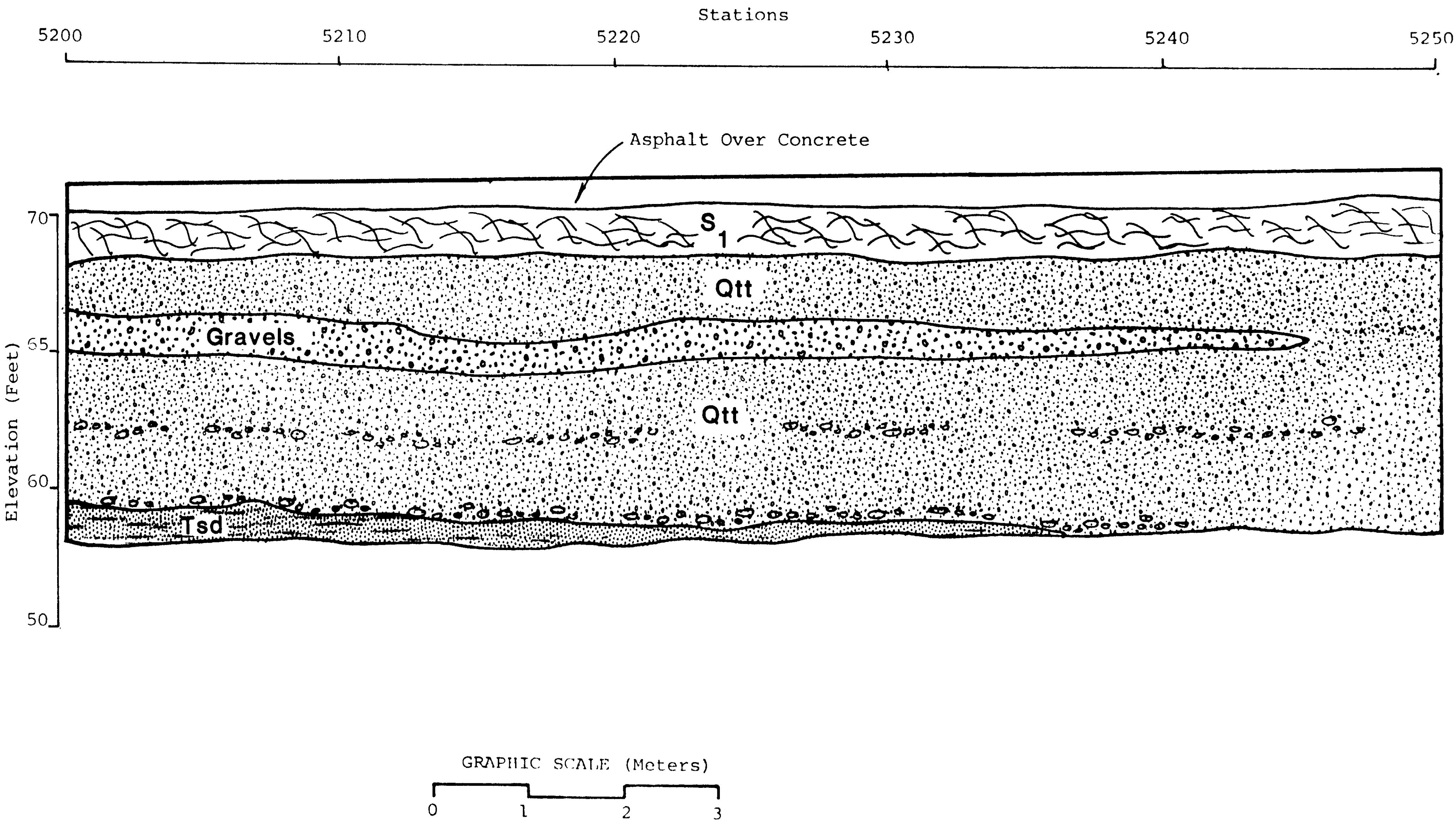
LOG OF TRENCH (NORTH WALL)
STATIONS 5100 TO 5150

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GEO1	DATE: 11-3-80	FIGURE NO: A-103



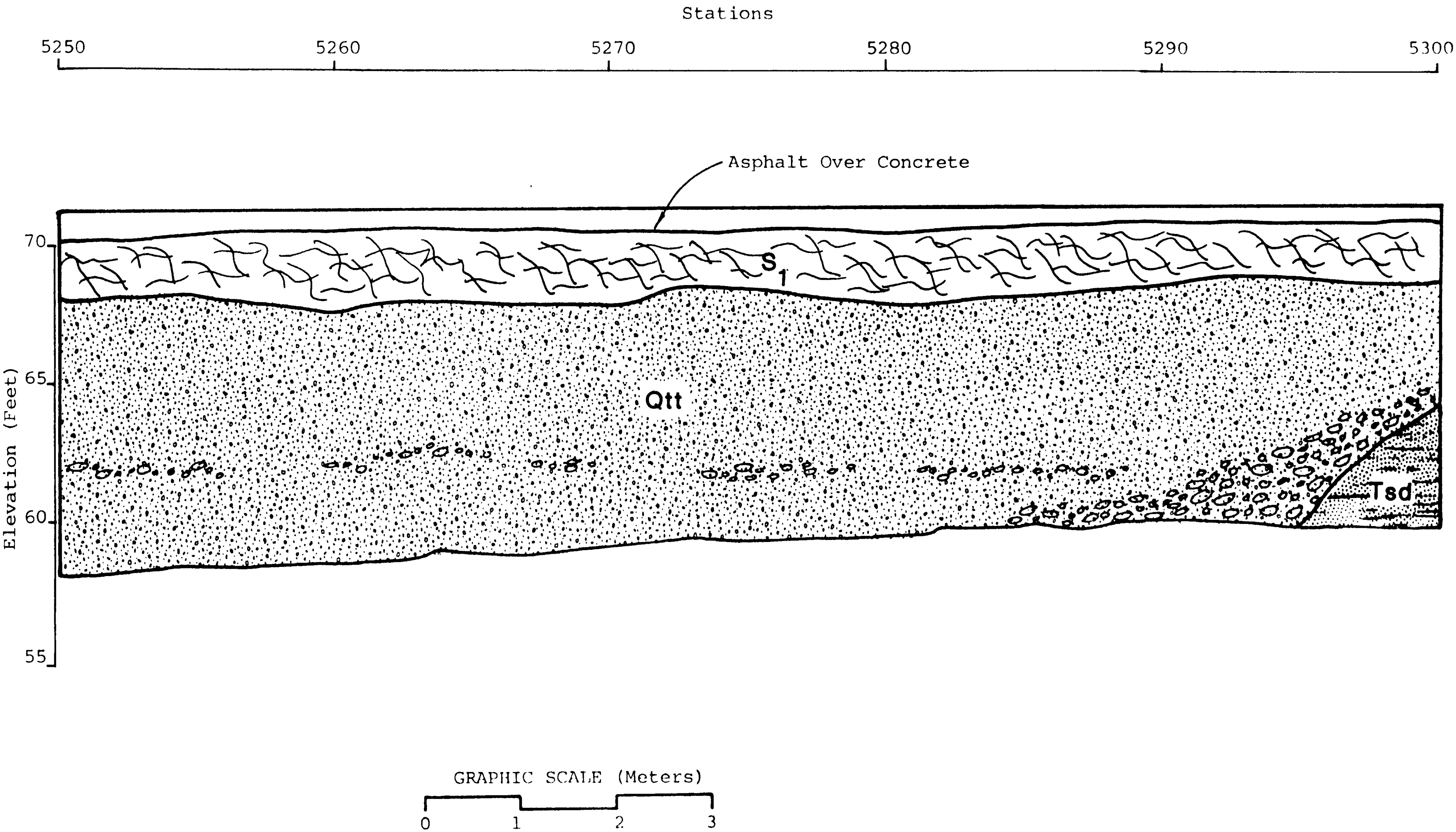
LOG OF TRENCH (NORTH WALL)
STATIONS 5150 TO 5200

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 11-3-80	FIGURE NO: A-104



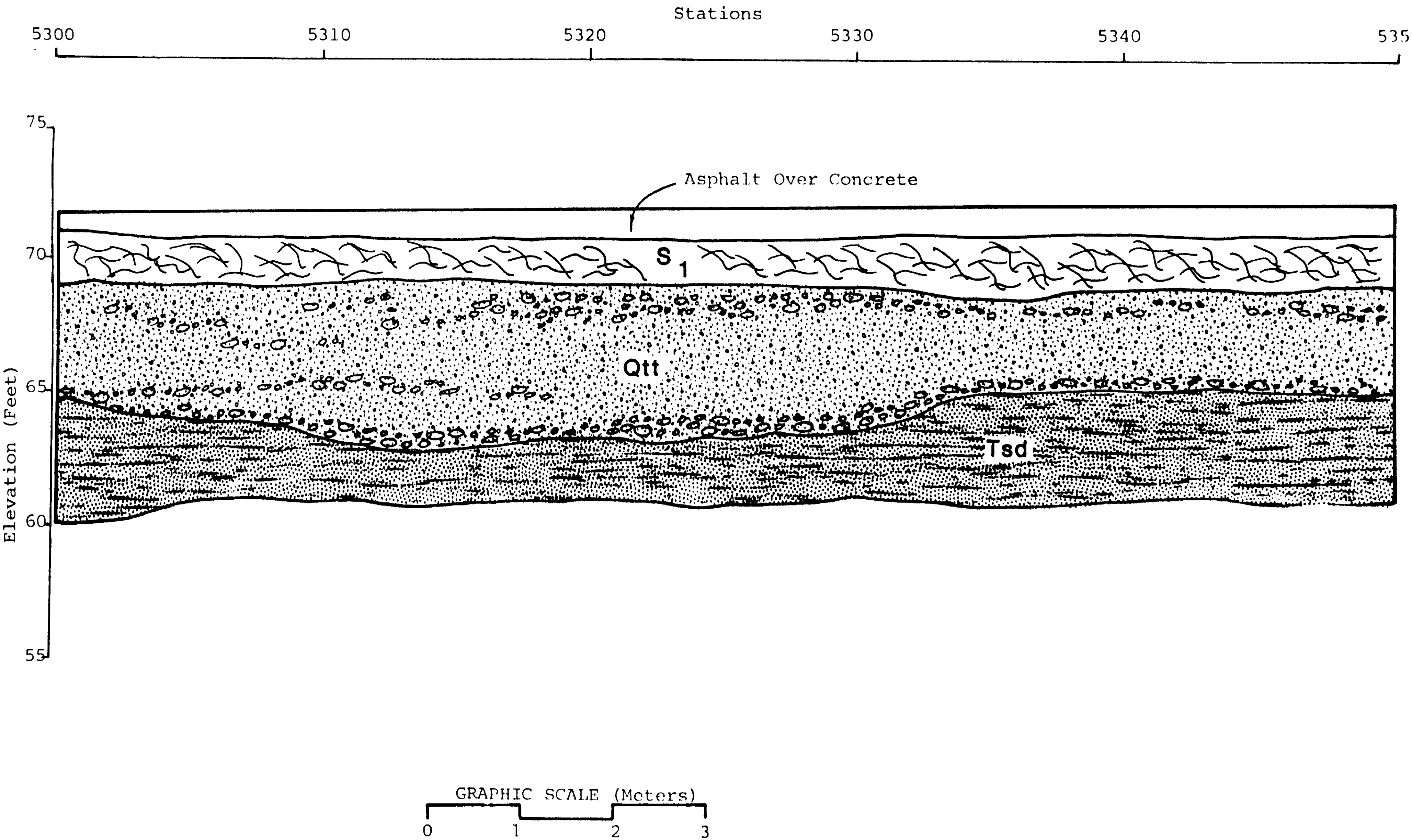
LOG OF TRENCH (NORTH WALL)
STATIONS 5200 TO 5250

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GE01	DATE: 11-3-80	FIGURE NO: A-105



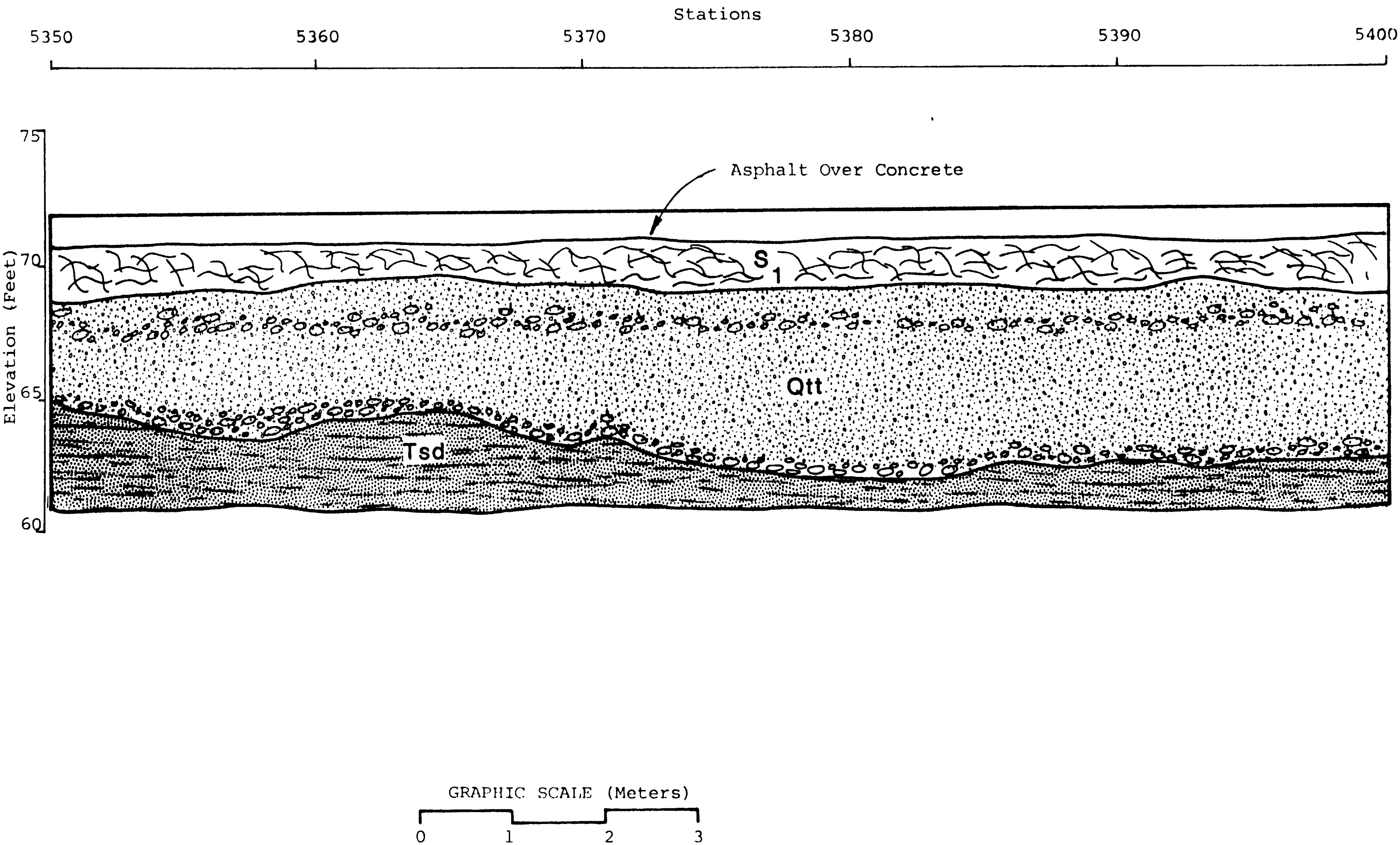
LOG OF TRENCH (NORTH WALL)
STATIONS 5250 TO 5300

DRAWN BY: ch	**CHECKED BY:** EA	**PROJECT NO:** 50135H-GEO1	**DATE:** 11-3-80	**FIGURE NO:** A-106

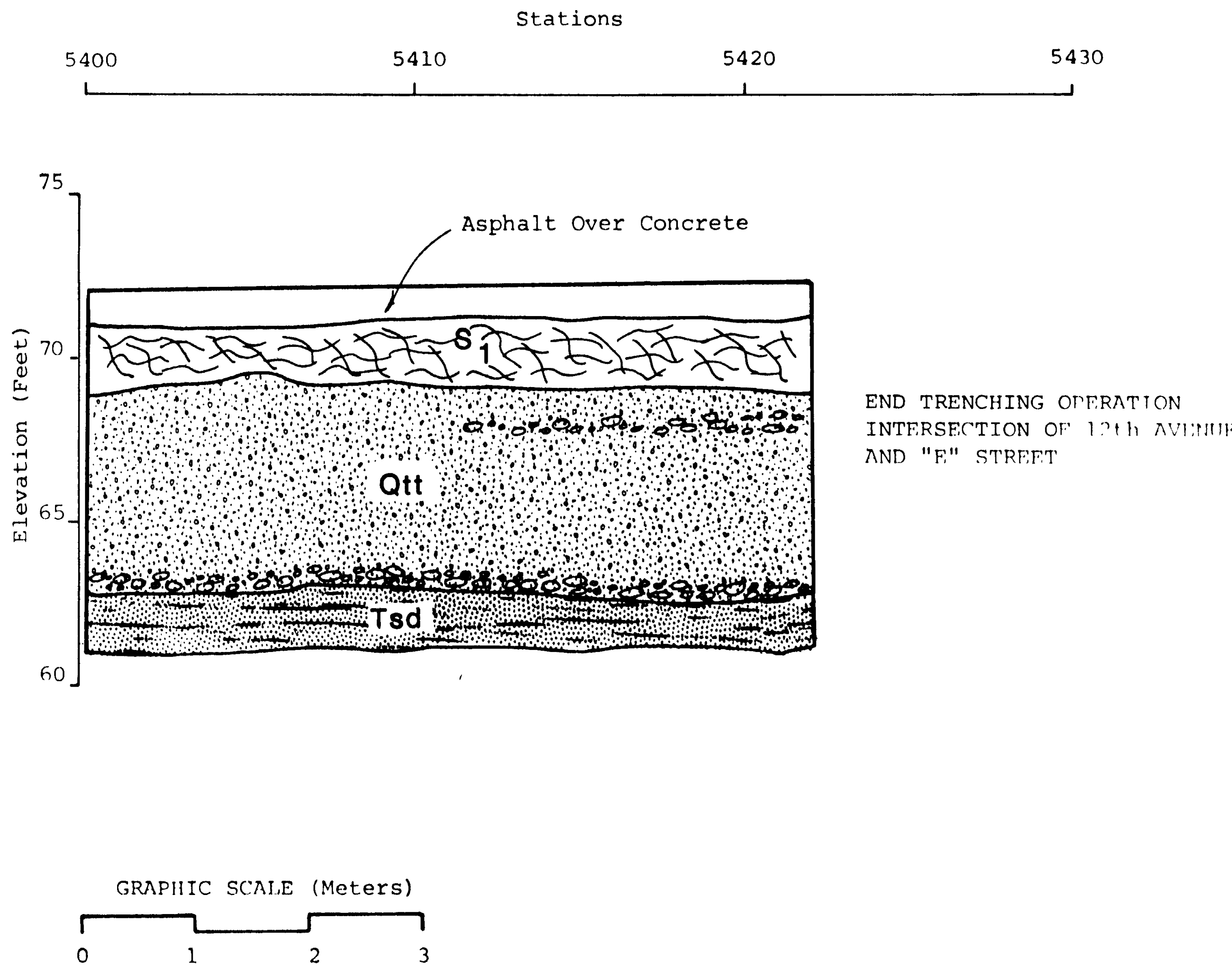


LOG OF TRENCH (NORTH WALL)
STATIONS 5300 TO 5350

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GEO1	DATE: 11-3-80	FIGURE NO: A-107



LOG OF TRENCH (NORTH WALL) STATIONS 5350 TO 5400				
DRAWN BY: ch	**CHECKED BY:** EA	**PROJECT NO:** 50135H-GEO1	**DATE:** 11-4-80	**FIGURE NO:** A-108



LOG OF TRENCH (NORTH WALL)
STATIONS 5400 TO 5430

DRAWN BY: ch	**CHECKED BY:** GA	**PROJECT NO:** 50135H-GE01	**DATE:** 11-4-80	**FIGURE NO:** A-109

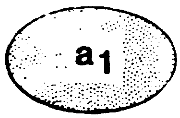
APPENDIX B

KEY TO LOGS

AND

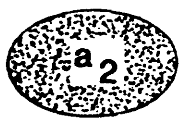
LOGS OF TRENCH IN CORONADO, CALIFORNIA

KEY TO LOGS



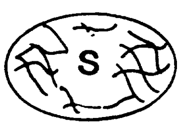
HOLOCENE AEOLIAN DEPOSITS

Very porous, friable, pale brown silty very fine-grained sand



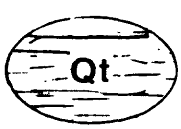
HOLOCENE ALLUVIAL DEPOSITS

Porous, friable, light reddish-brown silty fine sand; poorly formed soil profile in upper 5cm (12 inches) consisting of grayish brown, slightly clayey silty sand containing concentrations of manganese staining. Gradational "A" to "C" profile with no distinct "B" horizon.



PALEOSOL

Dark reddish-brown clayey sand. The paleosol is hard, and has a poorly to moderately well-developed, medium angular to crumbly structure and thin clay skins. Manganese oxide staining is concentrated along base of this paleosol.

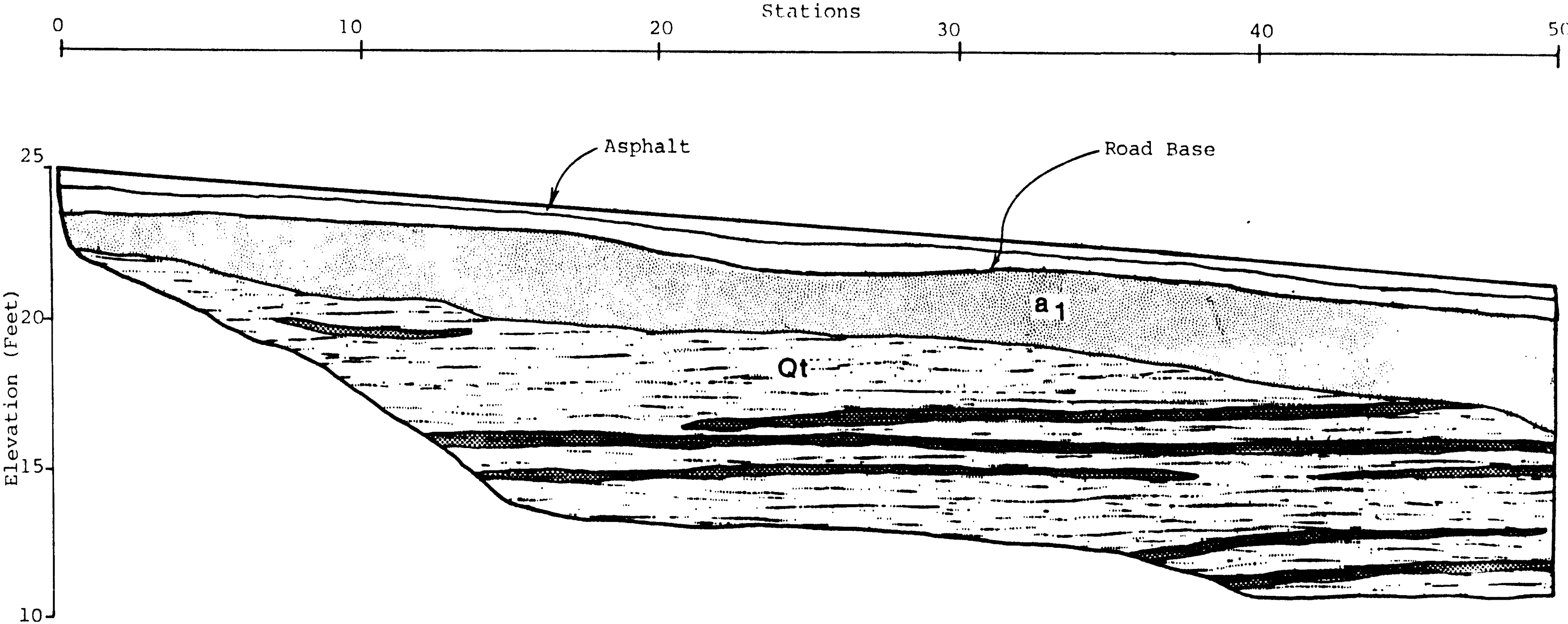


LATE PLEISTOCENE MARINE DEPOSITS

Thin to moderately bedded, light gray to light reddish-brown, silty fine to coarse-grained sand. The light gray beds are finely laminated friable sand, whereas the light reddish-brown beds are lightly cemented with iron oxide.

LITHOLOGIC OR GEOLOGIC UNIT CONTACT

FIGURE NO. B-1

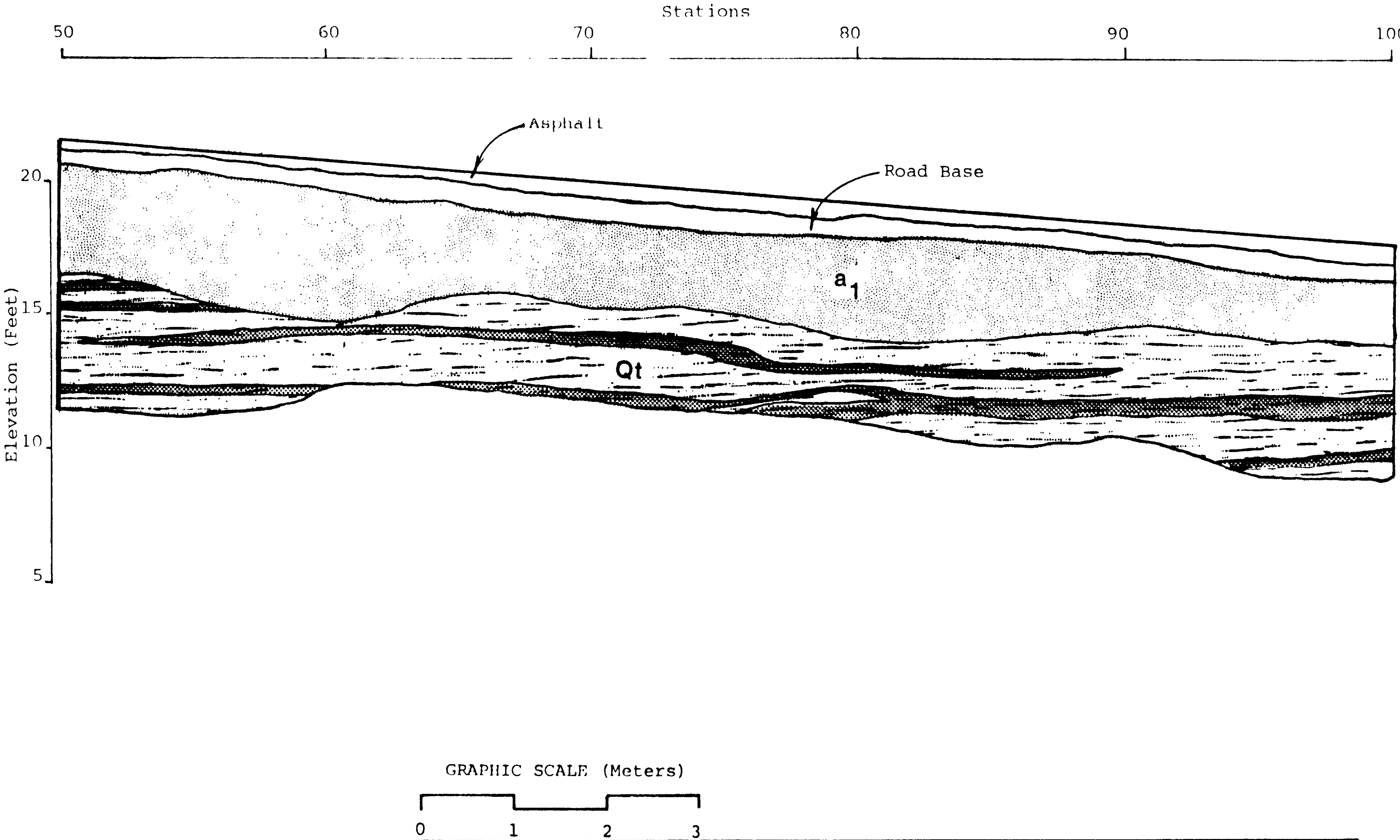


GRAPHIC SCALE (Meters)

0 1 2 3

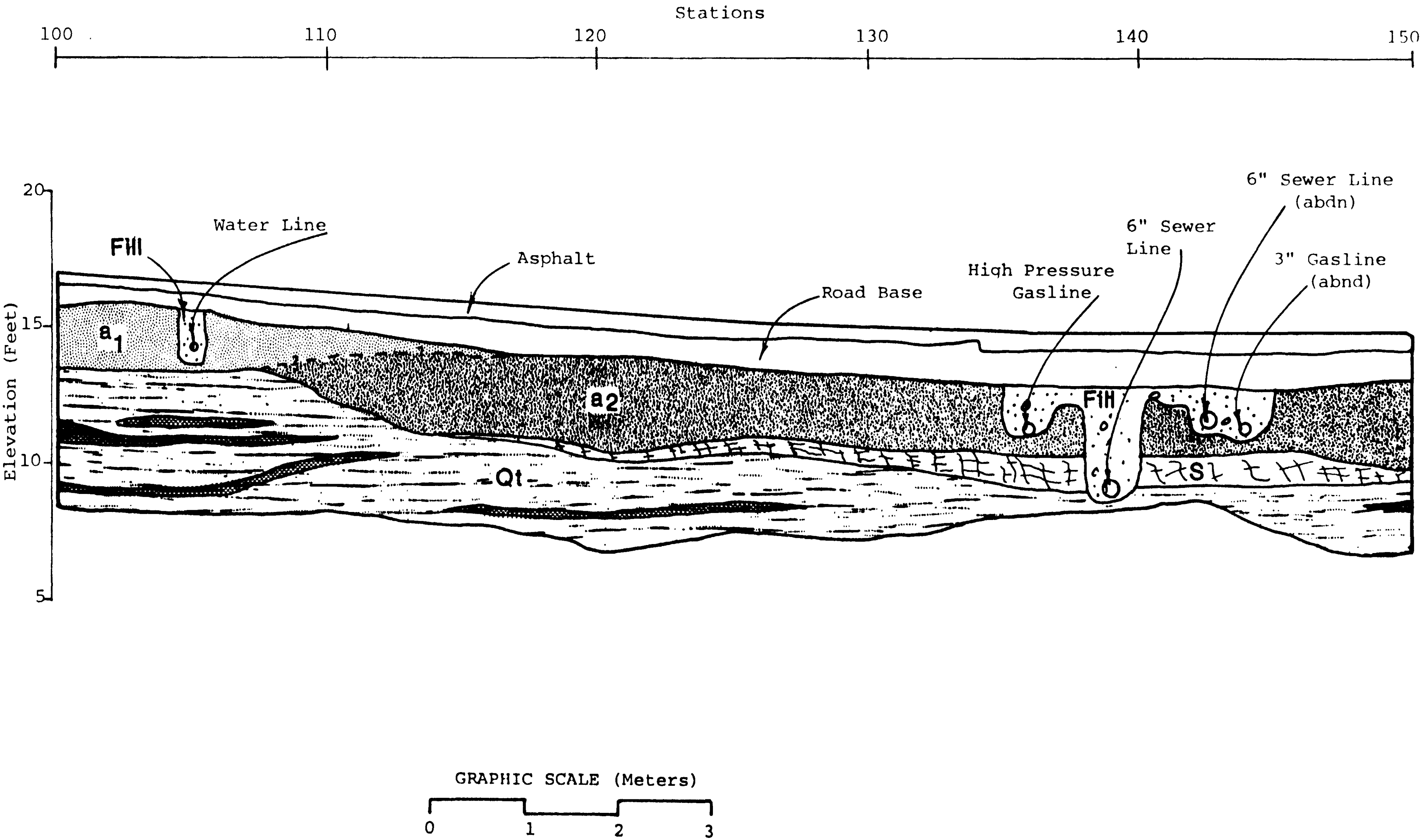
LOG OF TRENCH (NORTH WALL)
STATIONS 0 TO 50

DRAWN BY: ch	**CHECKED BY:** ЄA	**PROJECT NO:** 50135H-GEO2	**DATE:** 11-25-80	**FIGURE NO:** B-2

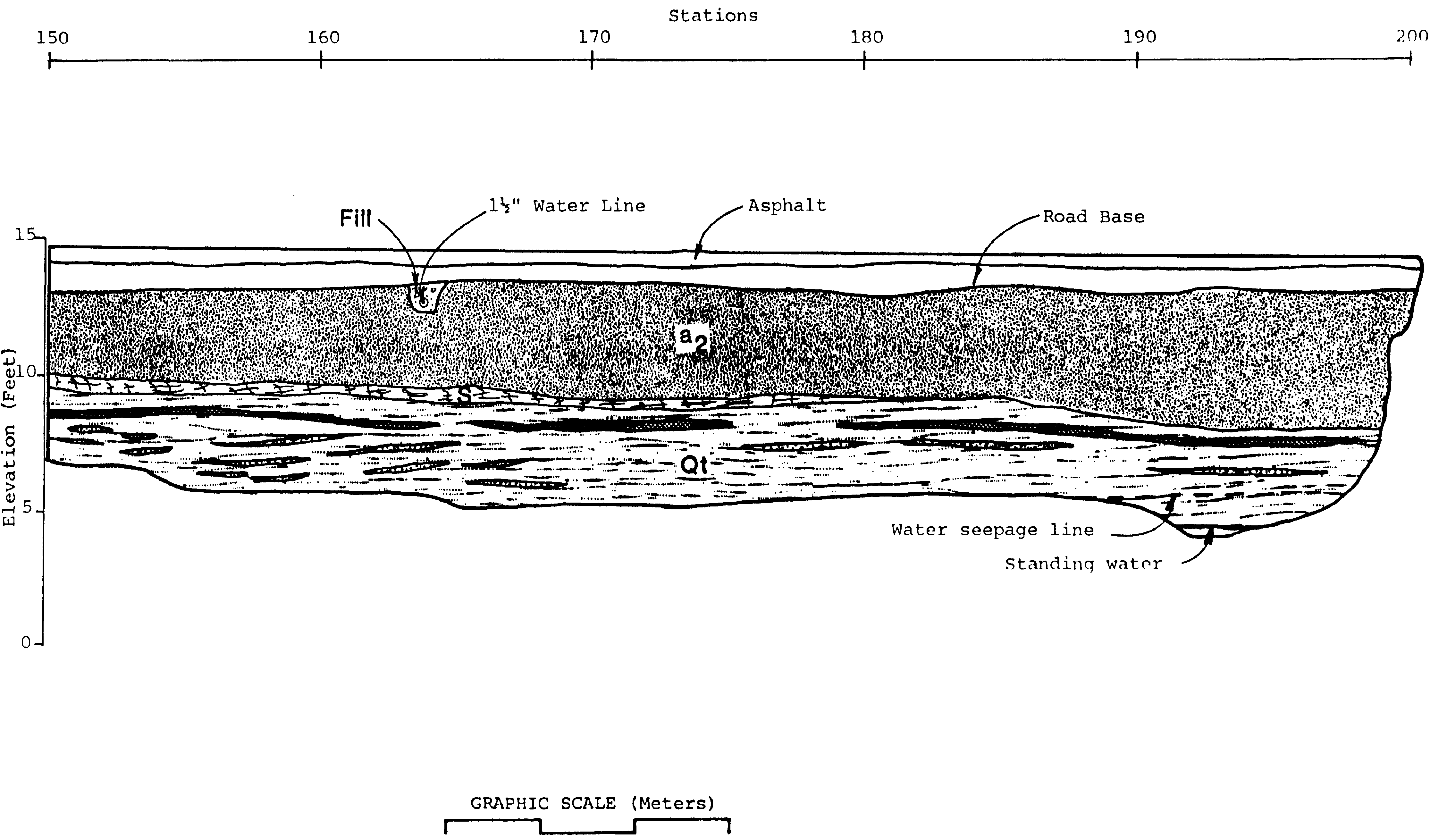


LOG OF TRENCH (NORTH WALL)
STATIONS 50 TO 100

DRAWN BY: ch	CHECKED BY: GA	PROJECT NO: 50135H-GEO2	DATE: 11-25-80	FIGURE NO: B-3



LOG OF TRENCH (NORTH WALL) STATIONS 100 TO 150				
DRAWN BY: ch	**CHECKED BY:** EA	**PROJECT NO:** 50135H-GEO2	**DATE:** 11-25-80	**FIGURE NO:** B-4



LOG OF TRENCH (NORTH WALL)
STATIONS 150 TO 200

DRAWN BY: ch	CHECKED BY: EA	PROJECT NO: 50135H-GEO2	DATE: 11-25-80	FIGURE NO: B-5

APPENDIX C

FAUNAL ANALYSIS

by

Thomas A. Demere and Kenneth M. Winterstein
Department of Geology, Natural History Museum
San Diego, California

FAUNAL ANALYSIS

Downtown San Diego - Pleistocene Faunas

Introduction

Pipeline excavations in the downtown area of the City of San Diego exposed fossiliferous marine sands that are the subject of this report. Ms. Dorian Elder of Woodward-Clyde Consultants made collections from these deposits during March and June of 1980. A total of four separate collections were examined; three from a series of localities along E Street between Columbia and State Streets and one from Broadway near its intersection with 2nd Street. These localities are plotted in Figure 1 and have been assigned the following San Diego Society of Natural History (SDSNH) locality numbers: 3061 (= WC 570), 3062 (= WC 490), 3063 (= WC 510), and 3064 (= WC 2340). Elevations for these localities as provided by Elder are as follows: 3061 (11' above sea level), 3062 (11' above sea level), 3063 (4' above sea level), and 3064 (31' above sea level).

Methods

The bulk fossil material with matrix was air dried and screened through a series of sieves producing the following size fractions: ≥ 4 mm, ≥ 2 mm, $\geq .85$ mm, and $\leq .85$ mm. All size fractions were examined for fossils both megascopically and microscopically. Recovered fossils were identified, counted and curated into the collections of the Natural History Museum where they are available for further study.

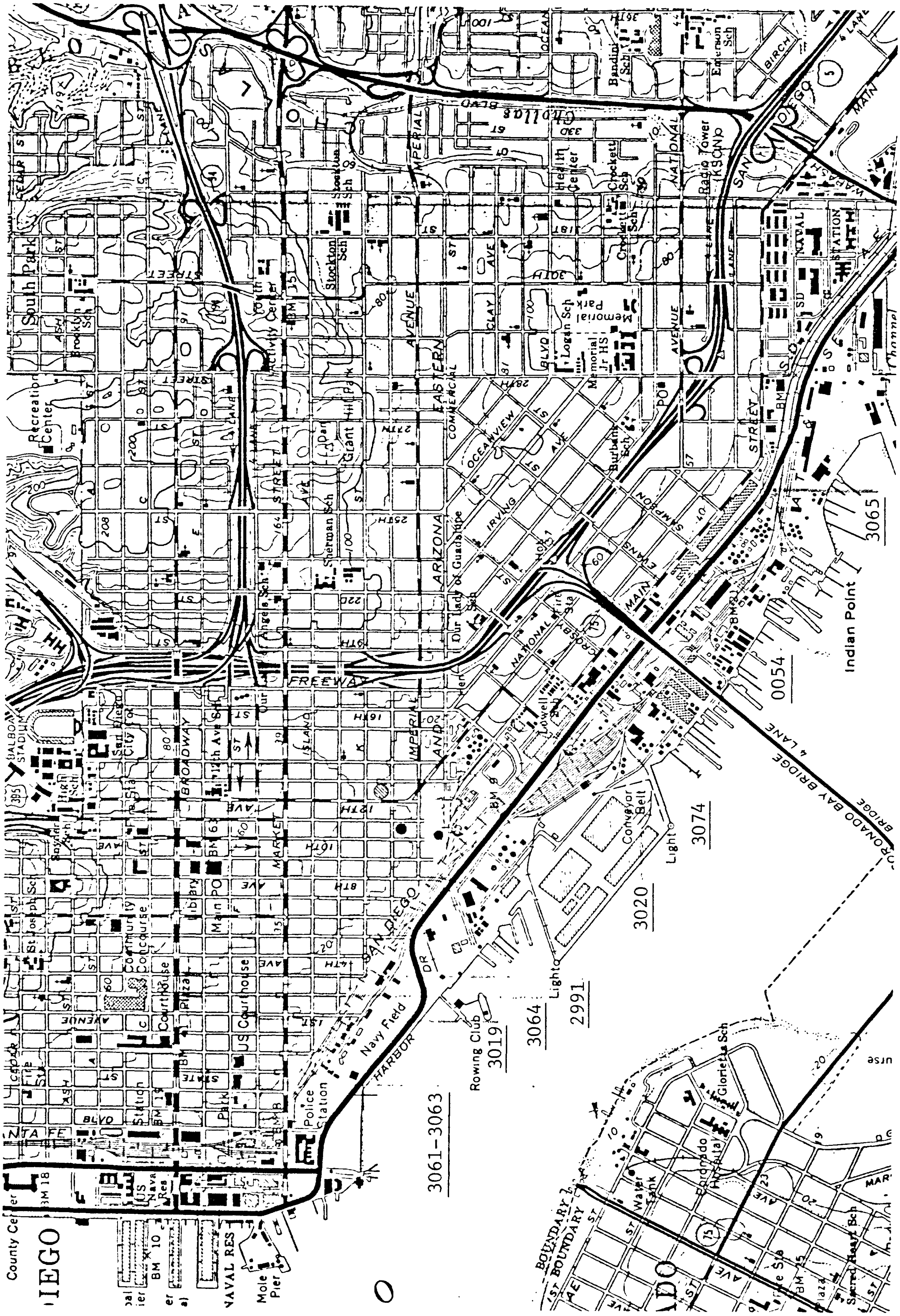


Figure 1. Location map of Pleistocene fossil localities (SDSNH) in the downtown area. Map is taken from the USGS 7.5' Point Loma and National City Quadrangles (scale 1:24000).

In counting specimens two pelecypod valves were counted as one individual. In the case of fragments only hinges were counted for pelecypods and apertures for gastropods.

The faunas were compared with previously known fossil assemblages from the San Diego area.

Results

A total of fifty-one (51) species of marine mollusks (24 gastropods and 27 pelecypods) were identified from the four localities. These are listed in Table I along with counts and relative frequency data. All fossil specimens retain their original shell material.

Localities 3061, 3062 and 3063 contain faunas so similar both in terms of species present and relative frequencies that they can be considered members of a single faunal unit. This lumping is also supported by the similar lithology at each locality, i.e., greyish-brown, well-sorted, subangular, medium grained, unconsolidated fossiliferous sand.

The characteristic species in the E Street faunal unit include: *Acteocina culcitella*, *Caecum californicum*, *Crucibulum spinosum*, *Nassarius tegula*, *Turbonilla tenuicula*, *Psammotreta viridotincta*, *Tagelus californianus* *Tellina meropsis*, *Chione californiensis* and *Felaniella sericata*. Of these taxa, only the last two were also encountered in the collection from 3064. This fauna, from Broadway, contains the following characteristic species: *Turritella gonostoma*, *Argopecten* cf. *A. aequisulcatus*, *Diplodonta subquadrata*, *Lucinisca nuttalli*, *Pecten vogdesi* and *Chione californiensis*. The lithology at 3064 consists of a reddish-brown, poorly sorted, subangular, coarse to

FAUNAL LIST OF FOSSILS

DOWNTOWN AREA -- SAN DIEGO CITY

N = number of specimens counted per species; % = relative frequency of species within individual localities. Counts are based on two hinges per individual pelecypod specimen and one aperture per individual gastropod specimen.

	LOCALITIES							
	WC 570 SDSNH 3061		WC 490 SDSNH 3062		WC 510 SDSNH 3063		WC 2340 SDSNH 3064	
	N	(%)	N	(%)	N	(%)	N	(%)
Gastropoda								
Acteocina culcitella (Gould)	12	(1.9)	8	(1.3)	26	(3.4)		
Acteocina cf. *A. harpa* (Dall)	2	(.3)						
Acteocina sp. indet.	12	(1.9)						
Alabina tenuisculpta Carpenter	1	(.2)						
Alabina tenuisculpta phalacra Bartsch					4	(.5)		
Barleeia cf. *B. californica* Bartsch	1	(.2)						
Caecum californicum Dall	15	(2.4)	14	(2.2)	12	(1.6)	2	(.9)
Cerithidea californica (Haldeman)	9	(1.4)	5	(.8)	8	(1.0)	2	(.9)
?*Cerithidea* cf. *C. californica* (Haldeman)							1	(.5)
Cerithiopsis carpenteri Bartsch	1	(.2)			2	(.3)		
Crucibulum spinosum (Sowerby)	10	(1.6)	5	(.8)	4	(.5)		
Cylichna cf. *C. veleronis* Strong & Hertlein	1	(.2)						
?*Eupleura muriciformis* (Broderip)	1	(.2)						
Gastropoda; fam., gen. et sp. indet.							2	(.9)
Melampus olivaceus Carpenter					1	(.1)		
Nassarius tegula (Reeve)	15	(2.4)	22	(3.5)	26	(3.4)		
Odostomia (*Menestho*) sp. indet.	1	(.2)						
Odostomia cf. *O. laxa* Dall & Bartsch	1	(.2)						
Odostomia (*Salasiella*) sp. indet.			1	(.2)				
Odostomia sp. indet.					2	(.3)		
Olivella sp. indet.	1	(.2)						
Polinices reclusianus (Deshayes)							1	(.9)
Teinostoma sp. indet.			1	(.2)				
Turbonilla tenuicula Gould	18	(2.9)	12	(1.9)	6	(.8)		
Turritella gonostoma Valenciennes							92	(43.4)

	LOCALITIES							
	WC 570 SDSNH 3061		WC 490 SDSNH 3062		WC 510 SDSNH 3063		WC 2340 SDSNH 3064	
	N	(%)	N	(%)	N	(%)	N	(%)
Pelecypoda								
Aligena cerritensis Arnold	2	(.3)	3	(.5)	1	(.1)		
Anomia peruviana Orbigny	1	(.2)					1	(.5)
Argopecten cf. *A. aequisulcatus* (Carpenter)							21	(9.9)
Cardiidae; gen. et sp. indet.	1	(.2)						
Chione californiensis (Broderip)	57	(9.1)	7	(1.1)	87	(11.3)	63	(29.7)
Chione fluctifraga (Sowerby)			1	(.2)				
Chione cf. *C. gnidia* (Broderip & Sowerby)					1	(.1)		
Corbula luteola Carpenter			2	(.3)	2	(.3)		
Crassinella branneri Arnold					2	(.3)	2	(.9)
Cryptomya californica (Conrad)			1	(.2)	1	(.1)		
Diplodonta subquadrata Carpenter							4	(1.9)
Donax californicus (Conrad)	1	(.2)	1	(.2)	3	(.4)		
Felaniella sericata (Reeve)	417	(66.6)	487	(77.8)	535	(69.8)	3	(1.4)
Laevicardium cf. *L. substriatum* (Conrad)			1	(.2)				
Lucinisca nuttalli (Conrad)							8	(3.8)
Mactra californica Conrad			2	(.3)				
Megapitaria squalida (Sowerby)					1	(.1)		
Nucula exigua Sowerby	1	(.2)	1	(.2)	1	(.1)	1	(.5)
Ostrea lurida Carpenter	1	(.2)	3	(.5)			1	(.5)
Pecten vogdesi Arnold							7	(3.3)
Pitar newcombianus (Gabb)							1	(.5)
Protothaca staminea (Conrad) var.					1	(.1)		
Psammotreta viridotincta (Carpenter)	10	(1.6)	8	(1.3)	5	(.7)		
Saxidomus nuttalli Conrad	1	(.2)						
Tagelus californianus (Conrad)	9	(1.4)	13	(2.1)	9	(1.2)		
Tellina meropsis Dall	21	(3.4)	26	(4.2)	26	(3.4)		
Trachycardium cf. *T. panamense* (Sowerby)			1	(.2)				
Other								
Bryozoa	3	(.5)						
Decapoda; crab claw			1	(.2)				
Echinodermata; sea urchin spine					1	(.1)		
Totals =	626		626		767		212	

Total number of specimens = 2231

fine grained, poorly indurated, argillaceous, fossiliferous sand. In places this locality contains calcareously cemented sand pockets that display external molds of mollusks. The fine grain fraction at this locality serves to separate it from the localities along E Street.

Age and Correlation

The modern aspect of the faunas (i.e., all species are extant) together with the lack of characteristic Pliocene species suggests a Pleistocene age for these four localities. In addition, *Chione californiensis*, a common taxon at each locality, appears to be stratigraphically restricted to the Pleistocene Epoch.

As concerns the E Street faunas, amino-acid analysis of *Chione* shells from 3061 and 3063 have yielded absolute ages of 300,000 years B.P. and between 200 and 300,000 years B.P. respectively for these two fossil assemblages (Bada, letter to Elder, 16 May 1980). This slight temporal distinction is not supported by faunal and lithological evidence which together suggest contemporaneity. Kern (1977, and personal communication) recognizes at least three distinct temporal intervals in the San Diego Pleistocene including his Bird Rock Terrace at 80,000 years B.P., the Nestor Terrace at 120,000 years B.P. and as yet, an undescribed faunal unit at 200-250,000 years B.P. It is to this oldest unit that the E Street faunas are correlated. Additional faunas in and around the downtown area that fall into this temporal framework include a small fauna from G and 1st Street (SDSNH 3019) which has been dated at 200 to 300,000 years B.P. and a series of faunas from deposits along Harbor Drive near Indian Point

(SDSNH 0054, 3065 and 3074). One of these (0054) has been dated at 210,000 years B.P. (Masters, letter to Deméré, 28 August 1980). All of these localities contain a distinctive warm water faunal element characterized by the following taxa: *Eupleura muriciformis*, *Dosinia ponderosa*, *Felaniella sericata*, *Psammotreta viridotincta* and *Tellina meropsis*. It is this warm water element that most closely ties these various faunas together. It should be mentioned that all of these assemblages reflect a protected marine facies.

The Broadway fauna is distinct from those discussed above and appears to correlate with an older and very poorly studied group of Pleistocene deposits which are recognized from only a few isolated outcrops in the San Diego area. Three species serve to separate this fauna from those at E Street; *Turritella gonostoma*, *Argopecten* cf. *A. aequisulcatus* and *Pecten vogdesi*. In addition, the condition of the shells, many heavily bored by sponges, appears to be an important characteristic of this fauna. Interestingly a small assemblage of fossils from Broadway and 3rd Street (SDSNH 2991) collected in 1918 is identical to the above described fauna.

Kern (1977) reported on a molluscan fauna (SDSU 2530) from Loma Portal at the north end of Point Loma and although at the time of publication he considered this fauna to be a Nestor correlative he has since received amino-acid data placing it at older than 500,000 years B.P. (Kern, personal communication). Stephens (1929) also reported on a fauna from Loma Portal (SDSNH 0070) and both he and Kern noted the occurrence of *Turritella gonostoma* in these deposits. This taxon is a locally extinct southern extralimital species that today lives throughout the Gulf of California south to approximately the latitude of Peru. It is suggested here that this taxon may, with further collecting and study, prove to be an index species for these older terrace deposits.

Another characteristic species in the Broadway fauna, *Pecten vogdesi*, may also prove to be somewhat of a faunal indice for these deposits. Hertlein and Grant (1972) in their discussion of this taxon report it from a deposit at 32nd Street near Logan Avenue in East San Diego. They considered this deposit to be Pliocene in age based on rather nebulous data but added that, "Except for its occurrence in the San Diego Formation *Pecten vogdesi* has been reported from southern California only in beds of Pleistocene age" (p. 182).

A collection of fossils from 32nd Street (SDSNH 3020) housed at the Natural History Museum contain common *Chione californiensis* and *Lucinisca nuttalli*. The *Chione* shells display severe boring by sponges as at the Broadway locality. Kern (personal communication) received an amino-acid date for this locality in excess of 600,000 years B.P. and has concluded that it represents an older Pleistocene terrace deposit.

Amino acid analysis of *Chione* shells from SDSNH 3064 have produced allo/iso ratios in excess of the limits of this dating technique (i.e., greater than 300,000 years B.P.) (Masters, personal communication). Although this date is not an absolute figure, it does serve as a relative measure of age. It is suggested here that the Broadway fauna and those at Loma Portal and 32nd Street are correlative and representative of an older Pleistocene interval previously unrecognized in the San Diego area. Interestingly, these three localities occur at roughly the same elevation; approximately 30' above sea level.

Paleoenvironment

The following discussions on the paleoenvironmental aspects of the downtown faunas are based on ecological data for living molluscan species.

Exposure.- Faunal elements in the E Street assemblages as well as those from Broadway suggest protected marine conditions. There are no strictly exposed coast species in either faunal group. The species *Cerithidea californica*, *Nassarius tegula* and *Tagelus californianus* from the E Street faunas are today restricted to the quiet waters of bays or estuaries. In the Broadway fauna the species *Cerithidea californica* and *Argopecten* cf. *A. aequisulcatus* suggest similar restrictions.

A simplistic but useful model for generating these protected marine conditions is given in Figure 2. In this model coastal San Diego is flooded by interglacially high sea levels creating an enlarged Pleistocene San Diego Embayment and isolating Point Loma as an island. Those areas in the lee of this Loma Island, including the present downtown area, would thus have been protected from direct wave attack.

Substrate.- The dominant infaunal pelecypod species in the E Street assemblages suggest a sandy bottom habitat. The most abundant species, *Felaniella sericata*, lives today only in sand. This is consistent with the nature of the sediment in which these faunas are preserved. A few rare species requiring a firmer substrate together with others requiring a muddier substrate suggests some mixing of taxa from these habitats.

In the Broadway fauna the dominance of the gastropod species, *Turritella gonostoma*, points to a finer-grained substrate for this deposit. This species today is commonly found on mud or sandy mud bottoms. Other species

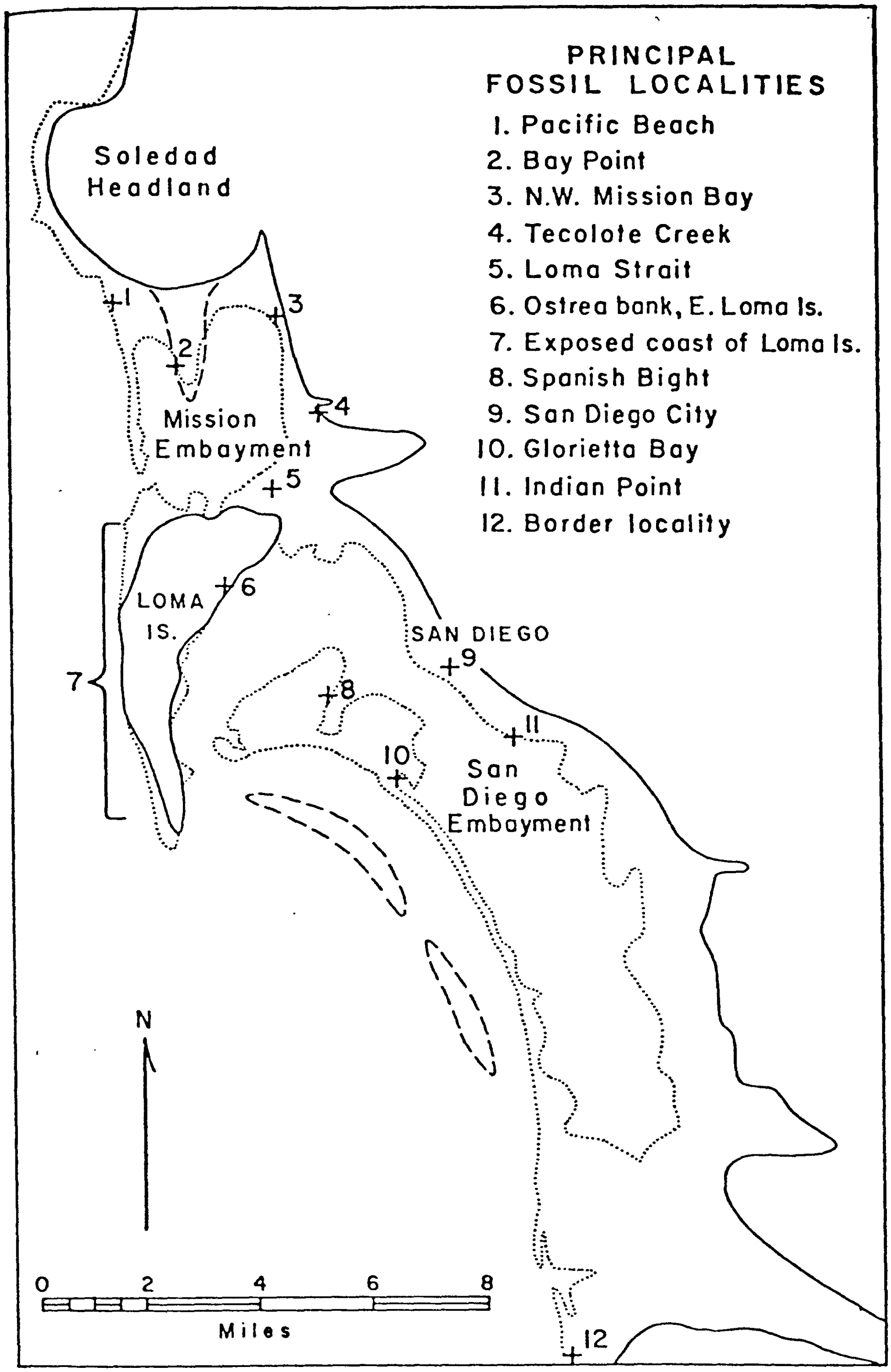


Figure 2. Map of southwestern San Diego County showing upper Pleistocene fossil localities and the approximate configuration of the corresponding shoreline (after Valentine, 1961, p. 353).

in the Broadway fauna, however, require sandy substrates and it appears that these two substrate types contributed molluscan species into a common post-mortem accumulation site. The greater fine grain fraction at 3064 and the poor sorting may also reflect this mixing of habitats.

Water Depth.- The majority of the molluscan species recovered from the E Street localities suggest a littoral to inner sublittoral environment. Several taxa, including *Nassarius tegula*, *Chione californiensis* and *Tagelus californianus* are characteristic of the littoral zone in present day bays and estuaries. The two gastropods *Cerithidea californica* and *Melampus olivaceous* have very restricted depth ranges, being confined to the upper portion of the littoral zone. Their occurrence with species more commonly considered sublittoral imples that post-mortem transportation carried these shells into the sublittoral.

The Broadway fauna suggests water depths somewhat greater than those at E Street. The species of pectens (*Argopecten* and *Pecten*) commonly occur in the sublittoral regions of bays or on protected bottoms offshore. The several littoral species in this fauna suggest that post-mortem shell transportation was at work here as well.

Salinity.- The majority of the species recovered from the E Street and Broadway localities reflect normal marine salinities. Only *Cerithidea californica* and *Melampus olivaceous* are indicators of brackish water conditions. As discussed earlier, these species were probably transported after death, in this instance probably from a restricted back-bay habitat out into the more open marine areas of the embayment.

Temperature.- A strong warm water element is represented in both the E Street and Broadway faunas. At E Street this element is characterized by abundant *Felaniella sericata*, common *Tellina meropsis*, frequent *Psammotreta viridotincta* and rare *Eupleura muriciformis* and *Megapitaria squalida*.

At Broadway, the characteristic warm water species include common *Turritella gonostoma*, frequent *Pecten vogdesi* and rare *Diplodonta subquadrata*. The remaining species in both faunal groups all include San Diego within their present zoogeographical range.

Summary

The four fossil collections examined can be divided into two distinct faunal groups of Pleistocene age.

Those from E Street are considered contemporaneous and appear to be correlative with other known fossil deposits in and around the downtown area. *Chione* shells from these deposits have been dated by amino-acid analysis at 200 to 300,000 years B.P. The E Street faunal group lived under protected marine conditions within the Pleistocene San Diego Embayment. The majority of its member species lived infaunally on sand bottoms within or just below the littoral zone. Post-mortem transportation probably carried their shells into the sublittoral where they accumulated with those species inhabiting this depth range. The presence of several southern extralimital species in this faunal group indicates that water temperatures were somewhat warmer in this embayment than at present.

The faunal group from Broadway appears to be older than the E Street group based on amino-acid analysis of *Chione* shells (i.e., greater than 500,000 years B.P.). This fauna contains several characteristic species not found at E Street (e.g., *Turritella gonostoma* and *Pecten vogdesi*) which allow for correlation with deposits at Loma Portal and 32nd Street. Together these three localities represent an older and previously unrecognized Pleistocene terrace accumulation in the San Diego area. In terms of environment, the Broadway fauna lived subtidally on sand and mud bottoms. Several strictly littoral species suggest mixing of shells from this depth zone with the more common sublittoral species.

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APPENDIX D

REPORTS ON AMINO ACID AGE ESTIMATES OF QUATERNARY MOLLUSKS

By

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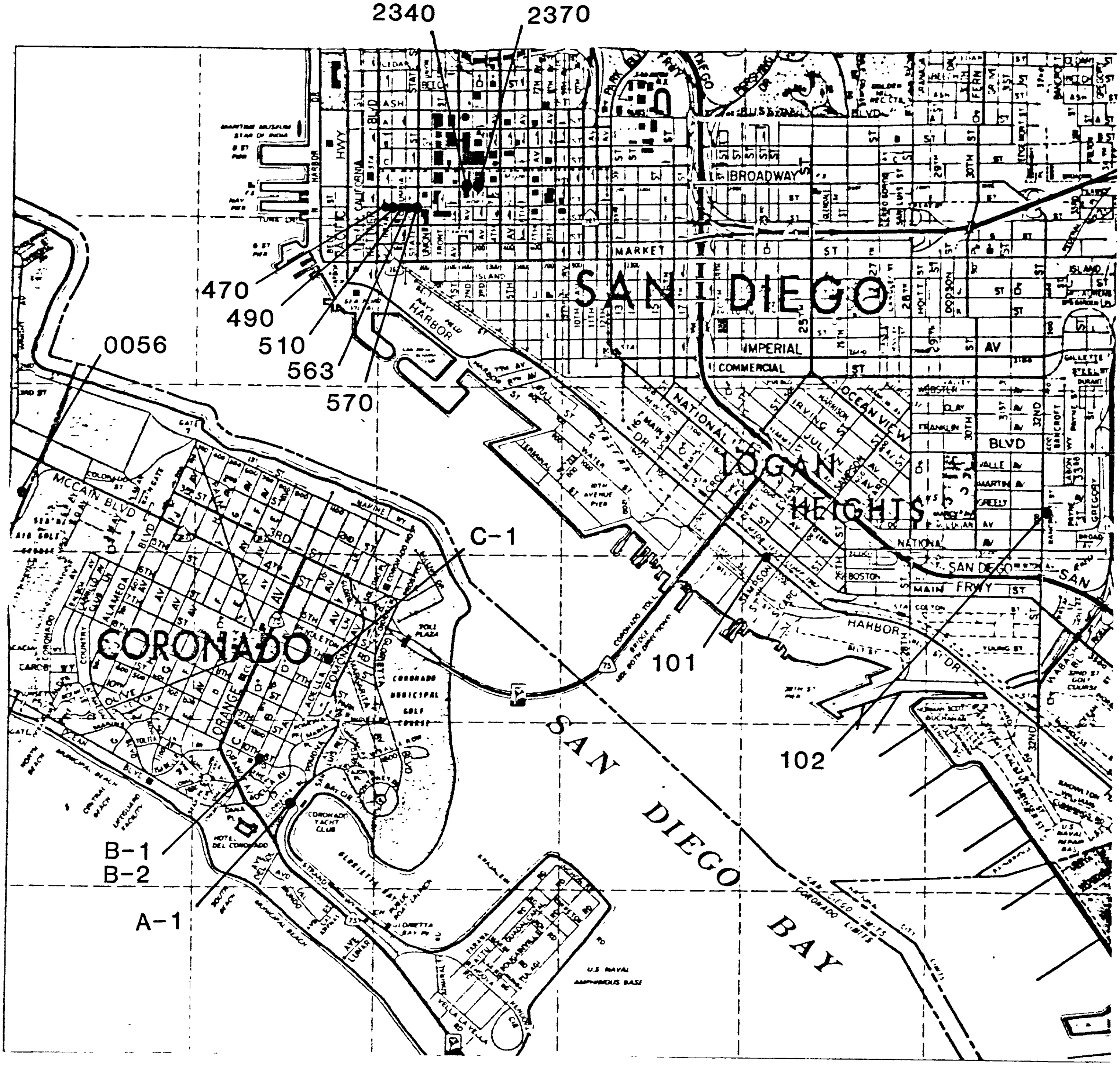

REFERENCE MAP FOR APPROXIMATE LOCATION OF AMINO ACID AGE DATING

REPORT TO WOODWARD-CLYDE CONSULTANTS
3467 Kurtz Street
San Diego, Calif. 92110

Attn: Mr. E. Artim

AMINO ACID AGE ESTIMATION OF QUATERNARY MOLLUSKS FROM A TRENCH IN DOWNTOWN SAN DIEGO

W-C Project No. 412381-0EC2
Cross Ref. No. 50135H-GE01

From:

John F. Wehmiller
Assoc. Prof.
Dept. of Geology
University of Delaware
Newark, Del. 19711

302-738-2926

Sept. 22, 1980

INTRODUCTION:

This report presents amino acid enantiomeric (D/L) ratios, and age estimations, for five samples of the mollusk Chione from a Quaternary marine deposit exposed in a trench in downtown San Diego, California. The exact locations of the samples are presented in the Appendix, in which the letter of transmittal of samples from Mr. Ernest Artim, Woodward-Clyde, to the Principal Investigator is included.

The methods of analysis and data interpretation are discussed in four primary references that will be used in discussions to follow: Wehmiller et al, 1977; Lajoie et al, 1980; Wehmiller and Belknap, 1978; Wehmiller and Emerson, 1980. Reprints of the latter two papers are included with this report.

Enantiomeric ratio data are reported in Table 1. These ratios have been determined on total hydrolyzates of approx. 1 gm fragments cut from the hinge area of each shell sample. Ratios are those determined from peak height measurements from at least two chromatograms of each sample.

AGE ESTIMATES:

Age estimatations are made using a combination of relative and semi-absolute kinetic model interpretative procedures. Previous studies have indicated that Chione racemization kinetics are similar to those for Protothaca (Wehmiller et al, 1977; Lajoie et al, 1980), so it is assumed that the Chione data of Table 1 can be interpreted in terms of Protothaca kinetic curves presented by Lajoie et al (1980: Figs. 2,3,& 9); Wehmiller et al (1977: Fig. 14); Wehmiller and Belknap (1978: Fig. 1); Wehmiller and Emerson (1980: Fig. 3).

In Figures 1 - 3, the data of Table 1 are plotted in the intrageneric relative racemization format of figures 9 - 11 of Lajoie et al (1980). These plots indicate that two age groups are represented by the results reported herein: localities 490 and 563 fall into the younger age group, while locality 2370 is distinctly more racemized and therefore distinctly older. Simple comparison of these results with those for a local calibration site, the 120,000 year Nestor Terrace on Point Loma, San Diego harbor, indicates that the samples analyzed here are significantly (2x or more) older in age than the Nestor Terrace. Figures 1-3 include data for Protothaca from the Nestor Terrace (marked as "N" on the horizontal axis). In Figure 4, the leucine data for the Nestor Terrace (and two other Pacific coast calibration localities) are compared with the results in Table 1 (a full discussion of this figure is found in Wehmiller and Emerson, 1980). Again, the great age (relative to the 120,000 Nestor Terrace) of the analyzed localities is apparent.

For absolute age estimates, the kinetic model of Wehmiller et al, 1977 and Wehmiller and Belknap, 1978 is used. The well-dated Nestor Terrace (120,000 $\pm$ 10,000) serves as a local calibration site for all amino acid dating in the San Diego area, as it can be reasonably assumed that the Effective Quaternary Temperatures for sites in this area have all been quite similar (generally the assumption is made that sites with equivalent present-day temperatures have had Effective Quaternary Temperatures within about 0.5° C. of each other - see Wehmiller et al, 1977 for further discussion). The kinetic model age estimates for the data groups defined from Figures 1-4 are 360,000 ± 50,000 years and 560,000 ± 75,000 years. These age estimates are derived from the kinetic curve for Protothaca at 13.5° C. (P-13.5 of Wehmiller et al, 1977). The uncertainties estimated for these ages are a results of both the analytical uncertainty at a given locality and an assumed temperature uncertainty (relative to the calibration locality) of ± 0.75° C. The leucine model age estimates presented here are also supported by other, more qualitative age estimates derived from glutamic acid and valine data, compared with the kinetic curve of Lajoie et al (1980: Figure 3) for these amino acids.

SUMMARY:

Five shell samples have been analyzed for amino acid enantiomeric ratios, and two age groups are apparent in these data. The younger group, with an age estimate of approximately 360,000 ± 50,000 years, lies near the western end of the trench from which the samples were collected. The older group, with an age estimate of about 560,000 ± 75,000 years, lies to the east of the younger samples

and stratigraphically lower (E. Artim, personal communication).

It is likely that additional analyses, including repeats, will be performed in the next two months in order to improve the precision of the reported data. These results, if obtained, will be communicated to Woodward-Clyde. More importantly, it would be desirable to analyze samples from stratigraphic positions intermediate to, or lower than, the localities reported herein.

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Lajoie, K. R., Wehmiller, J. F., and Kennedy, G. L. (1980) Inter- and intrageneric trends in apparent racemization kinetics of amino acids in Quaternary mollusks, in Biogeochemistry of Amino Acids , P. E. Hare et al, eds., John Wiley & Sons, New York, pp. 305-340.

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Wehmiller, J. F. and W. K. Emerson (1980) Calibration of amino acid racemization in late Pleistocene mollusks: results from Magdalena Bay, Baja California Sur, Mexico with dating applications and paleoclimatic implications, Nautilus 94, 31-36.

Table 1

Enantiomeric Ratio Data in *Chione* Samples, Woodward-Clyde Trench
San Diego, California

Locality	Sample No.	Leu	Glu	Val	Ala	Pro	Phe	Asp	Allo/iso	Method**
490-1										
	80-82-1	.66	.50	.50	.93	nd	.68	.74	nd	P
563-1										
	80-137-1	.72	.52	.47	.80	.77	.74	.73	.73	B
	80-137-2	.66	.48	.49	.87	nd	.63	.70	nd	P
2370										
	80-138-1	.79	.68	.68	1.02	.86	.75	nd	nd	B
	80-138-2	.84	.73	.67	.98	.86	.86	.83	1.18	B

Amino Acid*:

*Amino acid abbreviations: Leu = Leucine; Glu = Glutamic acid; Val = Valine; Ala = Alanine; Pro = Proline; Phe = Phenylalanine; Asp = Aspartic acid; Allo/iso = alloisoleucine/isoleucine

**Method - two chromatographic procedures used, one using isopropyl derivatives (P) and one using butyl derivatives (B); see references for discussion. Comparability of results from two methods is quite good, except for the data for phenylalanine.

nd = not determined

Figure 1: Leucine-glutamic acid trends (from Lajoie et al,1980) with Table 1 data plotted for comparison. Note two apparent age groups. Nestor Terrace Calibration data indicated.

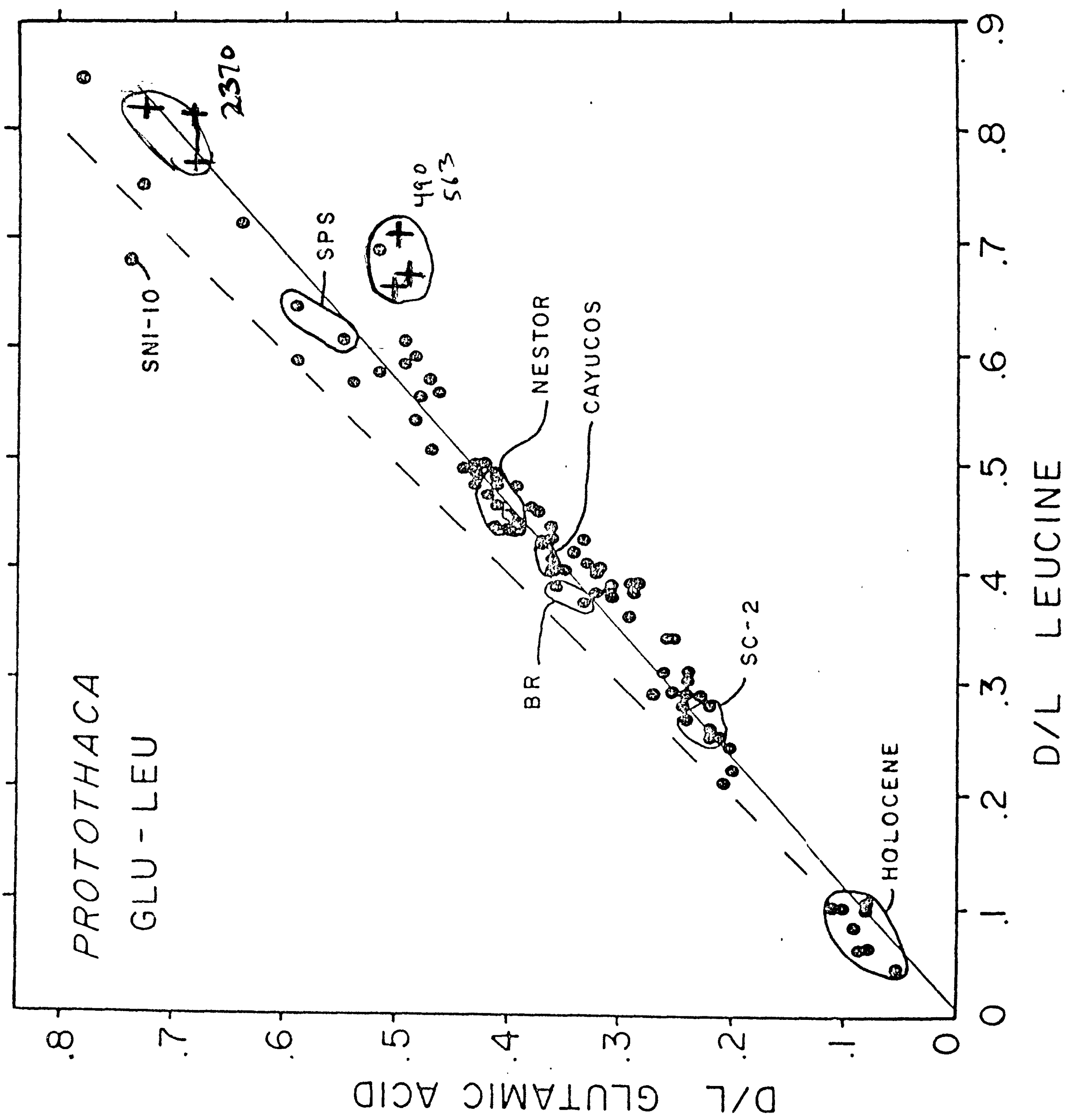


Figure 2: Leucine-valine trends (from Lajoie et al, 1980) with Table 1 data plotted for comparison. Note two apparent age groups (same samples fall into these groups as in the case of leucine-glutamic acid). Nestor Terrace calibration data indicated.

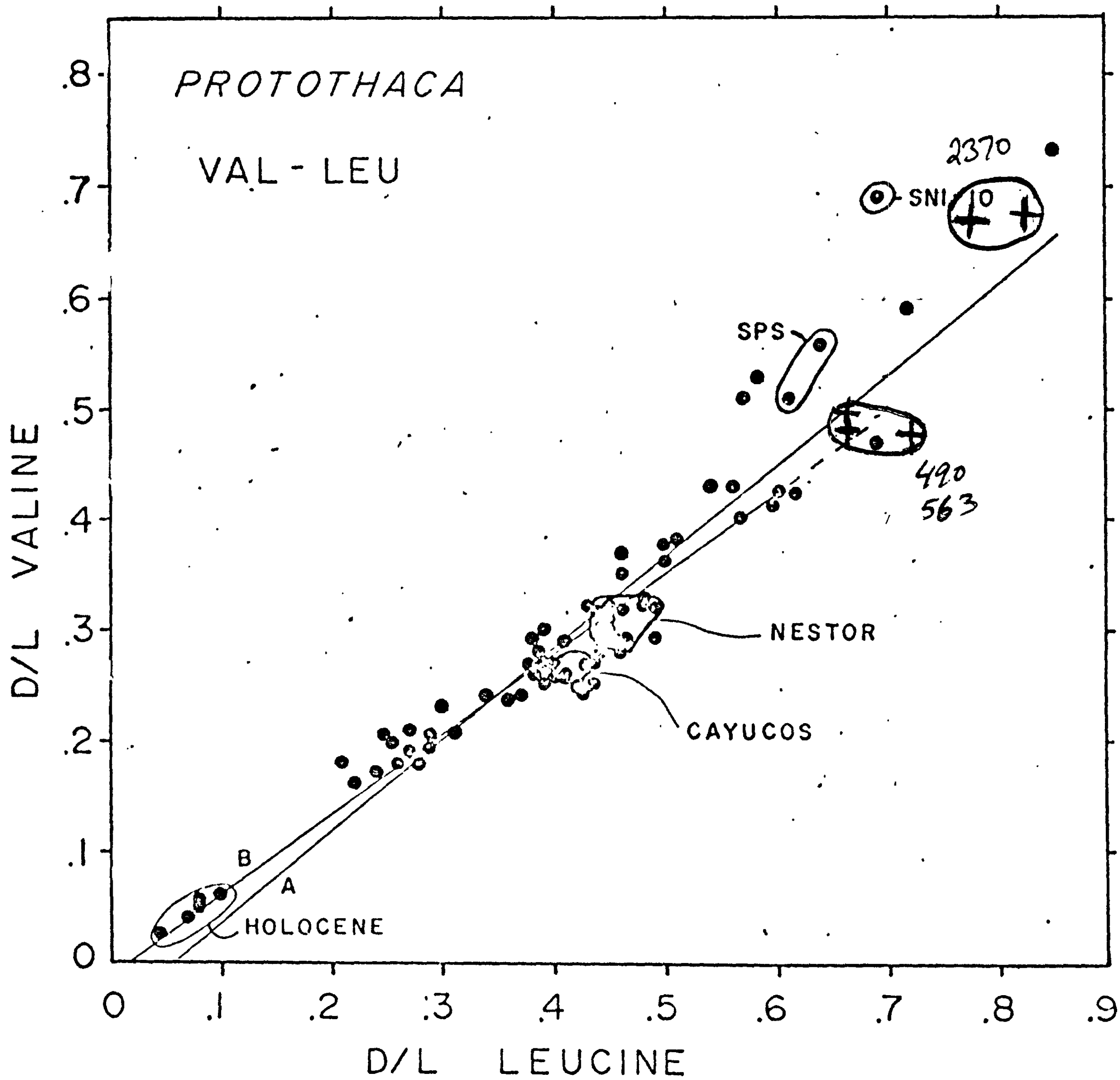
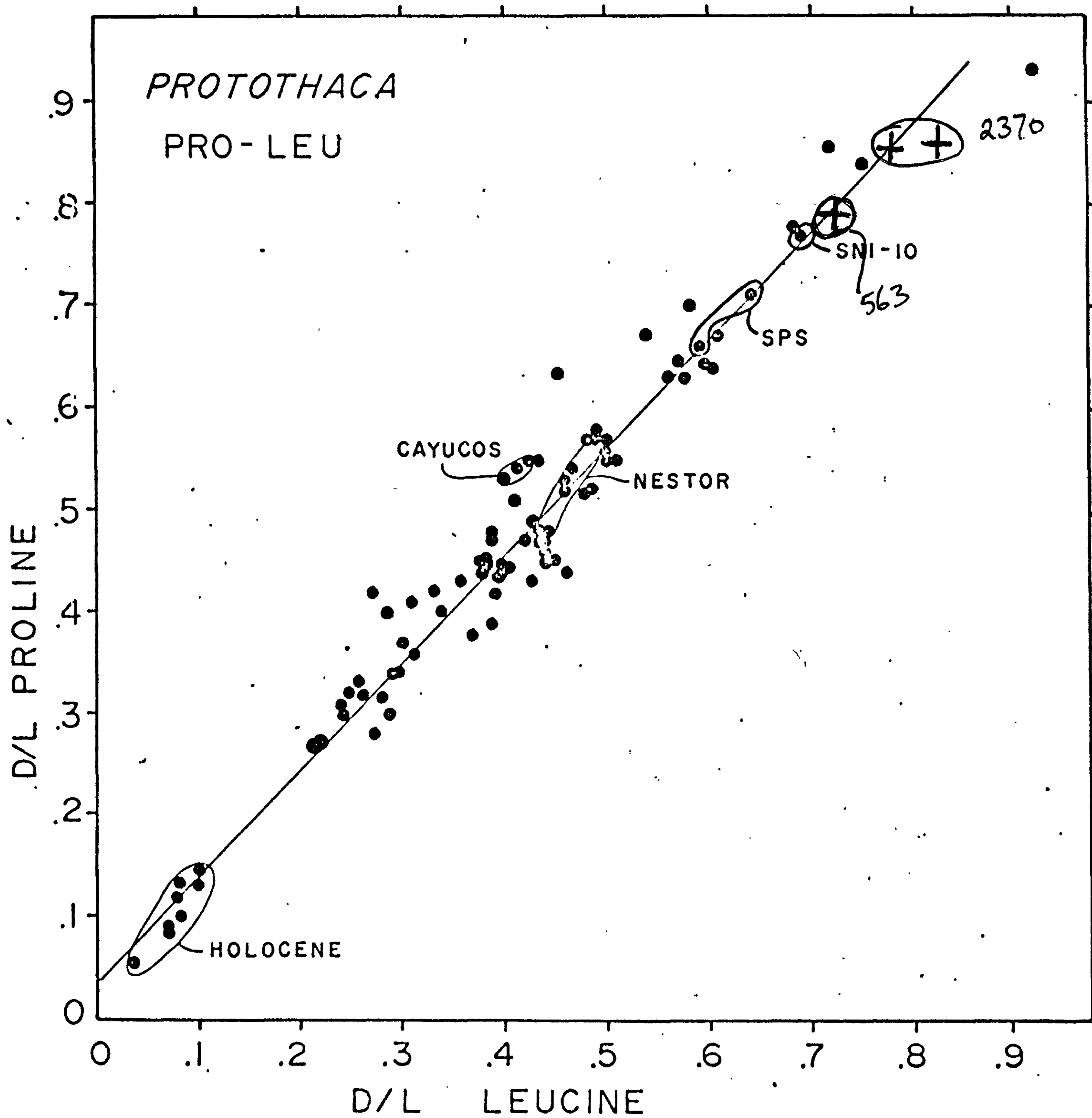


Figure 3: Leucine-proline trends (from Lajoie et al, 1980) with Table 1 data plotted for comparison. Note two apparent age groups (same samples fall into these groups as in the case of leucine-glutamic acid). Nestor Terrace calibration data indicated.



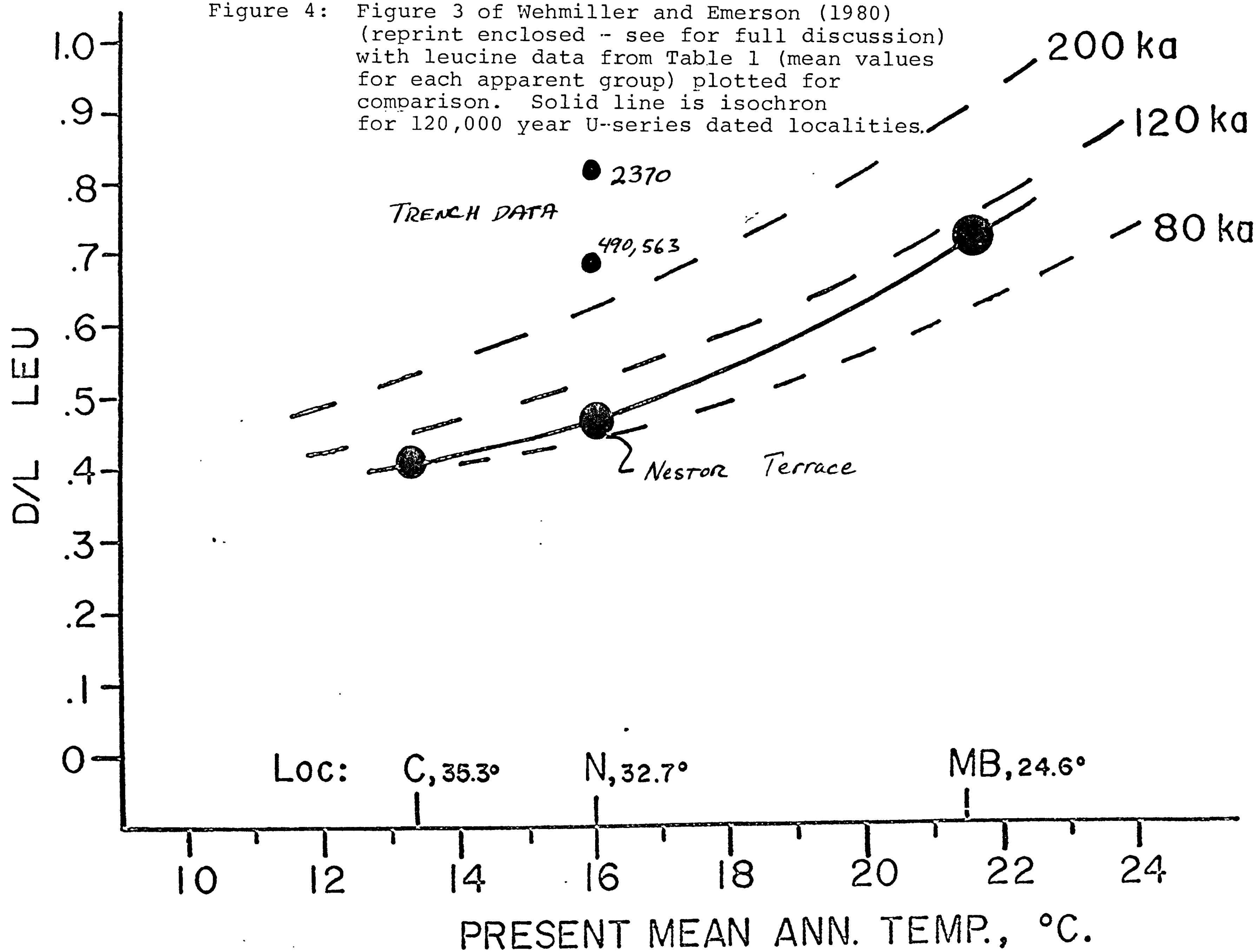


Figure 4: Figure 3 of Wehmiller and Emerson (1980) (reprint enclosed - see for full discussion) with leucine data from Table 1 (mean values for each apparent group) plotted for comparison. Solid line is isochron for 120,000 year U-series dated localities.

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December 10, 1980

Re: Project No. 50135H-GE01

Mr. Ernest Artim
Woodward-Clyde Consultants
3467 Kurtz Street
San Diego, CA 92110

Dear Mr. Artim:

This letter constitutes a final report of amino acid enantiomeric (D/L) ratio data for five mollusk samples that you sent in late October.

I enclose a copy of your original letter of transmittal of the samples, to serve as locality descriptions for the samples studied. It is understood that additional locality data will be available in the near future. Methods of analysis and data interpretation have been discussed fully in the report that I submitted to you in September 1980, so the interpretation presented here will rely upon the same figures as presented earlier.

Data for the five shells are given in Table 1. One Tivela sample was analyzed in addition to four Chione samples. Previous observations (Wehmiller et al, 1977; Lajoie et al, 1980) indicate that Tivela, Chione, and Protothaca are all kinetically equivalent, within normal analytical uncertainty, so the enantiomeric ratios given in Table 1 can be directly compared without any conversions.

Figures 1, 2, and 3 present the data of Table 1 in relation to the intrageneric relationships (Lajoie et al, 1980) and the Chione data previously reported. These figures demonstrate the apparent internal consistency of the intrageneric relative racemization kinetics of the data in Table 1, and the figures can also be used to infer relative ages. Locality 102 has yielded enantiomeric ratios quite similar to those from locality 2370 of the previous report. Localities 101 and 056 have yielded enantiomeric ratios less than those from localities 490 and 563 of the previous report, but greater than the enantiomeric ratios typically observed in the 120,000 year Nestor Terrace samples. Therefore, the results for localities 101 and 056 suggest an age intermediate between 120,000 years (Nestor Terrace) and the 360,000 ($\pm$ 50,000) year estimate for localities 490 and 563 as given previously.

Figure 4 (copy of Figure 4 of previous report) shows how the data of Table 1 plot in relation to the leucine kinetic model as presented by Wehmiller and

Emerson (1980). Kinetic model age estimates, derived from Figure 4 in combination with either Figure 14 of Wehmiller et al (1977) and Figure 1 of Wehmiller and Belknap (1978) (really all are equivalent expressions of the same kinetic model) are as follows:

Locality 102: 560,000 ± 75,000 years (same as loc. 2370 of previous report)

Localities 056 and 101: 220,000 ± 30,000 years

Uncertainties result from a combination of analytical uncertainty and an assumed uncertainty of ± .75°C. in Effective Quaternary temperature, as discussed in the previous report.

I trust that these data will prove of value. Please do not hesitate to contact me if you have further questions.

Sincerely,

John F Wehmiller

John F. Wehmiller
Assoc. Prof.

JFW/lb

cc: Thomas White, Contracts and Grants
Univ. Delaware
Account WCC AA Dating II
4-3-42-2544-01

TABLE 1

Enantiomeric Ratio Data in *Chione* and *Tivela* Samples
Woodward-Clyde San Diego Area Localities
(abbreviations as in previous report)

Locality	Sample No.	Genus	Amino Acid D/L Value							
			Leucine	Glutamic	Valine	Alanine	Proline	Phenylalanine	Aspartic	Method
WCC 101	80-142-1	*Chione*	.56	.47	.38	.90	.64	.71	nd	B
WCC 101	80-142-2	*Chione*	.54	.43	.37	.92	nd	.57	.69	P
WCC 102	80-143-1	*Chione*	.83	.73	.63	.94	.87	1.02	.77	B
WCC 102	80-143-2	*Chione*	.81	.70	.74	1.02	nd	.80	.70	P
WCC 056	80-144-1	*Tivela*	.56	.45	.34	.78	.66	.69	nd	B

Figure 1: Leucine-glutamic acid trends (from Lajoie et al,1980) with Table 1 data plotted for comparison. Note two apparent age groups. Nestor Terrace Calibration data indicated.

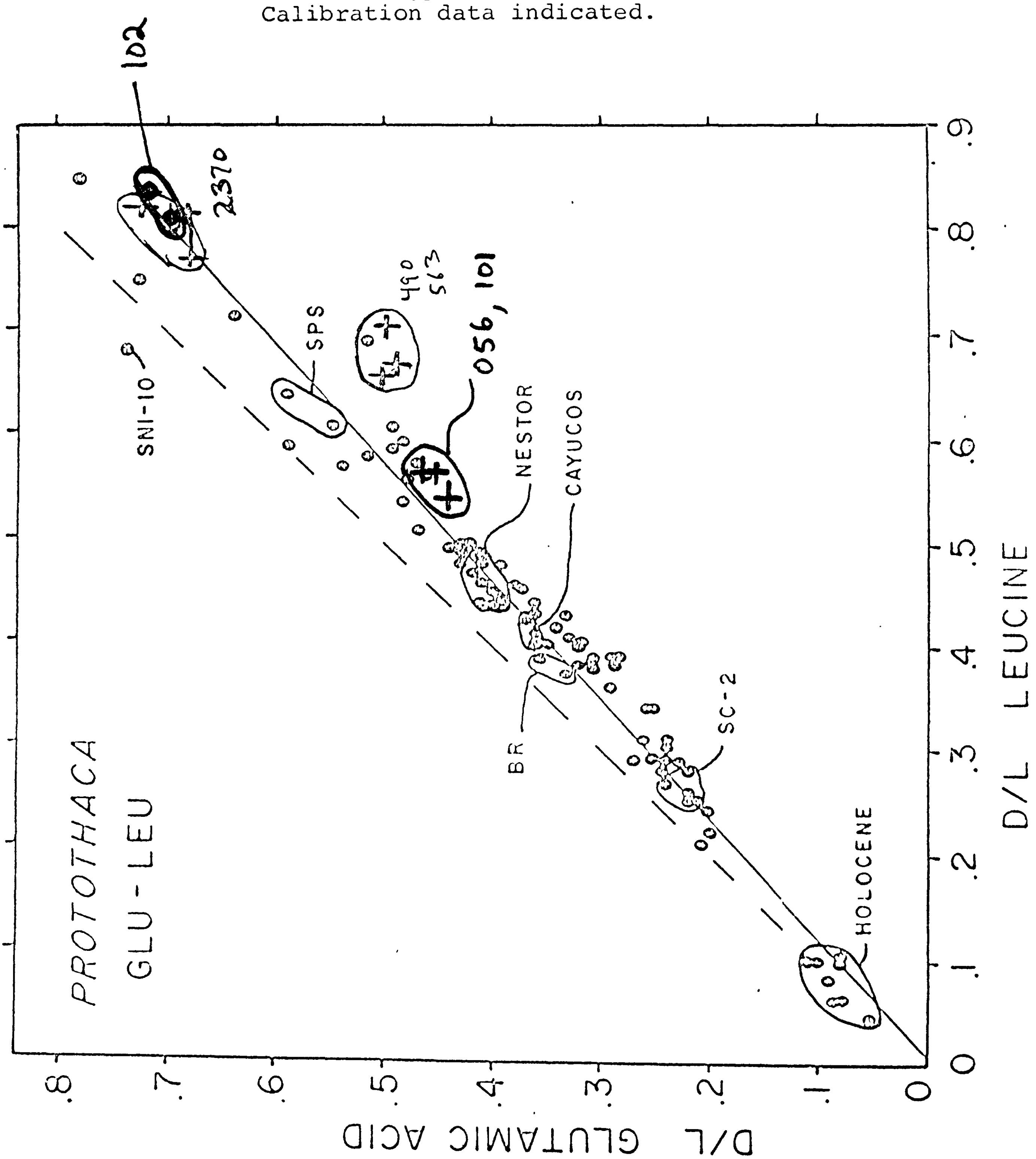


Figure 2: Leucine-valine trends (from Lajoie et al, 1980) with Table 1 data plotted for comparison. Note two apparent age groups (same samples fall into these groups as in the case of leucine-glutamic acid). Nestor Terrace calibration data indicated.

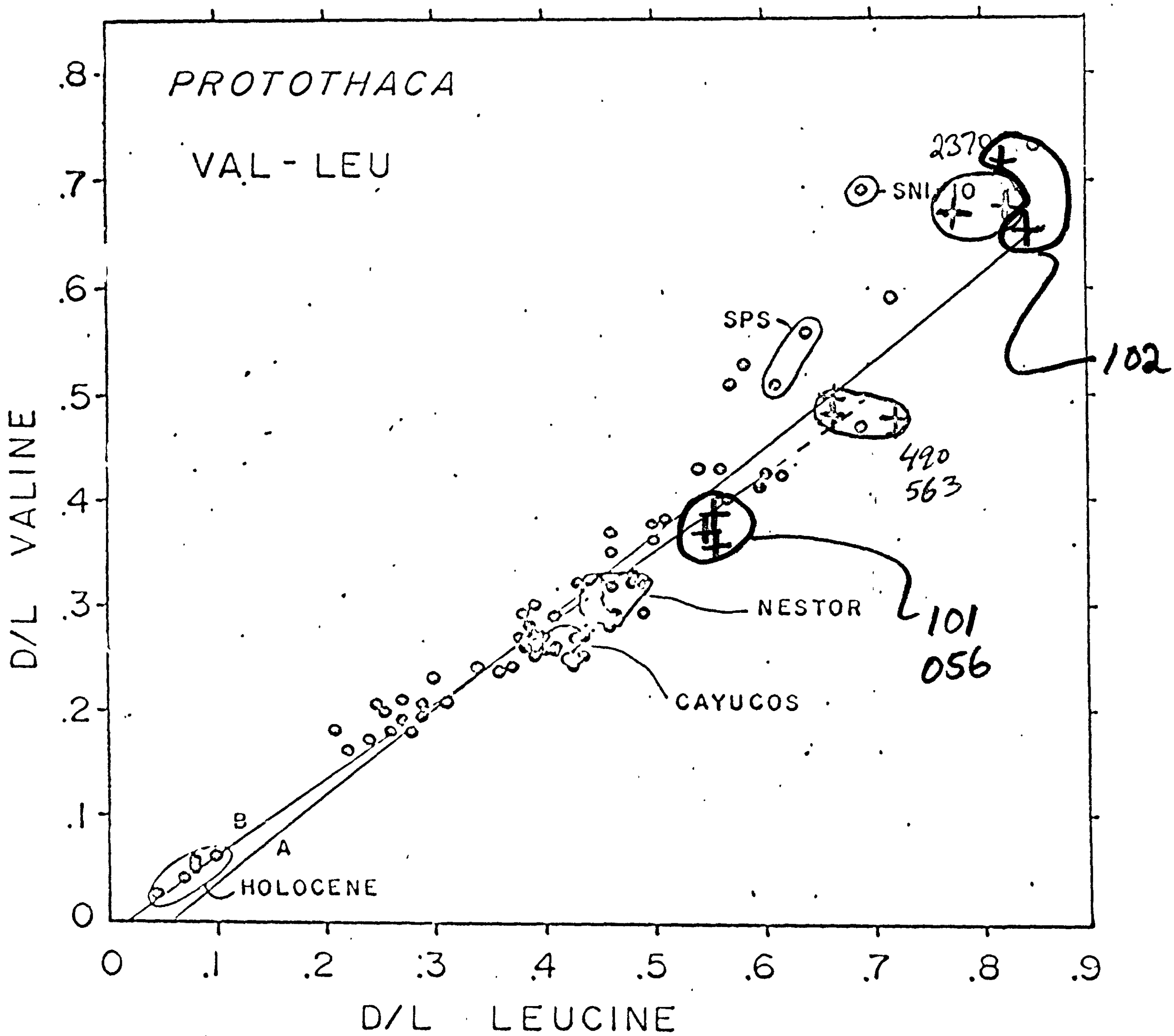


Figure 3: Leucine-proline trends (from Lajoie et al, 1980) with Table 1 data plotted for comparison. Note two apparent age groups (same samples fall into these groups as in the case of leucine-glutamic acid). Nestor Terrace calibration data indicated.

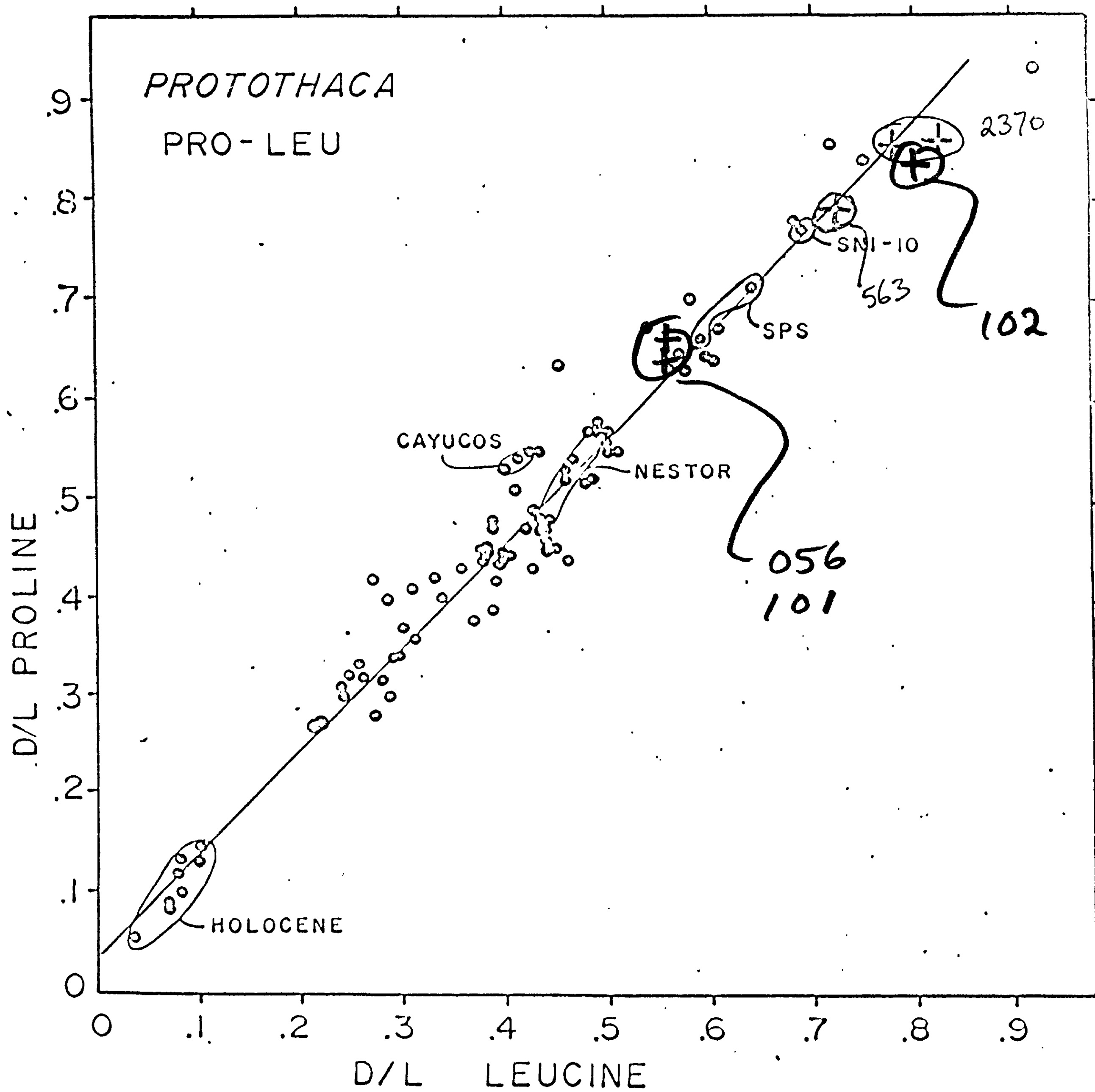
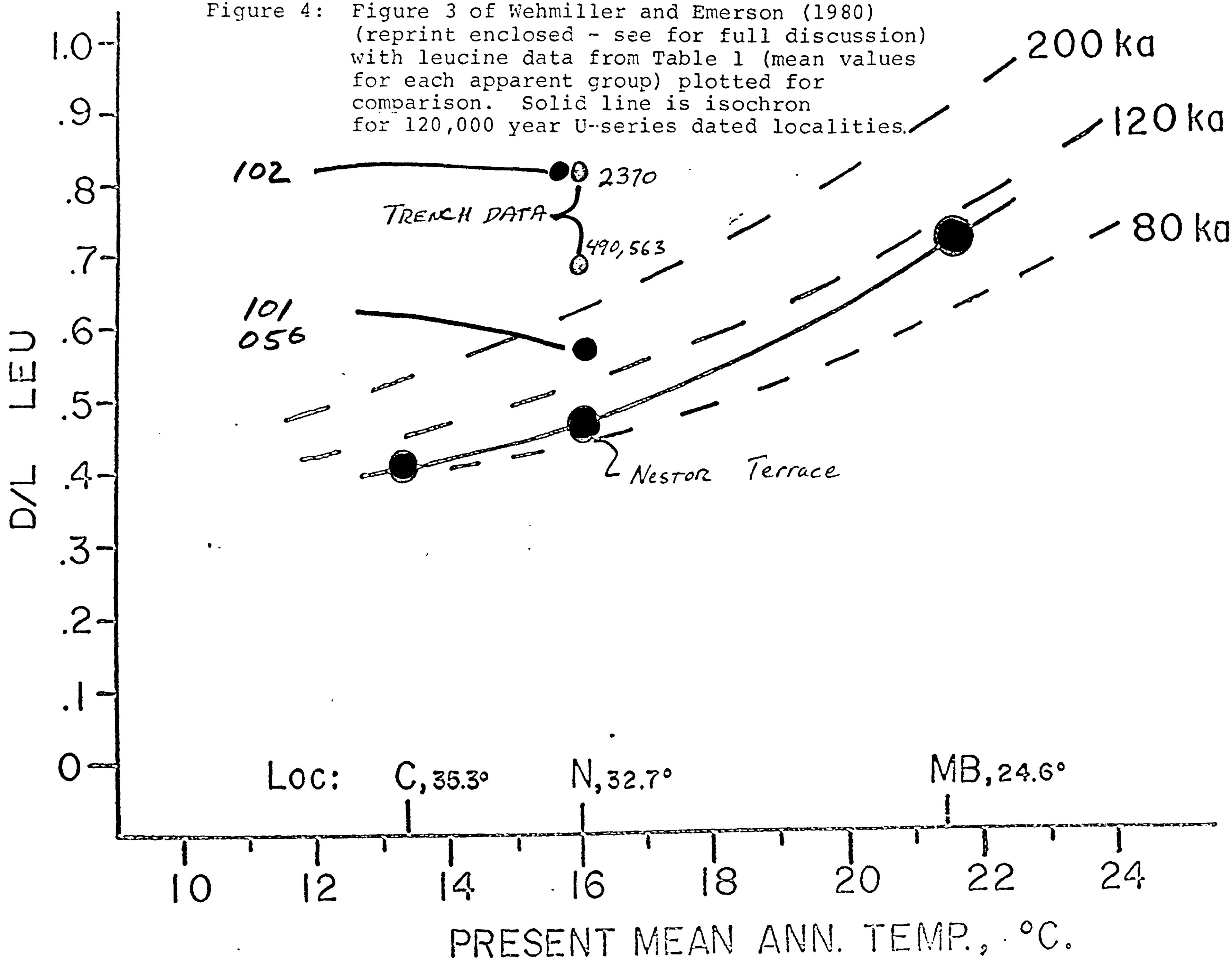


Figure 4: Figure 3 of Wehmiller and Emerson (1980) (reprint enclosed - see for full discussion) with leucine data from Table 1 (mean values for each apparent group) plotted for comparison. Solid line is isochron for 120,000 year U-series dated localities.



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DEPARTMENT OF GEOLOGY
101 PENNY HALL
PHONE: 302-738-2569

Dec. 31, 1980

Mr. Ernest Artim
Woodward-Clyde Consultants
3467 Kurtz Street
San Diego, Calif. 92110

Dear Mr. Artim: RE: Project No. 50135H-GE01

This letter constitutes a final report of amino acid enantiomeric (D/L) ratio data for five mollusk samples, collected from Coronado Island, San Diego, that you sent in early December.

I enclose a copy of your letter of sample transmittal, to serve as a locality and sample description. As we discussed by phone on Dec. 12, I have analyzed one Tivela from sample bag A-1, two Tivela from sample bag B-1, and one Saxidomus from each of sample bags B-2 and C-1. B-2 was collected at the same locality as B-1. Table 1 presents the results for these sample, as well as those for the Tivela sample (80-144-1) from the previous collection at your locality WCC 056 (data previously reported in letter of Dec. 10, 1980), a locality equivalent to that of sample A-1 of the present collection. Methods of analysis, data presentation, and interpretation, have been described in my earlier reports.

The first point to note is that the new results for Tivela samples 80-166-1, 80-167-1 and 80-167-2 essentially duplicate those for the Tivela sample (80-144-1) from locality 056. Therefore the conclusions of my report of Dec. 10 regarding the age of the Tivela samples from Coronado Island remain unchanged. As before, the graphical presentation of these results is shown in Figures 1 - 3, which also include all the previous results as well. You will note in these data (as well as some of the previous results) that there is some significant scatter in the results for glutamic acid and phenylalanine. This scatter is largely a consequence of the different derivatization procedures, rather than being a problem of reproducibility of the analytical method. The enantiomeric ratios for these two amino acids, using our current chromatographic conditions, are approximately 10-15% lower when determined by the isopropyl (P) method than when determined by the butanol (B) method. The apparent scatter for these amino acids is much less when results for only one analytical method are compared.

The two _Saxidomus_ samples are much more extensively racemized than the _Tivela_ samples. The _Saxidomus_ D/L values (converted to equivalent _Protothaca_ and/or _Tivela_ by the intergeneric regressions given in Lajoie et al, 1980), plot in the same range as the data for _Chione_ from localities 102 and 2370 of the previous reports. It should be noted that these _Saxidomus_ samples are worn fragments (with modest amounts of internal luster apparent on freshly-cut surfaces), in contrast to the well-preserved, lustrous whole _Tivela_ samples reported here. Therefore, the simplest explanation of the _Saxidomus_ results (at least for samples B-1 and B-2) is that the _Saxidomus_ samples have been reworked from a deposit roughly equivalent in age to localities 102 and 2370 (i.e., about 560,000 ± 75,000 yrs.) and that the _Tivela_ analyses represent the true age of the deposit at the site. As only one sample has been analyzed from bag C-1 (no _Tivela_ are in this sample), it cannot be said whether shells of two ages are actually present at this locality as well. Nevertheless, both the preservation condition and the analytical results for the _Saxidomus_ from both B-2 and C-1 are quite similar and a reworking origin for sample 80-169-1 seems quite likely. The available amino acid data do not permit a correlation of strata from B-2 to C-1, but rather suggest that the analyzed _Saxidomus_ samples from these sites have been reworked from a common source. Additional analyses from C-1 might solve this problem, but the samples now available appear to be just as worn (reworked?) as the one sample (80-169-1) already analyzed.

In summary, shells of two apparent ages have been analyzed from Coronado Island:

4 _Tivela_ (one from previous report)	:	220,000 ± 30,000 yrs.
2 _Saxidomus_ (reworked?)	:	560,000 ± 75,000 yrs.

Age uncertainties are primarily a consequence of temperature uncertainties, as discussed previously.

I trust that these data will prove of value. Please do not hesitate to contact me if you wish to discuss these results. I would be most interested in seeing a copy of your final grant report to the USGS, so that I might learn more about the use of these data.

Sincerely,

John F. Wehmiller

John F. Wehmiller
Assoc. Prof.

cc: T. White, Contracts and Grants
Account WCC AA Dating II, 4-3-42-2544-01

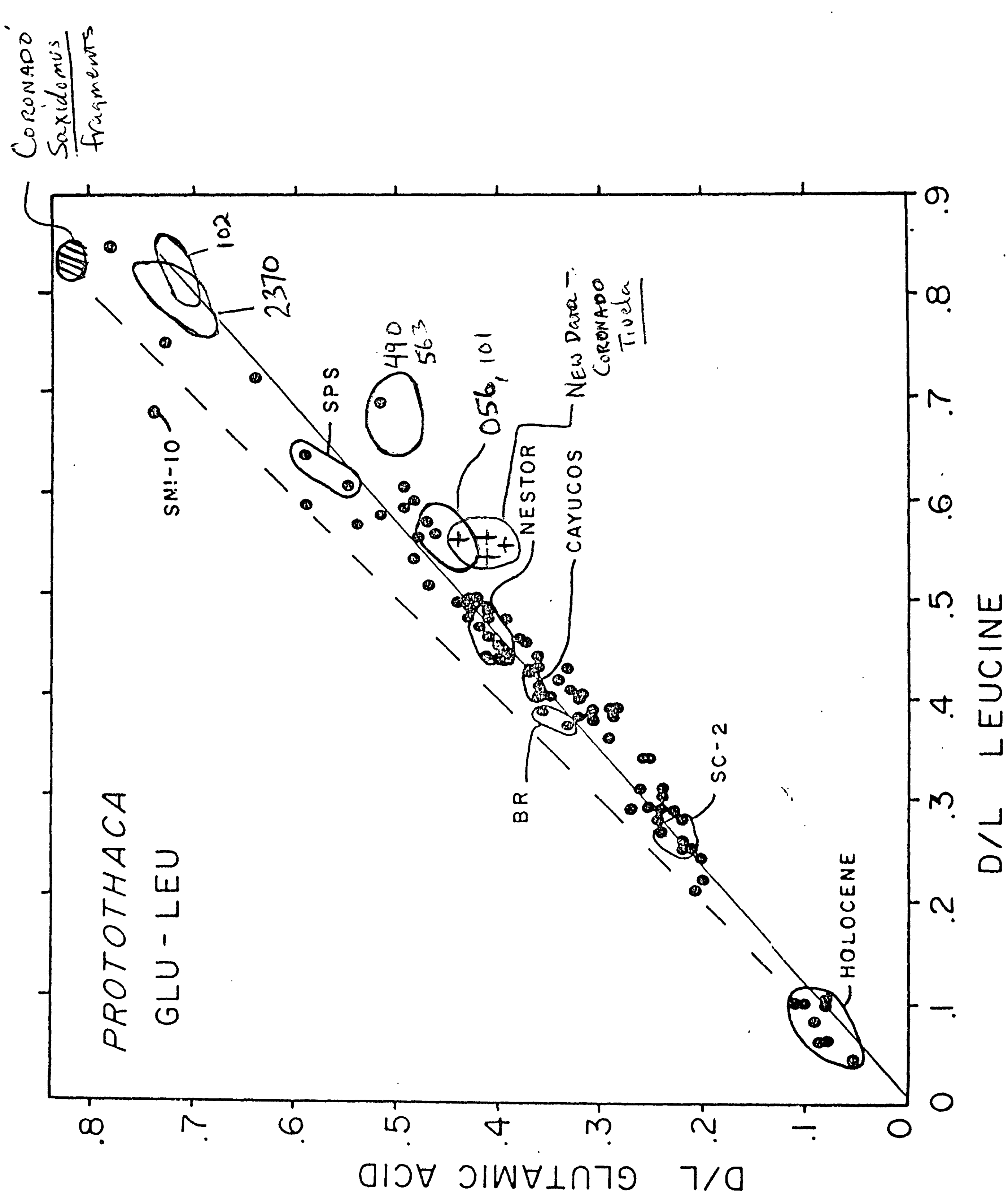
Table 1: Enantiomeric Ratio data in *Tivela* and *Saxidomus* Samples, Coronado Island, San Diego, Calif. (abbreviations as in previous report)

Sample Bag	Sample No.	Genus	Amino Acid D/L Value							Method	
			Leu	Glu	Val	Ala	Pro	Phe	Asp		
A-1	80-166-1	Tiv.	.58	.38	.35	.82	nd	.52	.60	P	(splits of same sample extract)
A-1	80-166-1	Tiv.	.58	.43	.36	.81	.66	.65	.63	B	
B-1	80-167-1	Tiv.	.56	.38	.35	.81	nd	.56	.64	P	
B-1	80-167-2	Tiv.	.58	.36	.35	.85	nd	.55	.59	P	
WCC056	80-144-1	Tiv.	.56	.45	.34	.78	.66	.69	nd	B	(from 12/10/80 report)
B-2	80-168-1	Sax.	.86	.80	.67(?)	.95	.87	.95	.90	B	
C-1	80-169-1	Sax.	.88	.81	.82	1.01	nd	.69	nd	P	

Figures 1 - 3: Intrageneric plots, showning leucine, glutamic acid, valine, and proline D/L values in all Woodward-Clyde San Diego area samples analyzed during late 1980. New data from Table 1 indicated, previous data shown only as open areas within which data points would fall.

Intrageneric plots are for *Protothaca*; no conversions of *Chione* and *Tivela* results have been made in this or previous reports in plotting results for either of these genera, because available evidence suggests that these three are kinetically equivalent (Lajoie et al, 1980). *Saxidomus* results plotted here have been converted (by regressions given in Lajoie et al, 1980) to "equivalent *Protothaca*" enantiomeric ratio values before plotting. These regression conversions are roughly 5% reductions in enantiomeric ratio values.

17


PROTOTHACA
GLU-LEU
Coronado Saxidomus Fragments
102
2370
490
563
056, 101
New Data - Coronado Tivela
SPS
SNI-10
NESTOR
CAYUCOS
BR
SC-2
HOLOCENE
D/L LEUCINE
D/L GLUTAMIC ACID
0
.1
.2
.3
.4
.5
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.7
.8
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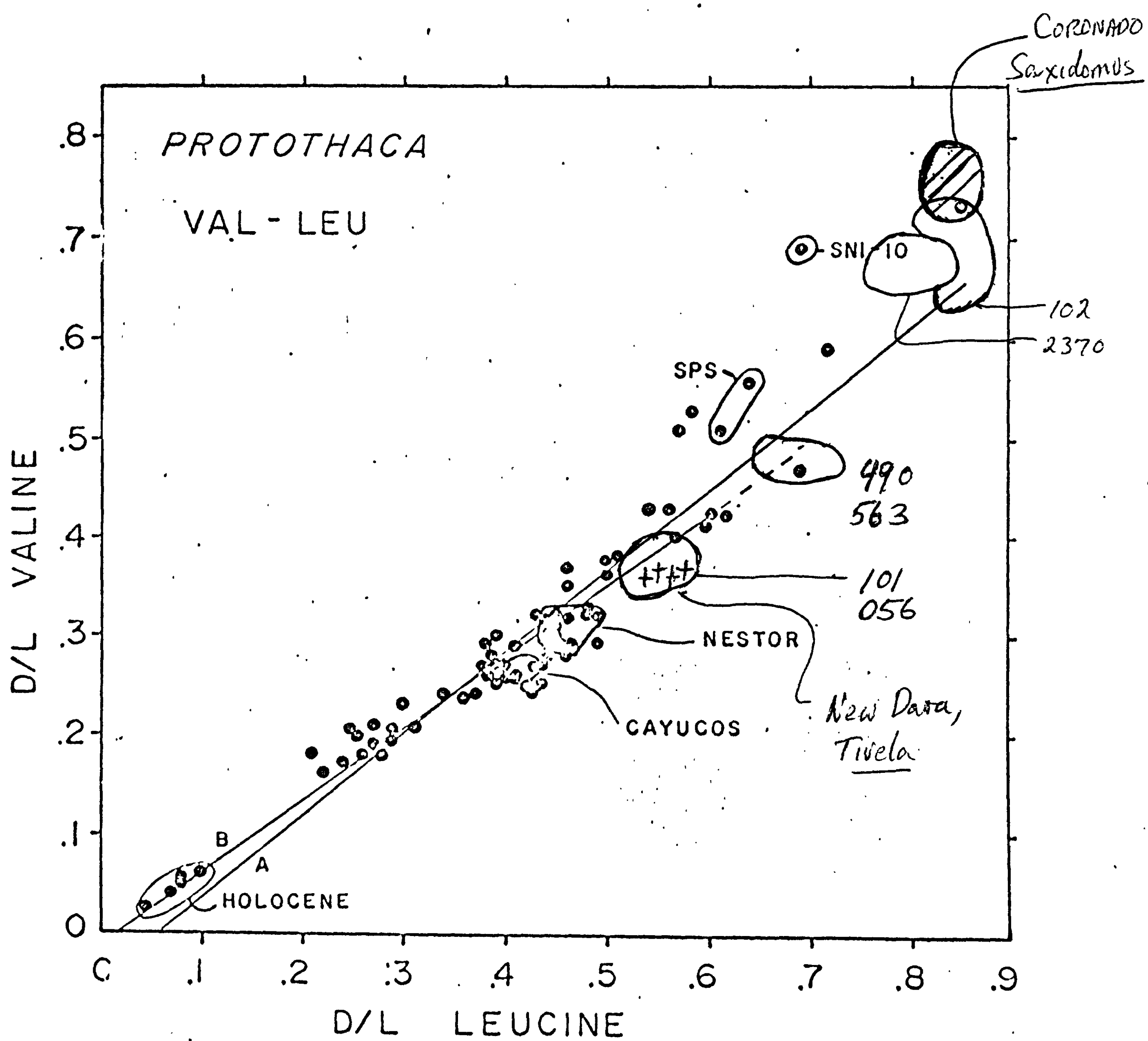

PROTOTHACA
VAL - LEU
CORONADO
Saxidomus
SNI-10
102
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NESTOR
New Data,
Tivela
CAYUCOS
B
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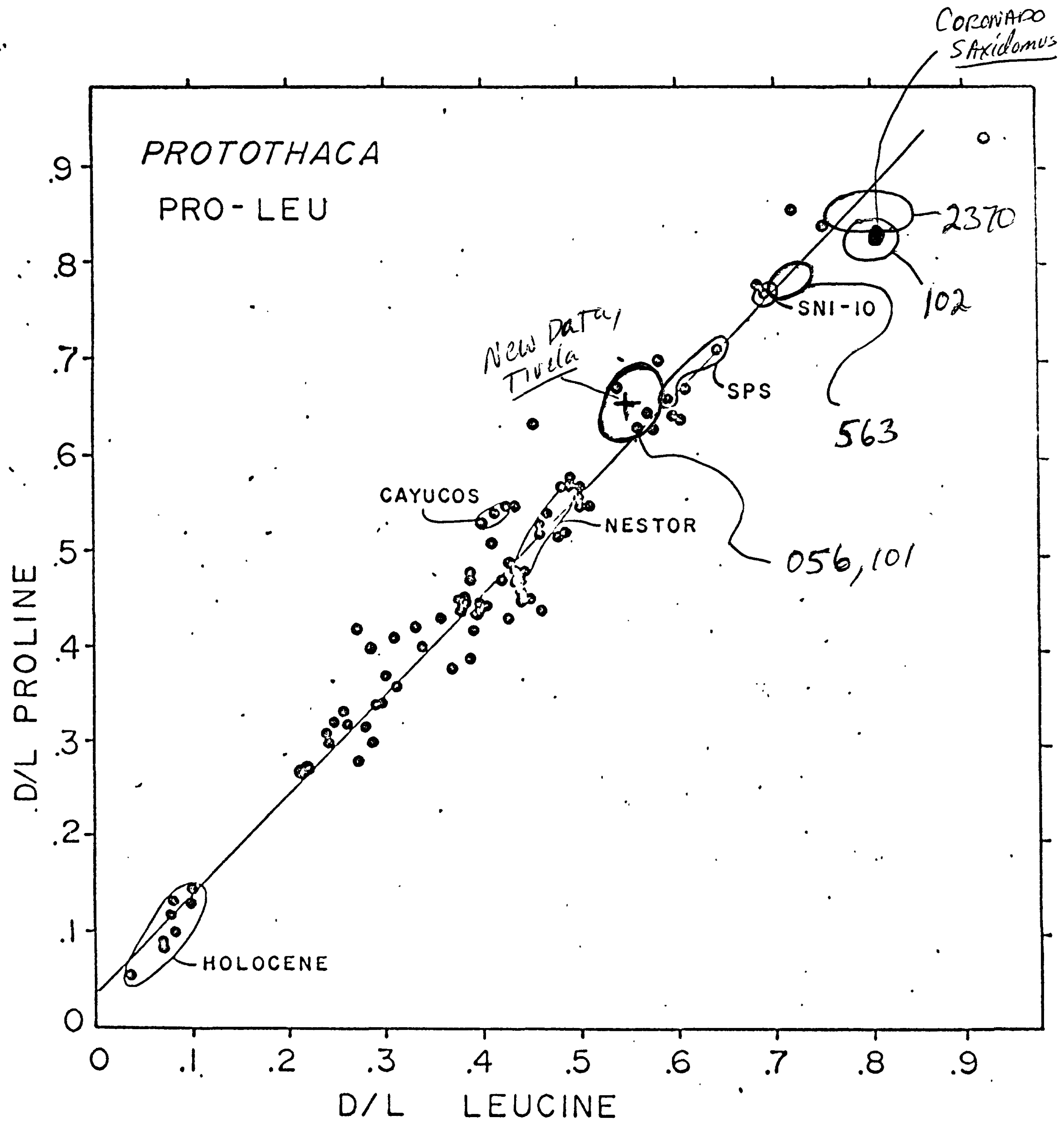

PROTOTHACA
PRO-LEU
D/L PROLINE
D/L LEUCINE
HOLOCENE
CAYUCOS
NESTOR
SPS
SNI-10
New Data, Tivela
056,101
563
102
2370
Coronado Saxidomus

AMINO ACID DATING OF FOSSIL SHELL SAMPLES
FROM DOWNTOWN SAN DIEGO

One *Chione* valve, weighing approximately 15-20 grams, from each sample was processed using the procedures described elsewhere (1,2). The results indicated that all the samples had a normal amino acid distribution pattern and were thus suitable for amino acid dating.

Previous work (1,2) on the amino acid dating of marine terrace deposits in San Diego County has shown that the following equation can be used to calculate the ages of *Chione* shells:

$$t(\text{age in years}) = \frac{\text{Ln}\ \dfrac{1 + \text{allo/iso}}{1 - 0.95\ \text{allo/iso}} - 0.033}{(1.95)\ (3.0 \times 10^{-6}\ \text{yr}^{-1})}$$

where allo/iso is the measures alloisoleucine --- isoleucine ratio in the sample. The only limitation in using this equation is that the allo/iso ratio should be less than 0.6. Thus, in this study, this equation can only be used to date sample #470-1 since the other samples were found to have an allo/iso ratio greater than 0.6. Using the above equation and the measures allo/iso ratio of 0.570, yields an age of 200,000 years. This age suggests that this sample represents the interglacial peiod defined by stage 7 in the oxygen isotopic paleotemperature curve (3). This age also indicates that this sample is a member of a group of deposits found throughout San Diego County which have been dated at ~ 200,000 years old (2).

The absolute ages of samples, #150-1 and #570-5, are more difficult to evaluate since the measured allo/iso ratios of these samples are greater than 0.6 and as mentioned earlier the above equation is no longer valid. However, it is possible to assign relative ages to these samples. Based on the allo/iso ratios, it can be concluded that the age of #470-1 is less than #510-1, which in turn is less than #570-5.

The allo/iso ratio of #570-5 is almost identical to that determined for Chione shells found at a locality near Morena Blvd. in northeastern Mission Bay (2). This locality was assigned an age of at least 300,000 years or greater by Karrow and Bada (2). It would thus appear that #570-5 is similar in age to the Morena Blvd. deposit. This is a highly significant result since the Morena Blvd. deposit was previously the only known representative of this ~ 300,000 year old deposit in San Diego County.

The allo/iso ratio of #510-1 indicates it has age intermediate between those of #470-1 and #570-5. So far, no other deposits in San Diego County have been found which fall into this age range. The allo/iso ratio for #570-1 suggests that it may represent a deposit formed in the early phases of the interglacial period which has an age of ~ 200,000 years. Alternatively, it may have been formed in some period of high sea level which occurred during the 200,000 year interglacial period and the interglacial period represented by the Morena Blvd. and #570-5 deposits.

A comparison of the ages of the Chione shells analyzed in this study with the groupings defined in the extensive study of Karrow and Bada (2), is given on the next page.

The total amino acid analyses for samples 2340-1 and 2340-2 look very good, and it is my opinion that these samples are not contaminated and can thus be at least relatively dated. The allo/ISO ratios determined for the two samples are essentially identical which suggests the measured ratios are reliable.

The measured allo/ISO ratio measured for this sample is the highest I've found for Chione shells in the San Diego area. They could very well thus provide some important new information about the geological history of this region.

Jeffrey L. Bada

THE CORRELATION OF THE SAMPLES ANALYZED IN THIS STUDY WITH THE GROUPS DEFINED IN TABLE 3 IN KARROW AND BADA (2)

Sample #	allo/iso
470-1	0.570
510-1	0.624
570-5	0.680
2340-1	0.962
2340-2	0.922

TABLE 3. GROUPINGS OF TERRACE DEPOSITS BASED ON THE SIMILARITY IN ALLEU/ISO RATIOS IN MOLLUSC SHELLS

	Group	Age	Site	alleu/iso (dialyzed)		
				Chione	Tivela	Mytilus
	I	100,000	#14	0.30		
	II	120,000	Torrey Pines*	0.34	0.40(0.12)	0.78(0.20)
			Crown Point		0.43(0.15)	
			Scripps			0.64(0.24)
			SDSU318	0.36		
			SDSU1854	0.39		
			SDSU2577	0.36		
#470-1 →	III	200,000	Del Mar NE	0.58(0.16)		
#510-1 early part of the group III interglacial, or a minor interglacial between groups III and IV??			Border Field	0.50	0.48	
			Tecolote Creek †	0.51		
			#1	0.55		
			#130	0.59		
#570-5 →	IV	300,000	Morena Blvd.	0.68(0.18)		
2340-1 and 2340-2 →	V	≥1,000,000	Linda Vista		1.2(0.71)	

*Age determination from extent of racemization in Chione shells; see Masters and Bada (1977).

†The Tecolote Creek Protothaca results (alleu/iso = 0.58) also support the placement of this terrace in this group, since the rates of racemization in Chione and Protothaca shells have been shown to be similar (Wehmiller and others, 1977).

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APPENDIX E

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