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Revision 0

A Review of Subsurface Soft Zones at Savannah River Site with Emphasis on H Area Tank Farm (U)

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Executive Summary

Beneath the Savannah River Site (SRS), at depths ranging from about 100 to 200 feet, soft zones exist in mixed carbonate/clastic strata of Eocene age. More than sixty years of investigation and research into their occurrence, origin, and behavior has revealed that:

- Soft zones beneath SRS are not cavernous voids, but are small, isolated, poorly connected, three-dimensional features filled with loose, fine-grained, water-saturated sediment.

- In spite of their underconsolidated nature, soft zones have survived for a very long time and remain structurally competent in the presence of significant overburden stresses.

- Soft zones appear not to be a critical influence on either groundwater flow or contaminant transport.

Historical Geologic Perspective

The Atlantic Coastal Plain sequence beneath the SRS consists mostly of semi-consolidated clastic sediments — layers and various mixtures of sand, silt, clay, and gravel deposited by water in shallow marine, marginal marine, and nearshore fluvial environments. The occurrence of fossiliferous calcareous rock (limestone) in this wedge of seaward-thickening sediments (Figure 1) has been known and its presence exploited for more than two centuries. An early and noteworthy scientific description belongs to Charles Lyell (1845), whose 1841-1842 travels in North America included expeditions in Georgia and South Carolina to observe and determine the fossil age of the “well-known white limestone” of the Savannah, Santee, and Cooper Rivers. Lyell’s work is certainly among the first published accounts that document the existence of sinks, holes, and caves associated with limestone strata in South Carolina. Subsequently, many other naturalists and geologists (Tuomey, 1848; Kerr, 1875; McCallie, 1896; Agee et al., 1913) noted the tendency of calcareous rocks in the southeastern Atlantic Coastal Plain to form cavernous conditions in response to dissolution by percolating rainwater.

Early Soft Zone Investigation and Remediation

By the mid-twentieth century, when parts of Aiken and Barnwell counties were selected as the site for SRS, it was widely known and well documented that the Eocene (56 to 34 million years ago) age rocks beneath the SRS included calcareous strata. The potential for subsurface cavities and earth subsidence resulting from dissolution of these strata was investigated as part of an extensive program of aerial photography, geologic mapping, and geotechnical drilling carried out by the US Army Corps of Engineers (USACE, 1951, 1952a) prior to construction of SRS facilities.

Noting that shallow topographic depressions (sinks) were most abundant in regions where calcareous rocks existed in the subsurface, and scarce or absent in areas below which such strata were not found, the USACE concluded that the sinks resulted from the dissolution of carbonate minerals in the Eocene age Santee Formation[1]. Figure 2 shows the locations of sinks and basins as interpreted by the USACE in the General Separations Area (GSA). Some of the larger oval-shaped features that the USACE identified as sinks are <u>not</u> sinks, but are now known to be Quaternary age Carolina Bays — shallow, elliptical

[1] Soft zones exist in the Santee Formation and in the lowermost part of the overlying Dry Branch Formation. References to soft zones in the Santee Formation include the lowermost part of the Dry Branch Formation as well.

depressions of probable eolian and lacustrine origin. The inset map at Figure 2 shows H Area Tank Farm infrastructure superimposed on a 1951 USACE map of sinks and basins; Tank 38 may have been constructed near the edge of one sink, but no other waste tanks appear to have been constructed on or near any sinks. *(The surface expression of any sinks, basins, or Carolina Bays in the H Tank Farm area has been obliterated by excavation and construction.)*

Concurrent with the mapping program, the USACE's drilling program identified weak areas and soft spots in the Santee Formation, concluding that:

- "removal of calcareous material by solution has led to the formation of a loose or cavernous condition in the soils"
- "voids of many feet in diameter do not seem likely; it seems probable that the materials are characterized by a honeycombed structure"
- "the cavities are not necessarily open, but probably are partly filled with soft, semiliquid clays or loose silts and sands."

Recognizing the engineering geotechnical importance of this phenomenon, the USACE recommended and received approval to execute a program of injection grouting to proactively mitigate soft foundation conditions in areas where critical facilities (reactors, reactor coolant pump houses, canyons, and waste tanks) were to be constructed. Grouting was prescribed based on the incidence of rod drops and/or fluid loss during the completion of borings on 50' centers (USACE, 1952b). Table 1 summarizes the grouting operation, including the number of holes drilled, number of holes in which carbonate was observed, number of holes that vented grout or water, depth of soft zones, and volume of grout pumped into each of 14 critical areas, including H Area Tank Farm. It is noteworthy that:

- Only 16% of H Area Tank Farm boreholes required grout; while slightly greater than other areas in the GSA, this percentage is much lower than the percentage of boreholes requiring grout in areas to the southeast, for example, pump house locations in L, P, and R Areas.
- Calcareous rock, presumably a precondition for formation of soft zones, was observed in fewer than 40% of H Area Tank Farm boreholes.
- Only two (fewer than 4%) of H Area Tank Farm boreholes vented grout or water during grouting operations; although other areas vented not at all, this percentage (the lowest "non-zero" observation) is again much less than in areas to the southeast.

Subsequent to the foundation grouting program, approximately ten years after critical facilities began operating, SRS engaged Moran, Proctor, Mueser, and Rutledge Consulting Engineers (MPMR) to review the foundation investigations and to evaluate the practice of subsurface grouting as a means to repair sub-soil defects. MPMR (1963) concluded that the Santee Formation beneath SRS did not contain large open caverns, but instead contained poorly connected, sponge-like zones of soft, semi-fluid material. Weighing the time and cost of comprehensive foundation investigation and grouting programs against the risk of possible differential settlement, MPMR suggested a tiered approach for classifying structures in regards to the importance of possible subsurface defects, and recommended that SRS continue to grout soft zones beneath critical facilities, including waste tanks. They also recommended that routine periodic settlement monitoring be performed for major structures. SRS implemented this strategy and, at both F- and H- Area Tank Farms, subsurface grouting was performed prior to the construction of new waste tanks during the 1970s and 1980s. SRS also continued the already established program of settlement monitoring in critical areas, a program that is still ongoing (e.g., SRNS, 2008).

Aadland et al. (1999) reported that the practice of grouting as an expedient means of remediating soft zones in the Santee Formation continued through the 1980s and into the early 1990s, until careful analysis of grouting operations at K Area (associated with reactor restart) demonstrated that the grout did not produce the anticipated or desired effects. Although significant volumes of grout had been injected into the subsurface, soft zones that were present before grouting still existed after grouting. "Post-mortem" drilling revealed that grout had traveled along preferential pathways, forming thin seams and sheets usually no more than 2" thick (WSRC, 1992); this resultant grout geometry was of little or no consequence in reducing the settlement calculated from hypothetical compression of soft zones. Subsequent to the K Area work, SRS discontinued the practice of grouting as a presumed means of remediating soft zones in the Santee Formation.

Later Soft Zone Investigations

In addition to the important discovery that grouting is ineffective in remediating soft zones, the K Area program (WSRC, 1991a, 1991b, 1992) was noteworthy because it was the first to use the cone penetrometer test (CPT) to map, characterize, and quantifiably define soft zones at SRS (Lewis, 2008).

Prior to the early 1990s, the site's institutional knowledge about soft zones resulted from empirical observations made during drilling: fluid loss and rod drops were qualitative evidence of soft zones; injected grout volumes and grout travel distances (i.e., the distance between the hole being grouted and the hole(s) venting grout) were semi-quantitative indicators of soft zone dimension. These observations formed the basis for understanding soft zone properties and their effect on foundation conditions. However, because of the associated time and cost, drilling was limited generally to critical areas (reactors, canyons, and waste tanks); hence, the associated empirical dataset about soft zones was narrowly focused on the 14 critical areas shown at Table 1, which summarizes the field grouting operations carried out during the period 1951-1952.

After the correlation of CPT results with measured soil properties (Robertson et al., 1983; Robertson, 1990), and with the advent of improved electronic tools and the adoption of ASTM standards D-3441 (in 1975) and D-5778 (in 1995), the CPT became popular during the late 1980s and 1990s for rapid, affordable, and repeatable geotechnical data collection.

The characterization program for K Area reactor restart (WSRC, 1991a, 1991b) established a quantifiable engineering definition of the SRS soft zone; in order to be considered a true soft zone, three criteria must be satisfied:

- CPT tip resistance of ≤15 tons per square foot or ≤200 pounds per square inch *(or standard penetration test of ≤5 blows)*

- continuous vertical thickness of at least 1 foot *(more recent soft zone analyses use a thickness criterion of at least 2 feet)*

- stratigraphic position in the Santee Formation *(or in the lower region of the overlying Dry Branch Formation)*

In practice, this is considered a working definition, as all three criteria accommodate some degree of judgment.

Following the K Area characterization, the CPT was deployed at SRS with increasing frequency as a first-line tool for characterizing the geotechnical behavior of the uppermost ~200 feet of the soil column. At about the same time, the CPT was being commonly used to characterize waste sites across SRS, primarily collecting soil gas and small volume groundwater samples but also acquiring data about the physical properties of the subsurface. As a result, during the mid- to late 1990s, the density of data concerning the SRS subsurface and soft zones increased considerably. Figure 3 shows the locations of soil borings and CPTs completed at SRS, many of which penetrate into or entirely through the Santee Formation.

Recent Investigations

During the 1990s and 2000s, several geotechnical investigations were completed in or near H Area as part of siting or constructing the following facilities:

- In-Tank Precipitation Facility (ITP)
- Tritium Extraction Facility (TEF)
- Replacement Tritium Facility (RTF)
- Salt Waste Processing Facility (SWPF)
- Accelerator Production of Tritium (APT)
- Saltstone Waste Vaults
- Defense Waste Processing Facility (DWPF)
- Glass Waste Storage Buildings (GWSB)

These investigations added significantly to understanding the occurrence, distribution, geologic history, and engineering significance of soft zones. A multi-year soft zone investigation by the Georgia Institute of Technology is also underway.

Occurrence and Geology of Soft Zones

In H Area and in the GSA, the Santee Formation is ~70' thick on average, occurring at depths between ~100 and 200 feet. The lithology of the Santee Formation varies both laterally and vertically and includes variably indurated quartz sand, calcareous sand/mud, and limestone (Aadland et al., 1995); some sand and limestone horizons are so hard and/or cemented that they are impenetrable by CPT.

Beneath H Area, within the Santee Formation and occasionally in the lowermost Dry Branch Formation, soft zones occur in two distinct horizons: an upper horizon (~160' to 175' elevation) and a lower horizon (~130' to 140' elevation). The spatial distribution of soft zones across SRS indicates that they occur more commonly in the southeast and less commonly in the northwest parts of the site (Aadland et al, 1999; USACE, 1952a). This distribution correlates strongly with lithologic variations (lithofacies) in the Santee Formation, ranging from an almost entirely clastic (non-calcareous) phase in the northwest, to a mixture of clastic and calcareous sediments in the central portions of the site (including H Area), to mostly limestone beneath the southeast regions of SRS (Figure 4). The orientation of these general lithofacies[2] reflects the geometry of the ancient

[2] The lithofacies map at Figure 4 is a greatly simplified schematic illustration of a gradational change from clastic sediments in the northwest to carbonate sediments in the southeast.

shoreline; the mineralogic and textural variations result from sediment deposition across a continuum of shallow marine and nearshore environments (Figure 5) during the Eocene epoch.

Owing to their loose and unconsolidated nature and to the fact that they occur beneath the water table and are fully saturated with groundwater, it is exceedingly difficult to obtain undisturbed soft zone samples. Nonetheless, a few samples have been obtained by fixed piston or similar sampling methods; geologic analyses of a soft zone interval from F Area (not necessarily an actual soft zone) indicated several lithofacies, including biomoldic chert, siliceous sandy mud, and terrigenous sand. Petrographic analyses indicated that carbonate had been extensively replaced with opal-CT and chalcedony (amorphous silica) (SAIC, 1999).

The origin of soft zones and the mechanisms of their formation and preservation are matters of debate, but their association with calcareous sediments is irrefutable. A recent hypothesis (Aadland et al., 1999) for soft zone formation invokes dissolution of calcareous strata by meteoric water, with synchronous or subsequent replacement of calcite with amorphous silica.

It is important to note that the dissolution thought to be responsible for soft zone formation is assumed in all hypotheses to have occurred under vadose conditions, at a time when the regional water table was lower than at present. Throughout the GSA, except in deep stream valleys (Upper Three Runs Creek and some tributaries), the Santee Formation is now beneath the water table; indeed it constitutes part of the Upper Three Runs Aquifer (lower aquifer zone) as defined in the GSA Hydrogeologic Model (WSRC, 1999, 1997). Assuming groundwater of relatively neutral pH, mineral dissolution in saturated conditions is very much slower than under vadose conditions — so much slower that the process of calcite dissolution and silica replacement has been described as negligible (Cumbest, 1994) for as long as saturated conditions persist.

The existence of soft zones in strata of Eocene age beneath SRS is compelling evidence for their long-term stability over geologic time. Some soft zones may have dissolved to the point of "collapse" in the subsurface, and this may be responsible for or at least associated with the sinks first noted on the SRS landscape by the USACE (1952a). However, many soft zones still exist in the Santee Formation (~40 million years old) and presumably are very old themselves.

Recent work by the United States Geological Survey (in concert with the Department of Energy and Georgia Institute of Technology) offers promise in determining the age of carbonate dissolution and development of soft zones in Eocene age rocks beneath the Central Savannah River Area. This preliminary and unpublished work suggests that soft zones may be at least 40,000 years old (personal communication from J.B. Paces, April 2010). If confirmed, such a finding adds valuable insight into the long-term stability of soft zones, especially in regards to whether soft zones can withstand significant seismic events. The estimated mean return period for a magnitude 6.9 Charleston, SC, earthquake (SRS's design basis event) is ~600 years

(Talwani and Schaeffer, 2001; Amick and Gelinas, 1991); soft zones that are ~40,000 years old presumably have withstood many such earthquakes as well as less frequent events of even greater magnitude.

Engineering Characteristics of Soft Zones

In spite of significant overburden pressures, soft zones (presumably zones of mineral dissolution) exist at depths of 100’ to 200’ beneath SRS. The apparent long-term stability of these underconsolidated, compressible zones is the subject of engineering debate, and many models and analogs have been suggested to explain the persistence of soft zones through geologic time. Most models invoke “arching” of vertical overburden stresses by small, localized, honeycomb-like soft zones, redistributing the stresses to the relatively strong sands that typically overlie and surround soft zones (WSRC, 1992; Lewis, 2008). Modeled thusly, soft zones maintain considerable structural competence, accommodate static loads from massive structures, and remain intact (uncompressed). The fact that no massive, reinforced structure has experienced greater than predicted settlement (Lewis, 2008) seems to support this hypothesis.

Numerous generic and facility-specific studies have demonstrated an acceptably wide margin of safety against liquefaction of SRS soils in response to modeled seismic events; nonetheless, conservative engineering analyses[3] assume that soft zones beneath a structure will compress in response to seismic shaking and that the compression will be propagated to the ground surface as settlement.

Various mathematical solutions have been used to calculate the dynamic settlement expected to result from soft zone compression; all solutions propagate the compression to the ground surface based on site-specific or assumed soil properties. Table 2 summarizes the thickness of soft zones found during recent investigations in H Area and nearby, along with the settlement predicted to result from compression of soft zones (measured or hypothetical) beneath these facilities. Some engineering exercises assume a greater soft zone thickness than is actually known to be present beneath a facility; for example, geotechnical studies for the In-Tank Precipitation facility modeled the existence and compression of a <u>hypothetical</u> 15’ thick soft zone, which when compressed resulted in 5” to 7” of computed surface settlement. Similar ratios — inches of computed settlement resulting from soft zones of several feet thickness — are apparent in the results of settlement exercises for other facilities throughout H Area and surrounding areas (Table 2).

Groundwater Hydraulic Significance

In most places at SRS, the Santee Formation, in which soft zones occur, is submerged beneath the water table and is itself a significant aquifer. Thus, it is important that groundwater flow and contaminant transport models adequately accommodate the occurrence, physical properties, and behavior of soft zones.

Although early reports correlated soft zones with the presumed existence of subsurface voids and

[3] The Department of Energy, the Defense Nuclear Facilities Safety Board, and various permit holders have concurred with this conservative approach to designing for dynamic settlement from soft zone compression.

cavernous conditions, the preponderance of evidence collected at SRS indicates that soft zones are not caverns or voids, but are small, isolated or poorly connected, honeycomb-like features filled with sediment (Cumbest, 1994). Cumbest and Syms (1996) cited P-wave velocities less than water as geophysical evidence that soft zones are likely filled with very loose, saturated sands. Physical evidence includes an absence of thick grout layers in subsurface regions where grout was injected to "remediate" presumed cavernous conditions (WSRC, 1992; Aadland et al., 1999). Additional physical evidence is shown at Figure 6, a still-frame image of a sediment-filled soft zone; the image was captured by video-CPT as the cone tip was advanced through a soft zone. *(Annotations on the image are those of the author, added to highlight the difference between soft and non-soft zones observed on the video record.)* Lastly, during the ~20-year period spanned by investigation of many waste sites in and near H Area, no void spaces, open flow conduits, or unexplained groundwater flow or contaminant patterns have been discovered.

Based on the weight of such evidence, soft zones seem not to require complex dual- or triple-porosity models to capture their hydraulic significance (or lack thereof). The data-rich and robust GSA hydrogeological model (WSRC, 1999) incorporates data from more than 140 boreholes that fully penetrate the Santee Formation; almost 40 of these control points (more than 25%) lie inside the boundaries of the H Area Tank Farm flow fields (Figure 7). The GSA model utilizes a variety of data about the Santee Formation, including lithology, porosity, permeability, grain size, hydraulic conductivity, and pumping test data from these and other locations. It is reasonable to conclude that soft zone hydraulic properties are encompassed by the range of physical properties included in the GSA hydrogeological model (WSRC, 1999) and other dependent models.

Remaining Uncertainty

Very many investigations and engineering analyses have focused on soft zones beneath SRS. Most reports have concluded that soft zones at SRS are not caverns or large void spaces. However, recent industrial excavations near Waynesboro, GA, have unearthed the existence of true cavernous conditions and speleothems in the Utley Formation (Syms et al., 2011), which overlies the Santee Formation and consists of similar calcareous rocks. The occurrence and thickness of the Utley Formation at SRS and the extent to which caverns and voids may exist in the Utley Formation (or the Santee Formation) beneath SRS are subjects of ongoing investigation.

If the Utley and Santee Formations at SRS do contain cavernous conditions on the scale noted at Waynesboro (up to 4' vertical thickness), the collapse of such caverns would yield surface settlements larger than for a sediment-filled soft zone of the same magnitude -- but still less than the computed settlement associated with the large, conservative, hypothetical soft zones modeled for ITP, for example.

Furthermore, if cavernous conditions exist in the Utley/Santee interval anywhere beneath SRS, it is reasonable to assume that they might exist in the same lithofacies as those observed at Waynesboro. Figure 4 shows the interpreted distribution of four Santee

Formation lithofacies (subdivisions based on the relative proportions of calcareous vs. clastic sediments). The excavations at Waynesboro lie in the "carbonate > clastic" facies; SRS areas in this same facies include K, L, P, and R Areas. H Area and the entire GSA lie ~5 miles updip, where clastic sediments are generally more prevalent than calcareous sediments. If caverns and karst conditions exist anywhere beneath SRS, the most likely locations are toward the southeast, in areas that overlie the more calcareous facies of the Santee Formation. Indeed, in 1951, the USACE identified as <u>uniquely</u> noteworthy a 150' diameter sinkhole near the former town of Dunbarton (southeast of P Area). This feature, known as Lark Hole by area residents, is almost certainly the result of carbonate dissolution and volume loss in the subsurface. And while anecdotal evidence indicates that the sinkhole may have developed very suddenly, the USACE (1952a) concluded that "the recurrence of such a phenomenon is unlikely."

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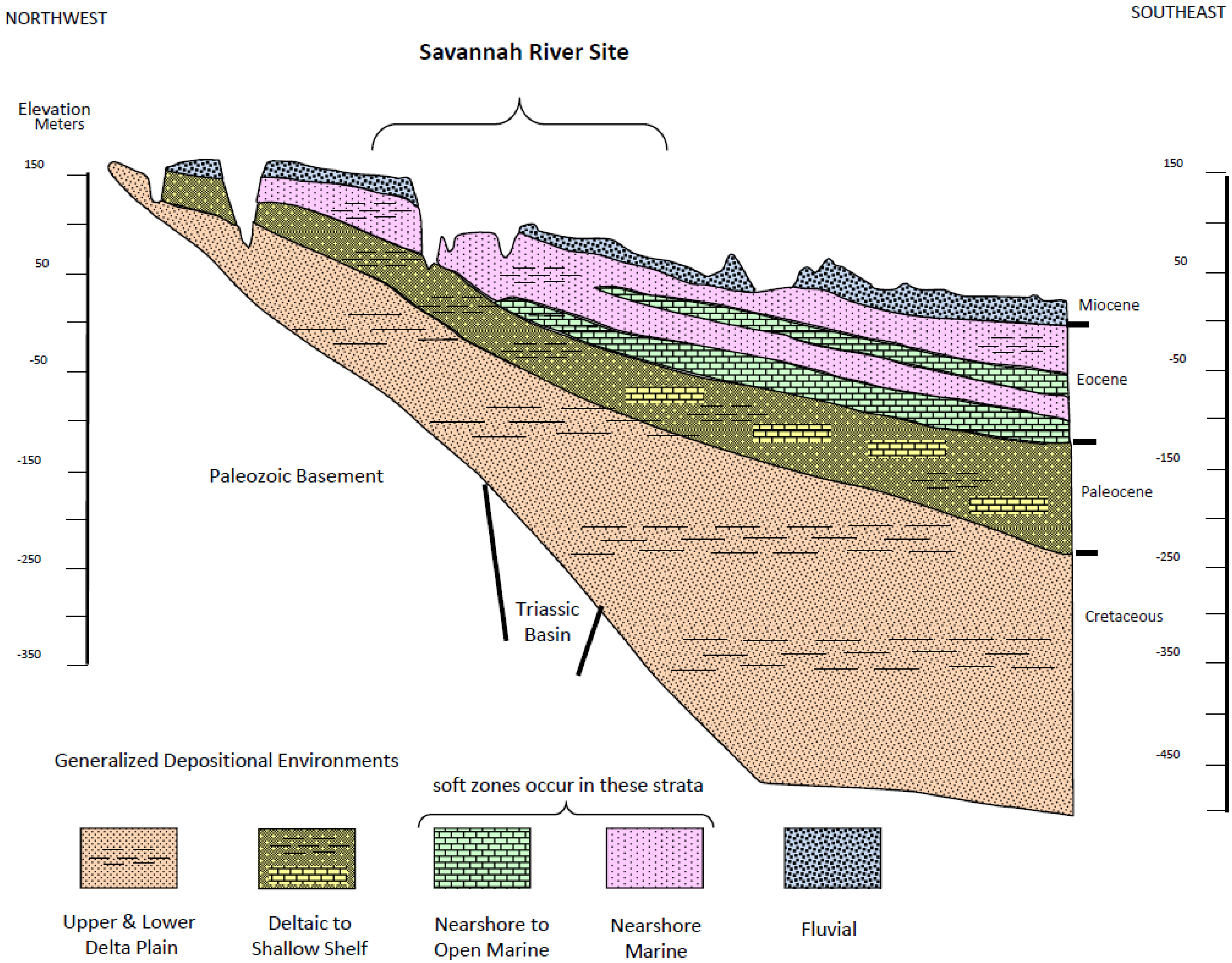

Figure 1. Schematic stratigraphic cross-section through the upper and middle Atlantic Coastal Plain, including SRS region.

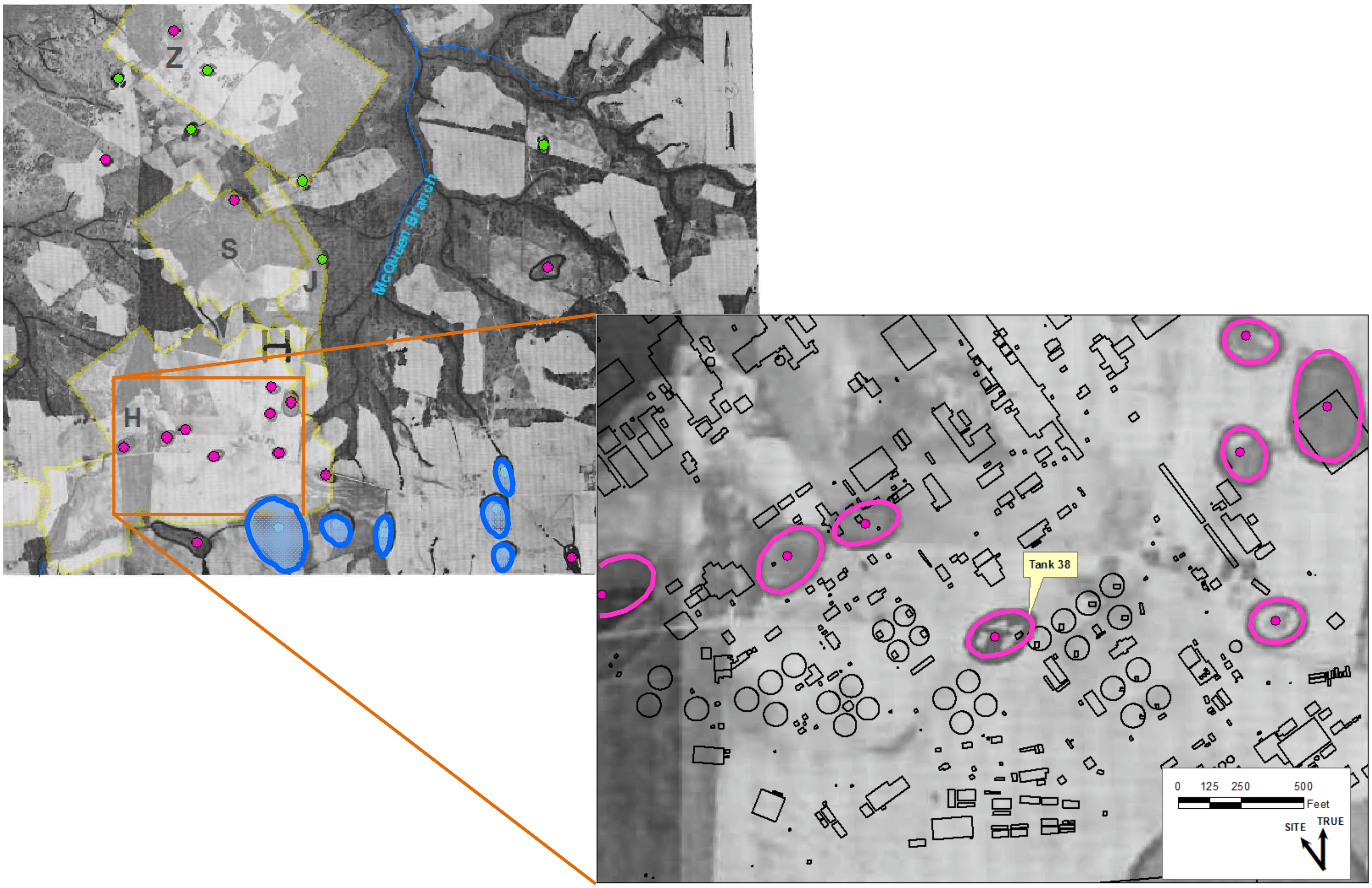

Figure 2. Pre-SRS aerial photograph of H Area, showing basins (green) and sinks (pink) identified by USACE; inset map shows H Area Tank Farm. *(Feature originally identified by the USACE as "sinks" but now known to be Carolina Bays are indicated in blue.)*

Table 1. Summary of field grouting operations (reproduced from USACE 1952x).

		Period of Operation									Quantity of Grout Pumped							Water and/or Mud Loss and Soft Spots Depth Ft		
Area	Building Number	Starting Date	Completion Date	Number Fishtail Holes	Number SplitSpoon & Undisturbed Holes	Total Number Holes	Linear Feet Holes	Total Number Holes Grouted	% Holes Grouted	(2) Number Holes Venting	Number Batches	Cu Ft per Batch	Total Cu Ft	Total Cu Yd	Number Borings Indicating $CaCO_3$	(3) Depth Center Calcareous Zone	Avg Surf Elev	Max	Min	Avg
C Area total				*365*	*8*	*373*	*74304*	*57*	*15%*	*17*	*4028*		*45154*	*1672*	*337*					
	190-C	23-Nov-51	28-Nov-51	25	2	27	5,400	9	33%	2	634	11.21	7,107	263	22	155	283	138	84	102
	105-C	27-Nov-51	19-Dec-51	268	6	274	54,404	35	13%	12	2423	11.21	27,162	1,006	266	154	282	282	77	128
	105-C rev	9-Sep-52	16-Sep-52	72	0	72	14,500	13	18%	3	971	11.21	10,885	403	49	154	284	138	98	133
K Area total				*408*	*10*	*418*	*89734*	*91*	*22%*	*34*	*14998*		*164978*	*6111*	*41*					
	190-K	30-Oct-51	8-Nov-51	36	2	38	7,964	10	26%	3	2335	11.00	25,685	951	17	164	273	153	100	133
	105-K	5-Oct-51	8-Nov-51	282	7	289	60,883	76	26%	31	11950	11.00	131,450	4,869	6	161	270	204	80	136
	105-K rev	18-Aug-52	23-Aug-52	90	1	91	20,887	5	5%	0	713	11.00	7,843	291	18	161	269	150	113	136
L Area total				*393*	*10*	*403*	*93166*	*127*	*32%*	*31*	*22778*		*245035*	*9075*	*317*					
	190-L	13-Sep-51	3-Jan-52	36	2	38	6,326	27	71%	6	8260	11.21	92,595	3,429	27	152	258	165	90	129
	105-L	28-Aug-51	9-Oct-51	260	6	266	66,023	67	25%	15	12445	10.50	130,673	4,840	197	144	251	170	108	152
	105-L rev	24-Jun-52	21-Jul-52	97	2	99	20,817	33	33%	10	2073	10.50	21,767	806	93	144	250	217	88	140
P Area total				*344*	*4*	*348*	*76212*	*77*	*22%*	*24*	*20265*		*212783*	*7881*	*276*					
	190-P	21-Aug-51	29-Aug-51	27	1	28	6,170	12	43%	6	3630	10.50	38,115	1,412	21	214	322	202	139	173
	105-P	6-Jul-51	25-Aug-51	317	3	320	70,042	65	20%	18	16635	10.50	174,668	6,469	255	211	319	227	36	182
R Area total				*162*	*7*	*169*	*32400*	*12*	*7%*	*8*	*8331*		*88428*	*3275*	*80*					
	190-R	24-Aug-51	12-Sep-51	27	1	28	5,502	12	43%	8	7950	10.50	83,475	3,092	18	157	283	180	115	152
	105-R[1]	15-Jun-51	-----	135	6	141	26,898	8[1]	6%[1]	0	381	13.00	4,953	183	62	160	286	180	136	173
F Area total				*93*	*15*	*108*	*18314*	*24*	*22%*	*0*	*830*		*8715*	*323*	*76*					
	221-F	25-Jul-51	2-Aug-51	63	7	70	13,491	20	29%	0	246	10.50	2,583	96	54	168	316	179	75	134
	241-F	16-Jul-51	20-Aug-51	30	8	38	4,823	4	11%	0	584	10.50	6,132	227	22	90[4]	238[4]	108	58	83[4]
H Area total				*163*	*4*	*167*	*37810*	*17*	*10%*	*2*	*2113*		*23918*	*886*	*46*					
	221-H	11-Nov-51	16-Nov-51	108	3	111	26,060	8	7%	0	1489	11.32	16,855	624	24	168	310	192	70	161
	241-H	14-Nov-51	21-Nov-51	55	1	56	11,750	9	16%	2	624	11.32	7,063	262	22	158	300	150	139	143
TOTAL ALL AREAS				***1,928***	***58***	***1,986***	***421,940***	***405***		***116***	***73,343***		***789,011***	***29,223***	***1,173***					

notes
(1) Program not completed. Grouting discontinued 3 July 1951 to permit construction.
(2) Borings venting either grout or water when grout was being pumped into another boring.
(3) Depth to center of a 60-ft thick calcareous zone as originally deterined from undisturbed and split-spoon borings. See Plate 8, Vol.II, Geologic- Engineering Investigations, SRP, March 1952.
(4) Fishtail borings were drilled in bottom of excavation. Tabulated depths measured from that point. Original average surface elevation approximately 283 ft.
105-x rev extended grouting program based on revision of 105 building design

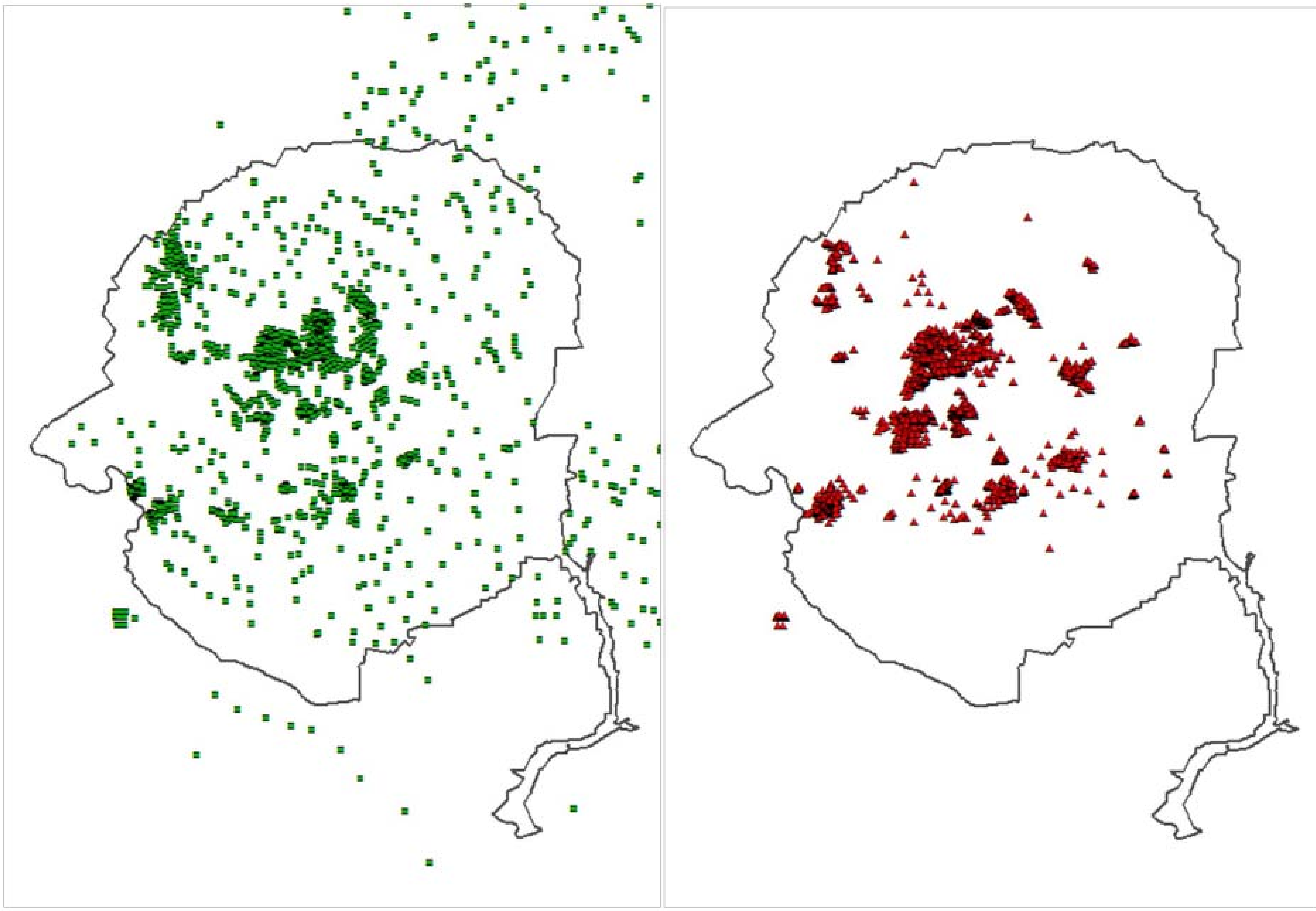

Figure 3. Locations of soil borings (green) and CPTs (red) completed at SRS.

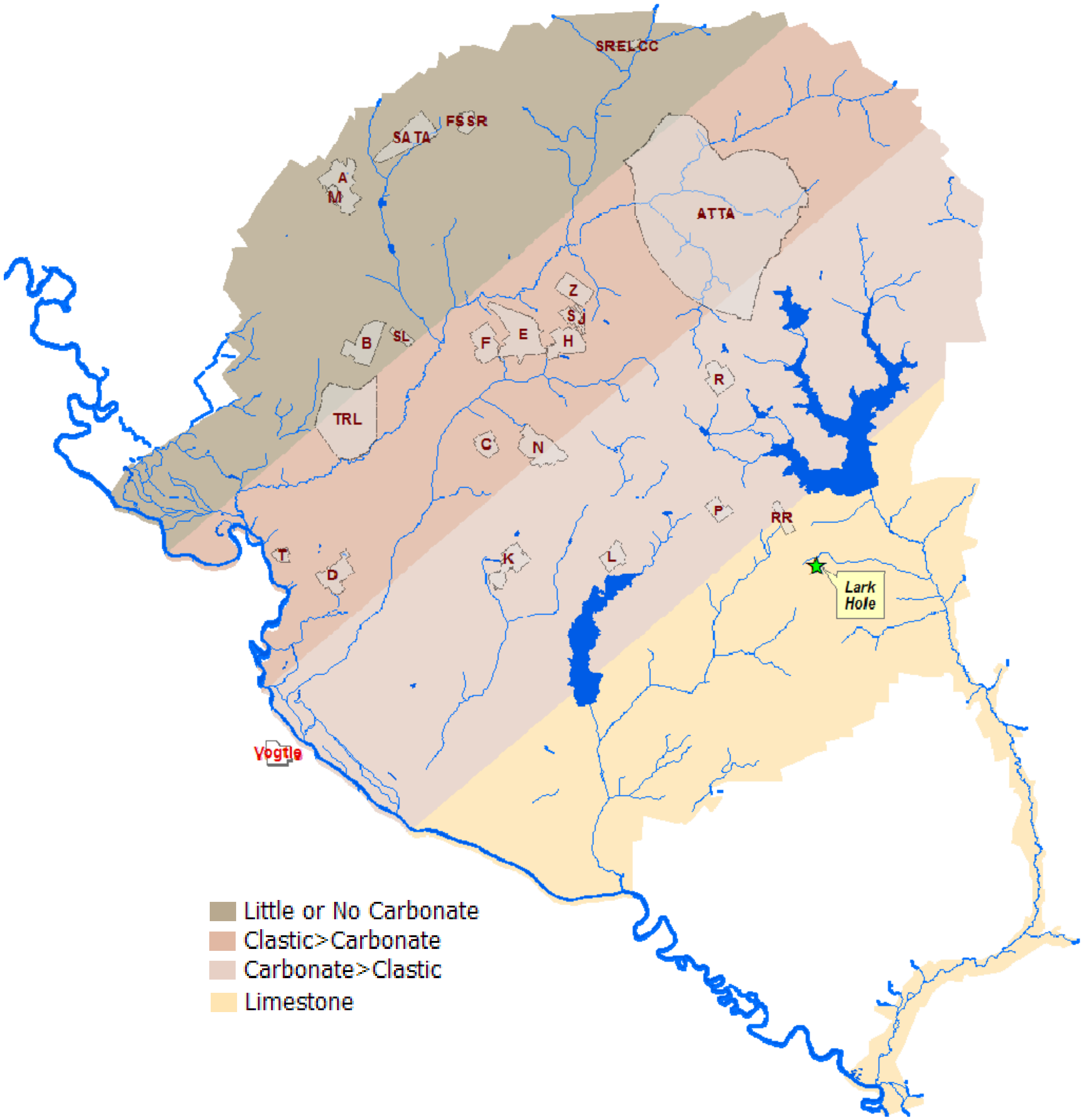

Figure 4. Santee Formation general lithofacies (modified from Aadland et al., 1999).

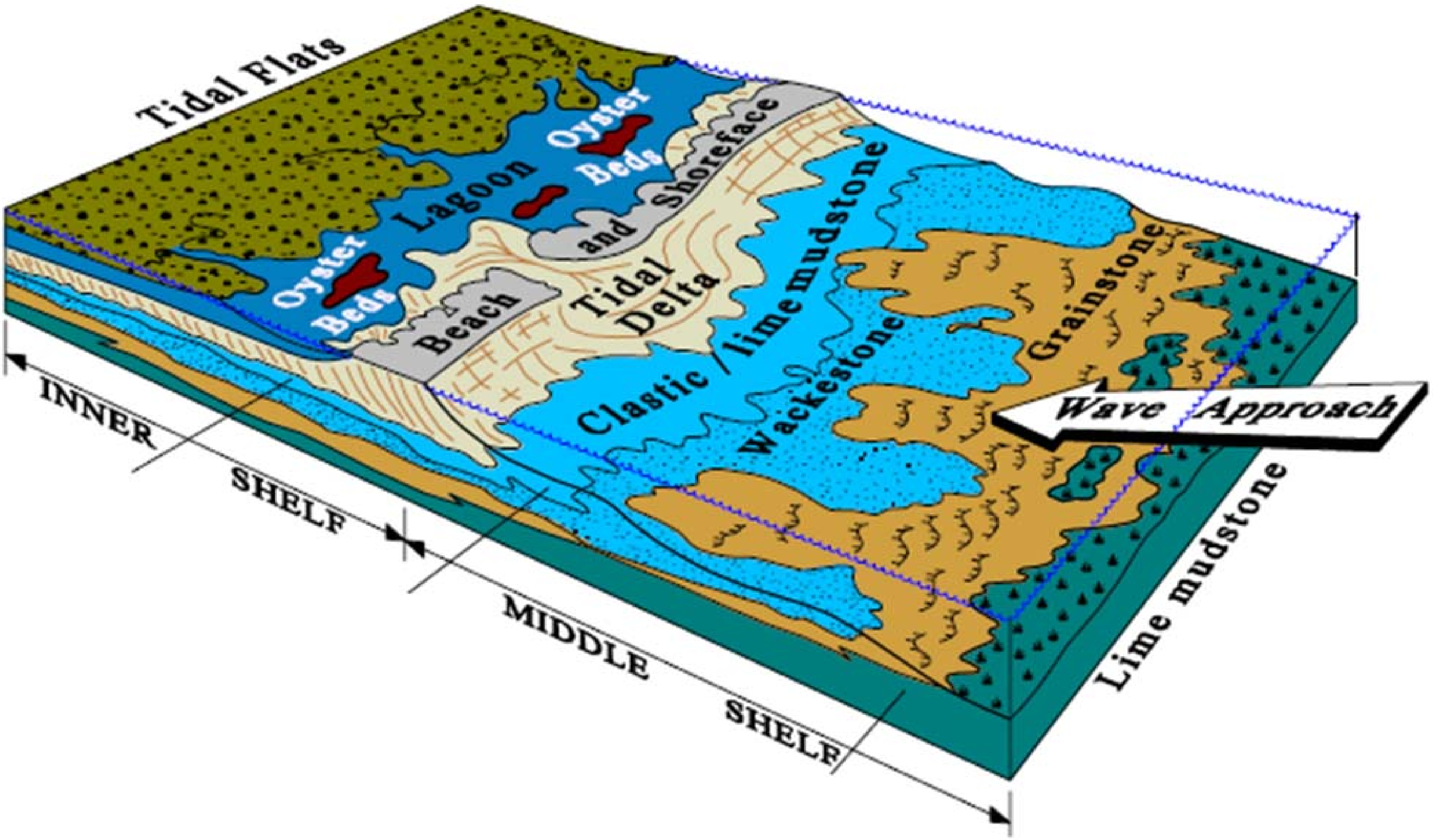

Figure 5. Shallow and marginal marine environments of sediment deposition (after Kerr, 1977).

Table 2. Soft zone thickness and computed surface settlement resulting from hypothetical compression of soft zones.

Facility	Soft Zone Thickness*	Computed Resultant Surface Settlement	Reference
Glass Waste Storage Building #2	6' maximum individual 7.5' maximum aggregate	0" to 2.5"	WSRC, 2007a
In-Tank Precipitation Facility	4' observed average 6.9' maximum observed 15' hypothetical	5" to 7" (from compression of hypothetical 15' thick soft zone)	WSRC, 1995a; Cumbest, 1994
Tritium Extraction Facility	3' maximum	1"	WSRC, 2000
Salt Waste Processing Facility	9.5' maximum aggregate	0" to 5.9"	WSRC, 2007b
Defense Waste Processing Facility		negligible	WSRC, 1995b
Replacement Tritium Facility	2.2' average 9' maximum		WSRC, 1993
Saltstone Vaults #2, #3, #5	14' maximum individual	0.5"	WSRC, 2006a,b; SRNS, 2009a,b; SRNS, 2012
Accelerator Production of Tritium Facility	7.4"	<1.8"	Burns and Roe, 1999

**variable minimum thickness criterion, but often 2'*

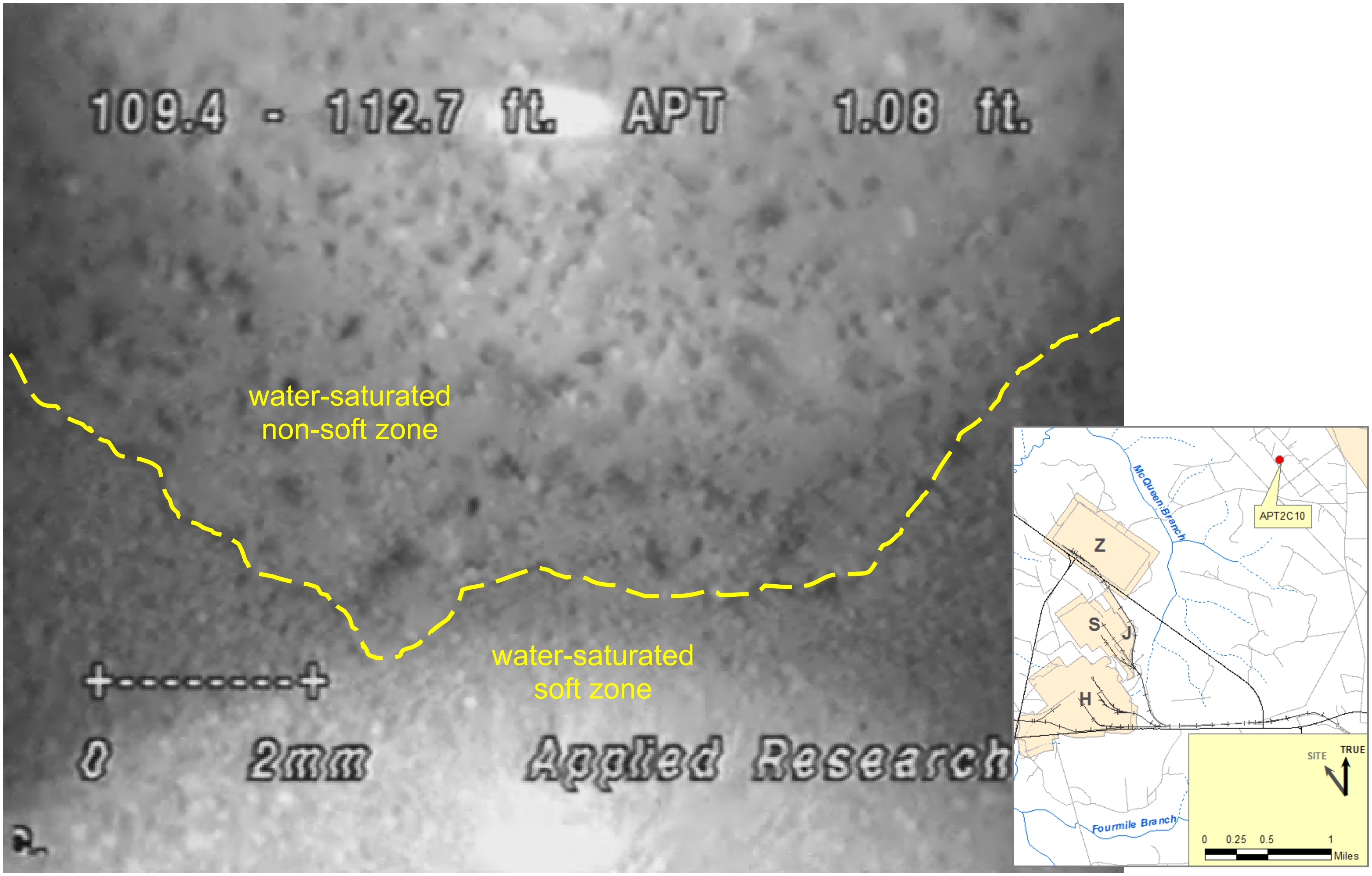

Figure 6. Annotated image from video-CPT collected at APT site, 2.5 miles northeast of H Area.

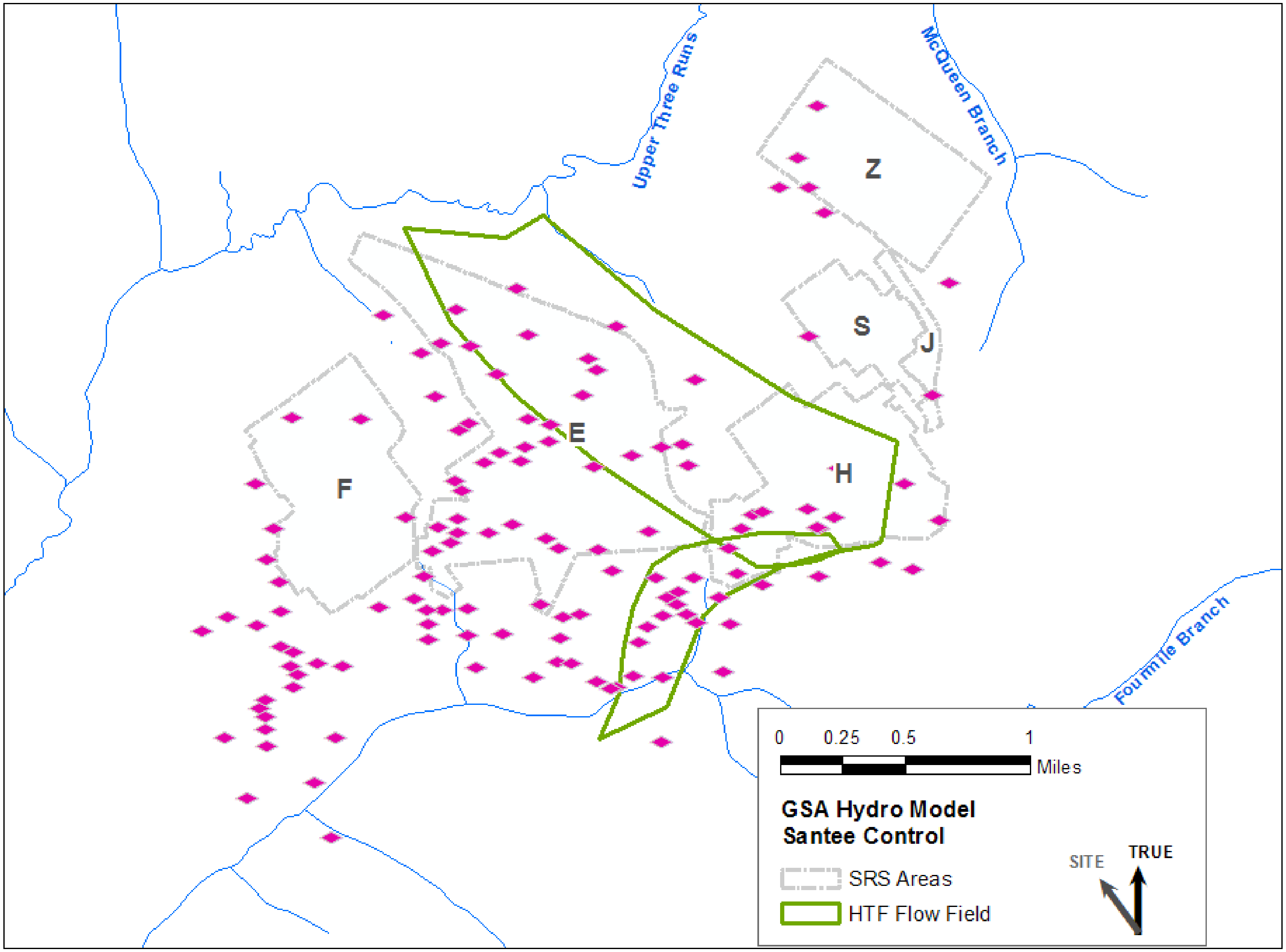

Figure 7. Location of GSA Model control points for Santee Formation lithology and hydraulic properties.