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Construction Materials in Delta Areas

Remote sensing techniques for identifying materials for engineering construction are most effective if a two-phased procedure is adopted consisting of a regional analysis followed by a detailed analysis.

THE PURPOSE OF this paper is to describe the approach and procedures for locating engineering construction materials using multi-spectral remote sensors and to report some of the results obtained during Phase III of Project SAND.

BACKGROUND

The U. S. Army Engineer Topographic Laboratories (USAETL), Fort Belvoir, Virginia, and the U. S. Army Waterways Experiment Station (USAWES), Vicksburg, Mississippi, have conducted investigations on the use of remote sensor imagery for locating engineer construction materials in the Mekong Delta, Vietnam, in support of Project SAND. The project was initiated in response to a request for assistance from the Engineer, U. S. Army Headquarters in Vietnam and was designed to be conducted in three phases.

Phase I was conducted by the Waterways Experiment Station during the summer of 1967. The objective of Phase I was to determine the extent to which construction materials and sites could be located using existing photography and background literature. Lack of security in the Mekong Delta had prevented an extensive ground survey. The Phase I study resulted in the compilation of several 1/250,000 scale map overlays depicting the distribution of potential sources of sands and areas suitable for construction.

ABSTRACT: *Procedures for identifying likely sources of materials for engineering construction with multi-spectral remote sensor are applied to a part of the Mississippi Delta. Sensors included panchromaticolor and color-infrared photographs, thermal-infrared imagery, radar, nine-channel multispectral scan imagery, and small-scale photo-index mosaics. Ground truth was acquired concurrently with the remote sensor overflights including soil moisture, soil temperature, wind velocity, ground photographs and soil samples. A two-phase procedure involved a regional analysis followed by a detailed analysis. The APQ-97 was the most versatile radar system for regional analysis. Color-infrared photographs were preferred in most instances for detailed analysis in the delta environment. Thermal-infrared imagery provided useful information where it was applied in conjunction with photographs. The highest potential sources of construction materials in this area were within the cheniers, point bars, river bars and active beaches.*

Phase II was initiated to extend the results of the work of Phase I through the use of different types of remote sensors and techniques. A remote sensor package and detailed flight plans were defined by USAETL for acquisition of multi-sensor imagery over priority areas of the Mekong Delta. The flight program was conducted during April 1968 and the imagery was returned to Fort Belvoir for analysis. A team of scientists and engineers performed a comparative imagery analysis during July 1968. It was determined

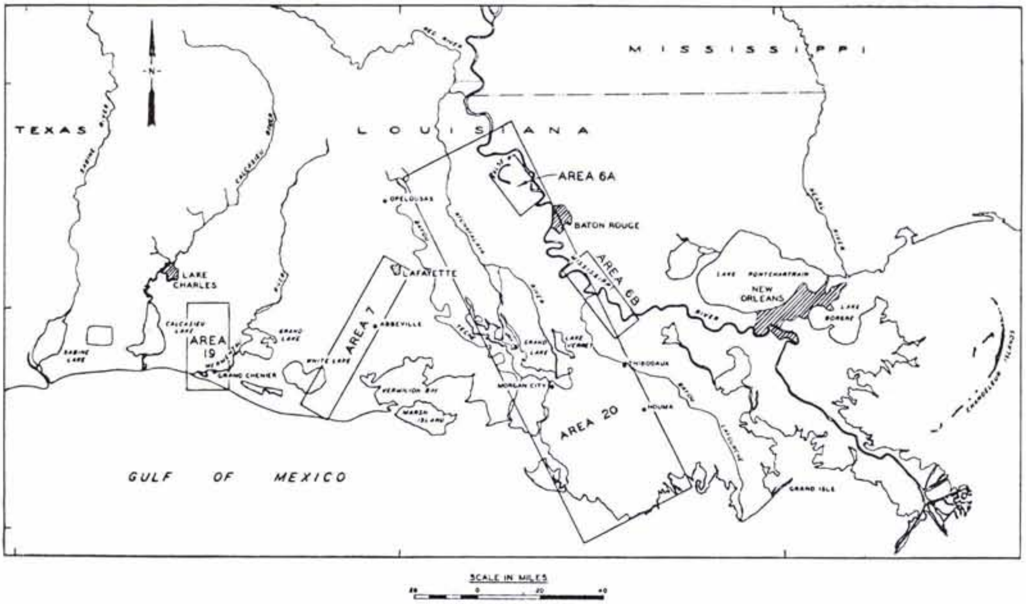

FIG. 1. Index map of Southern Louisiana showing the Phase III study areas.

that the primary sources of sand are the flanks of beach ridges and sand bars in the river channel. Other potential sources of construction material and techniques for discrimination were identified.

PHASE III DATA ACQUISITION

The Phase III test flight program was conducted during March 1969 over areas of the Mississippi Delta which contain similar landforms to those occurring in the Mekong Delta. It was assumed that the physical deltaic processes in the Mississippi Delta are similar to those in the Mekong Delta even though the geographic location and climatic conditions are different. Five areas shown in Figure 1 were identified for the flight tests based on known occurrences of surface and subsurface sand and gravels (see Figure 2). Through correlation of these known occurrences of sand and gravel with their remote sensor responses, the relative performance of each sensor could be evaluated for this application.

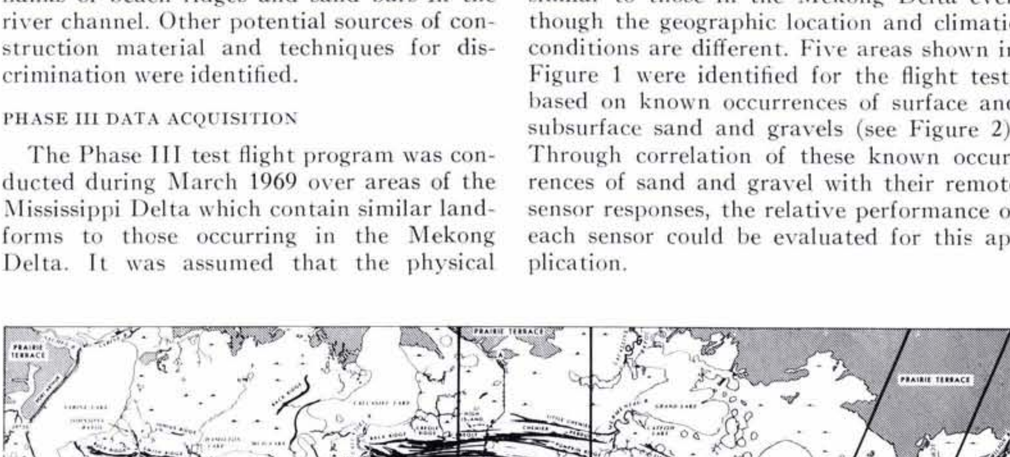

FIG. 2. Physiography of the marginal delta plain of the Mississippi Delta with Areas 7 and 19 outlined. The profile shows the chenier geometry and sedimentary facies compiled from borings taken along line A-A′. (After Gagliano from Byrne, Leroy and Riley, 1959.)

The remote sensor imagery was acquired through support of several organizations:

- Three types of aerial photographs (color, color-infrared and panchromatic) were collected at 5,000 and 20,000 feet altitude by the U. S. Air Force Aerospace Cartographic and Geodetic Service, Forbes Air Force Base, Kansas, using three mapping cameras (KC-1B, KC-4, and KC-7) mounted in an RC-130 aircraft.
- Thermal-infrared and coherent-radar imagery was collected by the U. S. Air Force Tactical Reconnaissance Squadron, Mountain Home Air Force Base, Idaho, using AAS-18 and APQ-102 sensors, respectively, mounted in RF-4C aircraft.
- "Brute-force" radar was collected by the U. S. Army 109th Aviation Company, Fort Lewis, Washington, using an APS-94 radar sensor mounted in an OV-1B aircraft and by the Westinghouse Corporation with APQ-97 mapping radar mounted in a DC-6B aircraft.
- Multispectral scanner imagery was collected by the Bendix Corporation using a nine-channel scanner mounted in a twin engine Beechcraft.
- Small-scale photo index mosaics were obtained from the Department of Agriculture. These are generally used as indexes for domestic photography.

In order to perform a sensor evaluation to define the capabilities of areas for survey of engineer construction materials, it was originally planned that the aerial imagery be acquired simultaneously if possible and all areas under study be covered with each sensor. Because this would have required an excessive amount of flight time, Area 19 was designated as the primary area for study and was covered with all sensors. The other areas were covered to a lesser degree as shown in Figures 3.

Concurrently with the remote sensor overflights, ground truth was acquired including soil moisture, soil temperature, wind velocity, ground photos and soil samples for mechanical analysis. Three sites in Areas 19 and 7 were instrumented with the ground-truth sensors. These instrument packages were assembled by USAWES and were capable of unattended data recording. In addition, ground reconnaissance was conducted throughout the areas by the field personnel. Coordination of the field parties and the aircraft personnel was maintained daily.

Study Rationale, Approach and Procedure

In concept, the acquisition of multispectral data with remote sensors that record energy in various portions of the electro-magnetic spectrum will provide more information about the terrain than any single sensor by itself. In order to reduce the time-variant effects it is also essential to acquire the data with the various sensors *simultaneously*. In actual practice, however, the concept becomes logis-

AREA AND PERCENTAGE COVERAGE					IMAGERY AND SENSOR DATA				
6A	6B	7	19	20	Date of Acquisition	Scale	Imagery Type	Format	Sensor
Complete	Complete	Complete	Complete	Complete	1957-1959	1/63,360	Index-USDA	20x24"	
"	"	"	"	"	Mar 69	1/62,500	Index-ETL	Variable	KC-1B
Complete	Complete				7 & 9 Mar 69	1/10,000	Plus X	9x9	KC-1B
			Complete		8 Mar 69	1/10,000			
		80%			10 Mar 69	1/15,000			
		20%			19 Mar 69	1/20,000			
Complete	50%			66%	10 & 19 Mar 69	1/40,000			
Complete	Complete				7 & 19 Mar 69	1/10,000	EKMS	9x9	KC-4
			Complete		8 Mar 69	1/10,000			
		Complete			10 Mar 69	1/15,000			
Complete	50%			66%	10 & 19 Mar 69	1/40,000			
33%	33%				7 Mar 69	1/10,000	EKIR	9x9	KC-7
			25%		8 Mar 69	1/10,000			
		50%	Complete		19 Mar 69	1/20,000			
33%	33%				24 Mar 69	1/20,000			
				25%	19 Mar 69	1/40,000			
		50%	50%	Complete	24 Mar 69	1/500,000	Radar	1.9" x Cont Strip	APS-94
Complete	Complete					1/1,000,000			
Complete	66%	33%	50%	Complete	22-23 Feb 69	1/200,000	Radar	3.5" x C. S.	APQ-97
Complete	Complete	Complete	Complete	Complete	6 Mar 69	1/800,000	Radar	1" x C. S.	APQ-102
			Complete		8 Mar 69 (Night)	1/17,000	Thermal IR	4" x C. S.	AAS-18
			Complete		24 Mar 69 (Day)	1/26,500	Thermal IR	70 mm x C. S.	Bendix
		10%	15%		20 & 24 Mar 69	1/24,000	Multi-spectral	70 mm x C. S.	Opt. Scan.

FIG. 3. Imagery available for evaluation.

TABLE 1. SENSOR EVALUATIONS FOR REGIONAL ANALYSIS

Regional Zones	*Landform*	*Sensors*			
		B&W Photo Index	*APQ-97 SLAR*	*APQ-102 SLAR*	*APS-94 SLAR*
Beach Zones	Active Beach	Excellent	Poor	Poor	Poor
	Chenier Zones	Good	Good	Good	Poor
Zones of Inundation	Marsh	Good	Good	Good	Poor
	Back-swamp	Good	Good	Good	Poor
Upland	Terrace	Excellent	Excellent	Excellent	Good
River Systems	Natural Levee	Excellent	Poor	Poor	Poor
	Abandoned Channel	Good	Excellent	Good	Poor
	Point Bars	Excellent	Good	Good	Poor
	Spoil Banks	Excellent	Good	Poor	Poor
	River Bars & Islands	Excellent	Good	Good	Good
Regional Trends & Lineations		Good	Excellent	Excellent	Good

tically complex. The various sensors are not operationally compatible with respect to flight altitude, field of view, or time of day for acquisition. For instance, it may be desirable to acquire thermal infrared at night and at low altitude which is not compatible for the simultaneous acquisition of photographs. Radar can be acquired during either day or night, under adverse weather conditions, and from high altitude; this is not true for thermal IR or photographs. Furthermore, the large amount of imagery that can be acquired during a multisensor mission is difficult to handle and analyze. As much of the analysis is done visually by the human interpreter, a large staff is required. Therefore, an objective of this study was to define sensor configuration and analysis procedures which would provide the maximum amount of information with the minimum expenditure of manpower and analysis time.

The approach to locating sources of construction materials using remote sensor imagery involves two basic analytical steps: (1) study of broad regional geomorphic and physiographic patterns to delineate the landforms having the highest potential as sources of the desired materials, and (2) study of the selected landforms in detail to assess the characteristics of the materials of which they are composed. Small-scale imagery provides a synoptic view for determining regional geomorphology and large-scale imagery is required for the detailed analysis.

A team of earth scientists and engineers was assembled to analyze the acquired remote sensor imagery. The team consisted of five geologists, five civil engineers, three geographers and a forester. Each team member was considered an expert in his field and had previous experience with one or more of the types of imagery for application to his scientific discipline. Through observations and interdisciplinary discussions it was intended that the conclusions would represent a consensus of opinion by the team.

The analysis was conducted at the U. S. Army Cold Regions Research and Engineering Laboratory (USACRREL) during 18-29 August 1969. The team reassembled at USACRREL between 15–18 September 1969 to consolidate its observations, evaluations and results. The results presented in this paper are highly condensed and represent the work of the team.

The study team analyzed the remote sensor coverage of Sites 19, 7 and 6B (Figure 1). Although sensor coverage was not the same for all of the sites, the procedure of analysis was consistent throughout the study. Small

PLATE 1. Color infrared photograph of the active beach in Area 19 at the mouth of the Mermentau River. The beach (white in tone) is composed of a mixture of sand and shells. The arcuate ridges on the seaward side of the river indicate successive deposition of sediments which are extending the river mouth to the west. Near-shore wave patterns indicate the presence of subsurface bars.

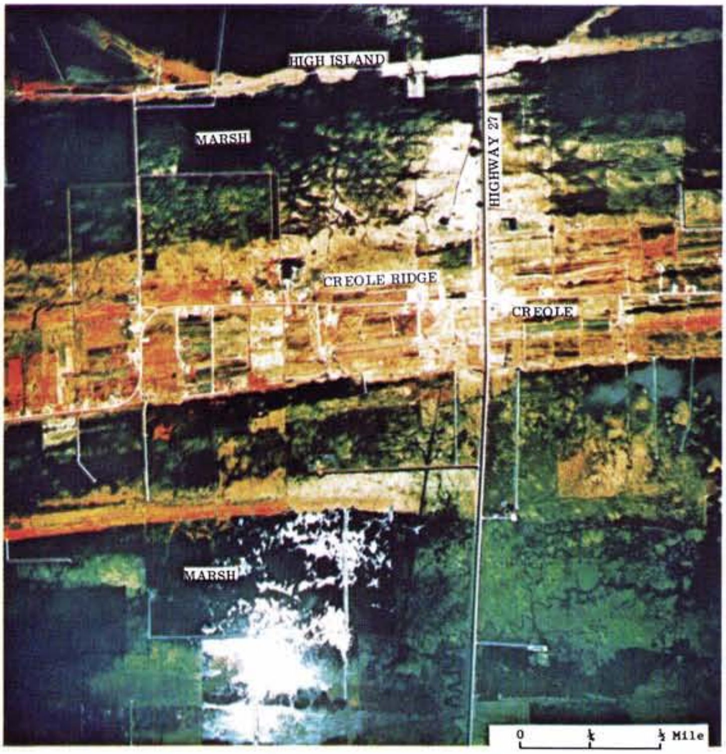

PLATE 2. Color infrared photograph of Creole Ridge and High Island in Area 19. The reddish tones produced by the grasses growing on the ridges contrast sharply with the dormant marsh vegetation. These ridges are predominantly composed of shells but locally contain sand lenses.

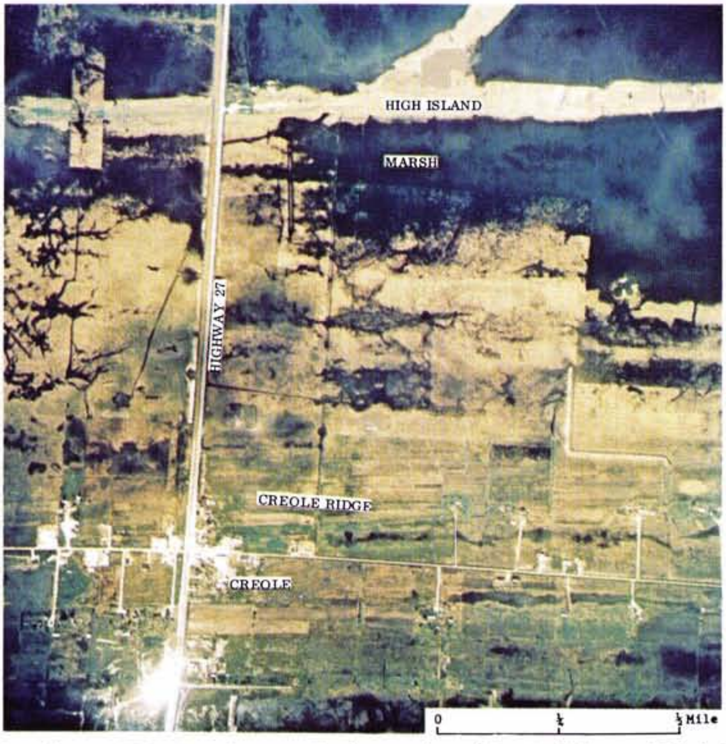

PLATE 3. Ektachrome MS color photograph of a portion of Creole Ridge and High Island shown in Plate 2. Note that the contrast between the ridges and the marsh is less distinct than in the previous illustration.

PLATE 4. Ektachrome MS color photograph of a portion of an abandoned channel in Area 7. The point bars have been veneered with fine grained sediments during flooding. Some of the swales (dark toned) are still evident. The dark circular areas are possible infiltration basins caused by internal drainage which would indicate coarse-grained materials at the shallow subsurface. The tan color of the silty sands (ground checked) in the point-bar areas contrast with the white soil tones (clay) across the channel.

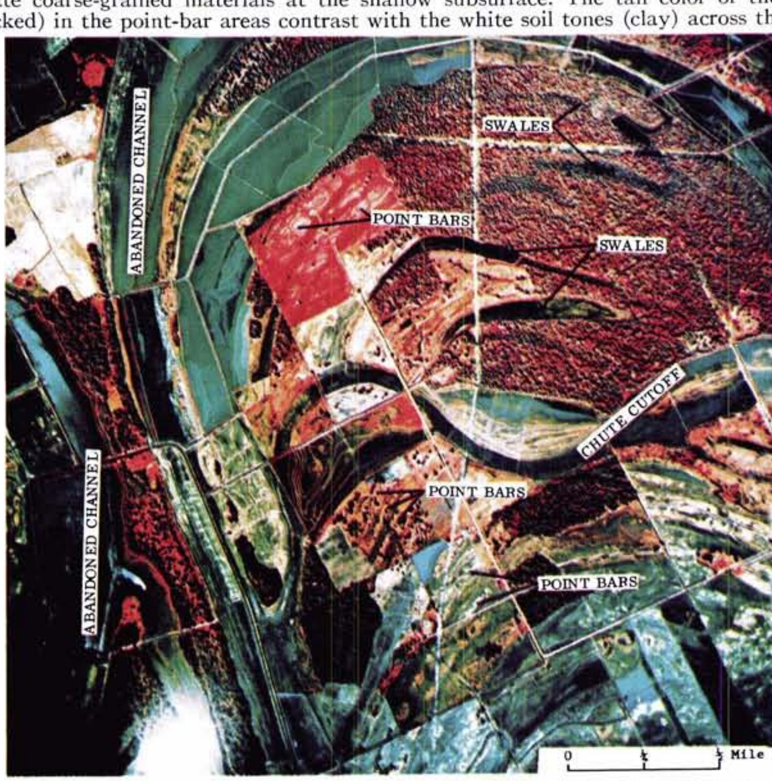

PLATE 5. Color infrared photograph of a major abandoned channel in Area 7. The inside of the old meander scar is marked by a complex series of point bars and swales formed as the stream migrated toward the outside of the bend. The point bars have high potential of containing coarse-grained materials (see Figure 7).

scale sensor coverage including photo indexes or radar imagery, was evaluated and analyzed to determine regional landforms, lineations and physiographic environments. Potentially sand-bearing landforms were delineated and those sites that required more detailed analysis on large-scale imagery were selected. These regional landforms were delineated by analysis of characteristic shapes, land-vegetation-water boundaries and regional trends or lineations. A comparative evaluation of these various small-scale imageries was made to assess their relative capabilities.

Detailed landform analyses were then performed using the large-scale imagery (panchromatic, color, color-infrared photography, and thermal-infrared imagery); each type of imagery was then comparatively evaluated for this purpose. The potential sources of construction materials were described next. Several anomalous areas for which compositions could not be ascertained were studied and described in anticipation of a field check.

In instances of both the small-scale and large-scale sensor coverage, the comparative evaluation was made through pattern-analysis techniques. The relative capabilities of each sensor was judged according to their ability to detect landforms, ease of interpretation and reliability of inferred composition.

IMAGERY COMPARISONS AND ANALYSIS

Regional Analysis. Small-scale imagery provided the synoptic view of the areas under study for delineation of the regional landform relationships. Department of Agriculture photo index mosaics and radar images were used for the regional analysis.

The sensor evaluations for regional analysis are listed in Table 1. In Area 19, the four physiographic units which were depicted from the photo index shown in Figure 4 include terrace remnants, marsh, cheniers (beach ridges) and beaches. These features were discernible also on the APQ-97 radar imagery as shown in Figure 5. There are relative advantages and disadvantages to each type presentation. The photo index contains a greater amount of detail than the radar imagery because of its higher spatial resolution and tonal range. Conversely, the variation in exposure between the individual photos and flight lines present some confusing tonal variations which make subtle trends difficult to recognize and interpret from the index. The active beach zone was most distinct on the photo-index mosaic. Although the beach zone could be inferred from the radar imagery, its resolution limitation and low contrast did not allow appraisal of the beach size or type of materials (i.e., sand or silt). The chenier complexes could be delineated on both the photo indexes and the radar imagery. High-return lineations evident on the radar imagery provided additional information for regional interpretations of the beach ridge development. The APQ-97 radar imagery was the best sensor for gross delineation of marsh zones. The uniform tones on the radar mosaic presented images which were easier to interpret for regional extent of the marsh zones. Although more difficult to interpret on the photo index, more details within the marsh areas are shown on the photo indexes. The contract line between the marsh zone and the terrace was more distinct on the APQ-97 radar.

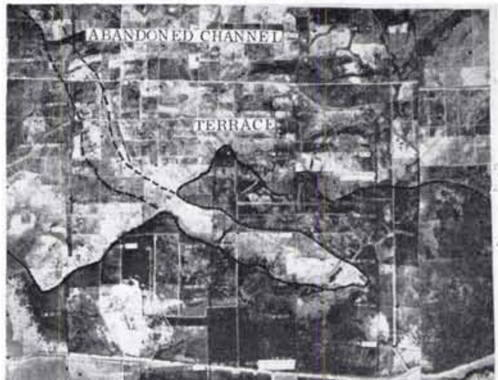

FIG. 4. Photo index mosaic of Area 19 showing the major landforms delineated during the regional analysis.

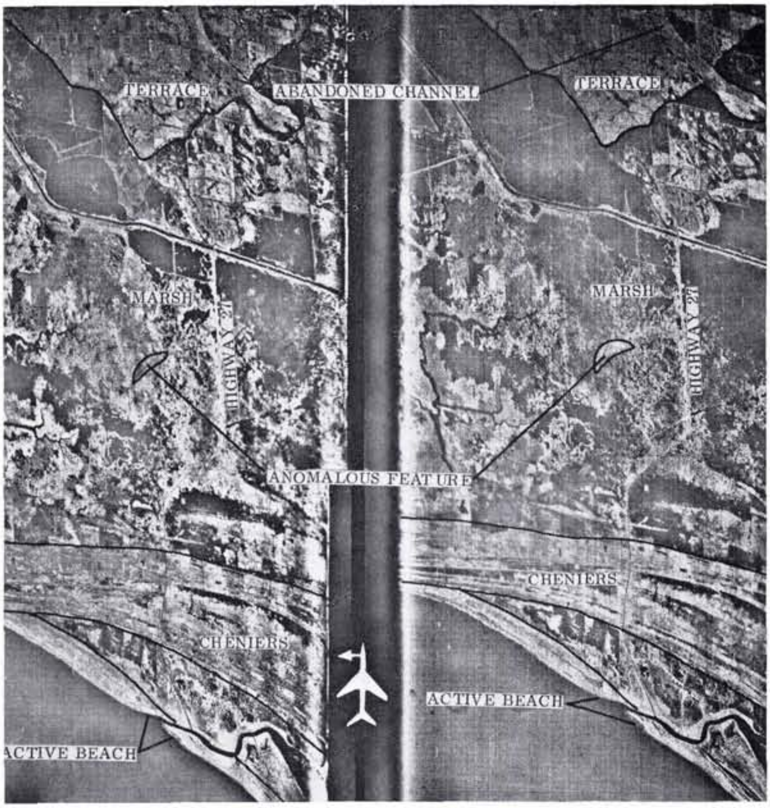

FIG. 5. APQ-97 radar imagery of the western half of Area 19. Compare the major physiographic units with those delineated on the photo index (Figure 3). Note the return from the crescent-shaped anomalous feature on the HV channel (right) as compared with the HH channel (left). The original scale was approximately 1:200,000.

The anomalous crescent-shaped feature in Area 19 was first noted on the APQ-97 radar. It was interpreted as being an old embayed shoreline feature which could contain coarse-grained materials but a ground check would be required to determine the soil characteristics.

The landforms of particular interest in Area 7 were the meander scars on the Pleistocene terrace left by abandoned courses of the ancient Mississippi River system. A major abandoned course is shown in Figure 6. Figure 7 is a profile sketch illustrating the deposition of point bars as the stream migrated laterally. These abandoned courses contain relic features such as point bars, islands, levees and backswamps. The relic point bars are the highest potential sources of construction materials within the abandoned courses. Although the abandoned courses and associate features were evident on both the photo index mosaics and the radar imagery, the radar was judged to be the best for delineation of abandoned courses. The photo-index mosaic was superior to radar for recognition of the relic point bars and natural levees because of the increased resolution and tonal range.

The landforms delineated in Area 6B were backswamps, natural levee, point bars and rivers bars. The photo index mosaic was easier to interpret because individual bars could be delineated. The same was true for river bars. However, radar imagery was adequate and the point bars could be inferred by association with other landform features. Photo index mosaics were superior to the radar imagery for regional delineation of backswamps and natural levees.

Detailed Analysis. The landforms identified during the regional analysis were studied in detail using the large-scale imagery. Obvious features, such as cheniers, were studied in an attempt to rank comparatively the sensors for information content and ease of interpretation. Subtle, anomalous features were also studied to assess their potentials for containing coarse-grained materials suitable for construction materials. The sensor comparisons and relative rankings determined during the detailed analysis of the landforms are listed in Table 2.

The active beach features were evident on all sensor types. The beach shape and extent were most obvious on color-IR photographs Plate 1 because of the distinctive hues produced by water or moist soil.

Color and color-IR photographs provided the most consistent tone differences between chenier and marsh (see Plates 2 and 3). Color-IR was superior to color in that soil-vegetation-water contacts are most distinctive. Thermal-infrared imagery provided distinctive tones relative to chenier complexes but could not be interpreted to any advantage over photography in this environment. Thermal provided additional information where it was used in combination with photographs; the emitted and reflected energy from the cheniers cause tone reversals on the thermal-IR.

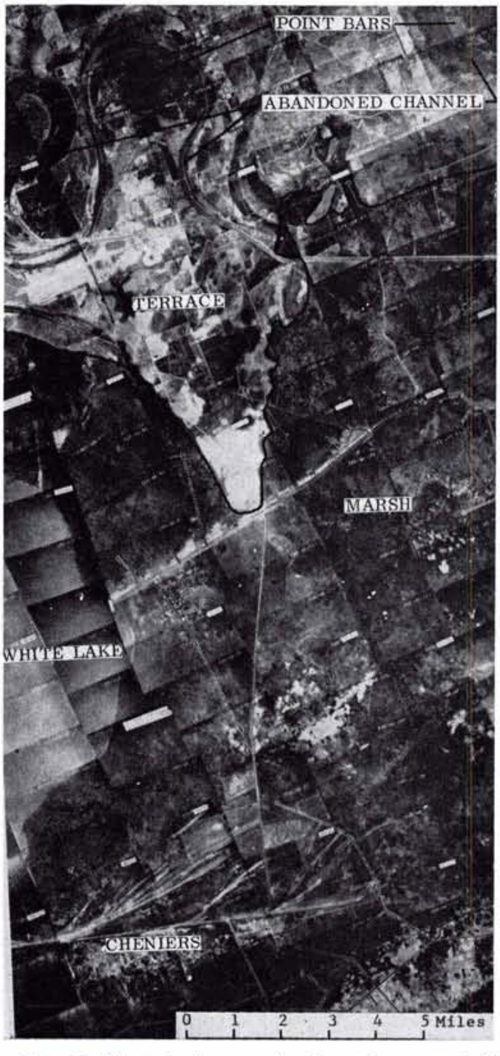

FIG. 6. Photo index mosaic of southern one-half of Area 7. The abandoned channels and associated point bars located at the top of this illustration were delineated for detailed study.

Color-IR photographs were judged to be the best single sensor for detailed mapping within the marsh. Water areas could be readily distinguished from vegetation and soil zones. Thermal-IR provided excellent contrasts due to differences in water depth in the marsh. Thermal-IR also provided differentiation between floating vegetation, marsh grasses and exposed soil areas.

In the terrace zone, color was superior to the other sensors for interpreting the differences in soil types. Color IR-provided some advantage in delineating vegetation boundaries, drainage and special features such as pimple mounds. Thermal-infrared provided additional information where it was used with photographs because of the tonal reversals between reflected and emitted energy from soils of varying grain sizes and moisture content.

Color and color-IR were excellent for detailed study of natural levees and associated backswamps Each provided particular advantages depending on the terrain condition. Soil differences and vegetation types were easier to interpret with color. On the other hand, color-IR emphasized soil mosture variations and differences between swamp vegetation and standing water.

Abandoned channels and associated features were easier to delineate and map in detail using color and color-IR than using panchromatic photographs. The differentiation between relic point bars composed of silt as opposed to those composed of sand was easier to make with color where the soil was exposed (see Plate 4). Where vegetation and soil moisture were the influencing criteria, color-IR was superior to color (see Plate 5). In general, color-IR was udged to be better than the other photographs because it provided sharper tonal contrast with enhanced the interpretability of terrain features.

Color photographs were the best for shallow water penetration and provided the best means of locating river bars. River bars are exposed only during periods of extremely low-water level and their location therefore usually require penetration of the water.

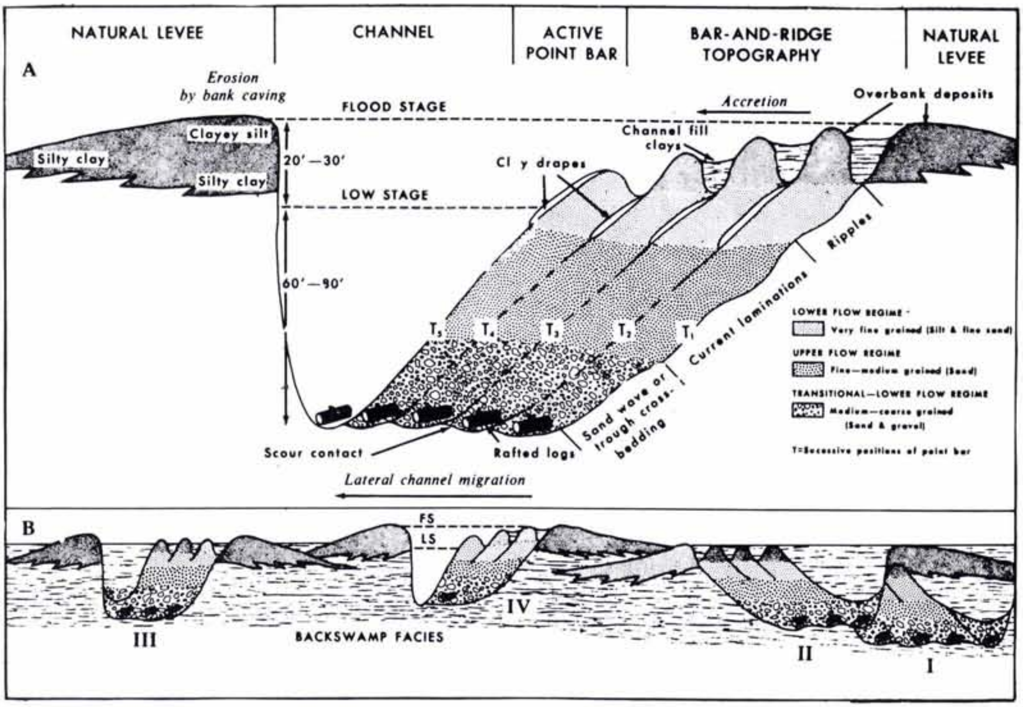

FIG. 7. Diagrammatic cross sections of a meandering channel and meander belt. The upper section is a profile along the axis of bend and illustrates the geometry and sedimentary characteristics of sand bodies that result from the process of lateral channel migration. Note that the point bar has migrated progressively from right to left (T_1 to T_5). The lower section illustrates the facies and may be partially veneered by younger channels (relative ages indicated by roman numerals). (After Gagliano, 1969).

TABLE 2. SENSOR EVALUATIONS FOR DETAILED STUDY

Landform	*Sensor*			
	Pan Photo	*Color Photo*	*Color IR Photo*	*Thermal IR*
Active Beach	Good	Good	Excellent	Good
Chenier	Good	Good	Excellent	Fair
Marsh	Fair	Good	Excellent	Excellent
Terrace	Good	Excellent	Good	Fair
Backswamp	Good	Good	Excellent	No Coverage
Natural Levees	Good	Excellent	Excellent	Fair
Abandoned Channels	Good	Excellent	Excellent	No Coverage
Point Bars	Good	Excellent	Excellent	No Coverage
River Bars & Islands	Good	Excellent	Good	No Coverage
Spoil Banks	Good	Good	Good	Good

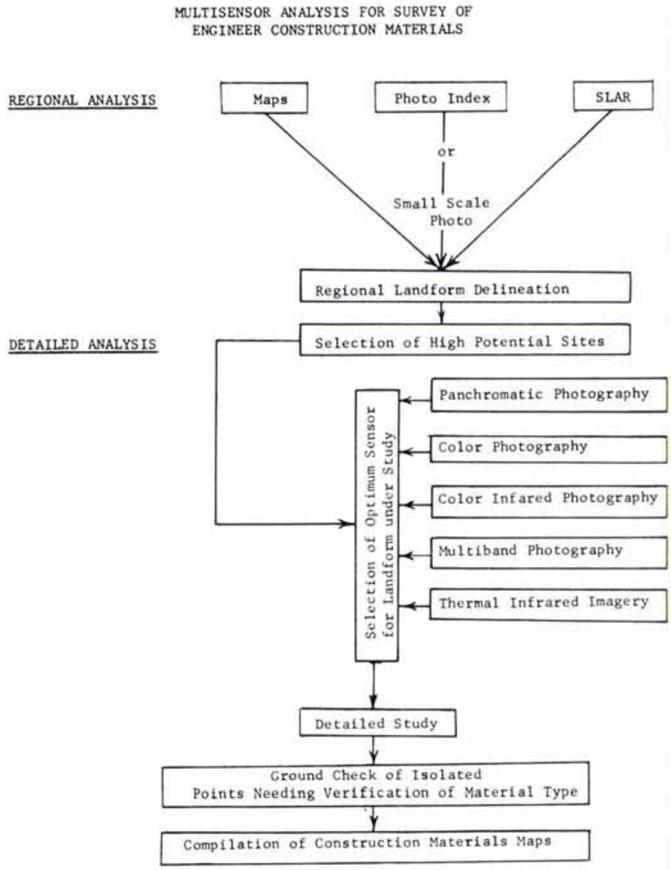

FIG. 8. Sequence of events for the survey of engineer construction materials with remote sensors.

Spoil banks are man-made features occurring on both sides of the canals and are composed of materials dredged to form the canal. They were studied to determine the type of materials that occurred at the shallow subsurface. Slumping of the spoil banks and variations in the width of the canal were indicators of the type of material through which it was dredged. In general, the spoil banks were highly reflective and provided little color differentiation. The type of materials composing the spoil banks were inferred through stereoscopic analysis. For this reason, all of the photographic types of imagery were considered to be adequate for study of spoil banks.

SUMMARY AND CONCLUSIONS

The most efficient utilization of remote sensors for the location of construction materials is realized when a two-phased procedure is adopted. The general sequence of events is illustrated in Figure 8. For regional analysis, or the first phase, maps and photo indexes should first be used for delineating the regional landforms and selecting sites considered of high potential as sources of construction materials. If photo index mosaics are not readily available, radar coverage should be requested. From Table 1 it can be seen that the APQ-97 radar is the most versatile radar system for this regional analysis phase. The APQ-102 radar system is adequate for regional analysis. The APS-94 radar system was ranked as the poorest of the radar systems because of the poor image quality. However, the latest version of the APS-94 may be adequate for regional survey.

The regional analysis allows the construction planner to assess the possible location of construction materials with respect to his operational requirement. In other words, he can determine whether construction mate-

TABLE 3. PHASE III ANALYSIS TEAM

Name	*Organization*	*Discipline*
Dr. David Barr	University of Cincinnati	Civil Engineer
Mr. Wilkes Covey	U. S. Army Waterways Experiment Station	Geology
Dr. Louis Dellwig	University of Kansas	Geology
Dr. Sherwood Gagliano	Louisiana State University	Geology
Mr. Alan Kover	U. S. Geological Survey	Geology
Mr. Robert Leighty	U. S. Army Cold Regions Research and Engineering Laboratory	Civil Engineer
Dr. Aulis Lind	U. S. Army Cold Regions Research and Engineering Laboratory	Geography
Mr. John May	U. S. Army Waterways Experiment Station	Geography
Mr. Paul B. McCracken	U. S. Army Engineer Topographic Laboratories	Geography
Professor R. D. Miles	Purdue University	Civil Engineer
Professor O. Mintzer	Ohio State University	Civil Engineer
Dr. Harold Rib	Department of Transportation	Civil Engineer
Mr. James F. Tazelaar	U. S. Army Engineer Topographic Laboratories	Geology
Mr. Robin Welch	Stanford Research Institute	Forestry

rials are likely to be available within a reasonable distance from where they are needed. If they are, then the low-altitude flights can be requested for acquisition of imagery for the detailed analysis of the most likely areas of occurrence. Coverage of only those sites that will be useable within the area of operation and have the potential of containing construction materials will greatly reduce the flight time and imagery to be analyzed.

Table 2 should be useful to the planner in requesting the sensor relative to the type of landform in his area of operation. In general, color-IR photographs were considered to be the best imagery for the widest range of landform interpretations in a deltaic environment. The tonal contrast between land-vegetation-water boundaries accounts for this ranking. Color photographs are useful for detailed analysis, and in some instances ranked higher than color-IR. Panchromatic photographs were considered adequate for detailed analysis but did not rank as high as color-IR or color photographs.

In general, thermal-infrared provides the most useful information where it is used in combination with photographs. Tonal variations on the thermal-IR imagery caused by differences in the emissivity of the terrain materials were distinct but were difficult to interpret in this environment. Although the type of sensor or sensor combination will probably be determined by availability, the requestor should ask for the sensor best suited for his job.

As a result of this research, the sources of highest potential for occurrence of construction materials in the Mississippi Delta are within the cheniers, point bars (in both the active and abandoned river systems), as well as the river bars and the active beach. The optimum time for acquisition of imagery regardless of type is ordinarily in early spring. The photo-index mosaics and radar imagery were determined to be the best for regional analysis, and color-IR photographs were the best for detailed studies of landforms.

It should be pointed out that the findings of this study pertain only to a deltaic environment and are not necessarily applicable to other physiographic regions or other sources of construction materials. We believe the approach and procedures to be valid for similar type of surveys in other regions and provide for the most efficient utilization of time, material and personnel.

ACKNOWLEDGEMENTS

The analytical work on this project was performed by the following individuals listed on Table 3.

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