GCAGS JOURNAL
A Publication of the Gulf Coast Association of Geological Societies
www.gcags.org

Coastal Studies Institute: A History of Science Contributions for 60 Years

Harry H. Roberts[1], James M. Coleman[1], and H. Jesse Walker[2]

[1]*Coastal Studies Institute, School of the Coast and Environment, Louisiana State University, Howe-Russell Geoscience Complex, Rm. 331, Baton Rouge, Louisiana 70803, U.S.A.*

[2]*Department of Geography and Anthropology, Louisiana State University, Howe-Russell Geoscience Complex, Rm. 227, Baton Rouge, Louisiana 70803, U.S.A.*

ABSTRACT

The Coastal Studies Institute (CSI), Louisiana State University, is celebrating 60 years of trend-setting research contributions to understanding coastal and deeper marine systems. The Institute was founded by the internationally respected physical geographer, Dr. R. J. Russell with funding from the Office of Naval Research (ONR), Geography Programs, under the direction of Dr. Evelyn Pruitt. Although unofficially organized in the early 1950s, the LSU Board of Supervisors formally recognized CSI in 1954 when it became an independent unit under the School of Geoscience.

Following World War II, Russell served on a National Academy of Sciences panel designed to evaluate environmental problems faced during the war years by the Department of Defense. The panel concluded that invasion forces were deployed with very little coastal environmental data or predictability of coastal conditions. This knowledge gap led Russell and Pruitt to start a research group at LSU dedicated to building a better understanding of the world's coasts. The Institute was structured as a self-contained unit so that its researchers could start with research ideas, collect and process field data, and prepare manuscripts for publication. Initial studies of trafficability and stability of various parts of the Mississippi River Delta quickly shifted to other coastal types at both domestic and foreign sites. By the late 1960s, CSI was recognized by the science community as one of the world's most productive coastal research groups. By the mid-1970s, CSI had fielded projects on every continent except Antarctica and research programs were expanding beyond the coast to deeper water environments.

Largely because of the research conducted by geologists, geomorphologists, and sedimentologists through CSI, the Mississippi River Delta became the "standard" to which other deltas were compared. Fundamental knowledge of the delta cycle that built the coastal plain, delta stratigraphy, sand body geometries, sedimentary structures, fluid mud dynamics, delta-front instabilities, and worldwide delta variability derived from the Institute's work. A long involvement with arctic deltas and tropical deltas has added to the Institute's reputation for deltaic research.

With the addition of researchers trained in coastal engineering, physical oceanography, and coastal meteorology to the Institute's research staff, multidisciplinary research quickly became an early characteristic of CSI field projects. This teamwork approach was first applied to the sandy beaches where sea-air-land interaction studies produced fundamental research project results that explained beach morphology changes, rip currents, and both eolian and subaqueous sediment transport related to their physical process environments. Later, this approach was applied to foreign deltas plus carbonate and fluid mud coasts with results that were equally productive.

With the loss of ONR institutional funding in the mid-1980s the CSI research program broadened to meet national research initiatives and available support from state and national funding agencies. From the mid-1980s through the early 2000s large physical oceanography and marine geology projects drove much of the Institute's research. Significant contributions to our knowledge of: (1) Gulf of Mexico shelf and deepwater currents, (2) the dynamics of the world's major sea straits, (3) physical processes and marine geology associated with the delta front of the Yellow River and Nile River deltas, (4) marine geology of the Mahakam Delta and eastern Java Sea shelf, and (5) surficial geology of the northern Gulf of Mexico continental slope. During this period the Earth Scan Laboratory (ESL), the first satellite receiving station in the Gulf Coast region, was founded within CSI. This facility continues to support CSI projects with data from six different satellites. Like ESL, the nearshore ocean observing stations, Wave-Current Surge Information Systems (WAVCIS), established in 1998 have provided and continue to provide near-real time physical process data for support for many coastal research projects.

The Institute's research and training of students has had a far-reaching impact on academic institutions, industries,

Manuscript received March 28, 2014; revised manuscript received May 29, 2014; manuscript accepted May 29, 2014.

GCAGS Journal, v. 3 (2014), p. 94–110.

and government agencies worldwide. As the CSI researchers and field support personnel hired during the early years of the Institute cycle out, a new generation of researchers is faced with a challenging set of coastal problems related to the steady disappearance of Louisiana's coastal plain forced by conditions of subsidence, an increasing rate of sea level rise, and a decreasing supply of Mississippi River sediment to help offset growing coastal plain accommodation. Many deltaic coasts of the world face similar problems. The 60 years of CSI's fundamental coastal and marine research achievements will provide a strong foundation for facing these and other coastal challenges at home and abroad.

HISTORICAL OVERVIEW

This year, 2014, marks the 60th anniversary of Coastal Studies Institute (CSI) as an official unit of Louisiana State University (LSU). The concept of a research institute dedicated to the study of coasts resulted from a National Academy of Sciences (NAS) panel convened in 1951 to evaluate problems encountered by our troops as they landed on various types of coasts during World War II. Dr. Richard J. Russell, Geography Department at LSU, served on this NAS panel which concluded that a lack of knowledge of coasts and coastal processes resulted in many unnecessary casualties and equipment failures during wartime operations (Fig. 1a). Following the NAS panel evaluation, Russell met in Washington, D.C., with the Office of Naval Research (ONR) Director of Geography Programs, Dr. Evelyn Pruitt, to act on the panel's findings (Fig. 1b). Dr. Russell convincingly made the case that a long-term and systematic research program oriented toward understanding coasts and how they vary worldwide was badly needed. He argued that a focus on coasts would pay dividends for science, industry, and government. From discussions between Russell and Pruitt, a long-term contractural relationship between ONR and LSU was established and CSI was formed. With the first contract designed to assess the trafficability and stability of Louisiana's deltaic coasts (McIntire, 1954), Russell started enlisting both faculty and graduate students into studies performed under the canopy of the new research-oriented institute. Although the name of the institute and its initial funding were established in 1952, it was not until 1954 that CSI was officially recognized by the Louisiana State University Board of Supervisors as an independent unit under the School of Geoscience.

Initially, research projects conducted through the Institute were focused primarily on various parts of the Mississippi River delta plain. Geomorphology, sedimentology, and impacts of hurricanes were the themes of most of these initial projects that lasted from 1952–58 (Morgan and Larimore, 1957; Morgan et al., 1958; McIntire, 1958; Chamberlain, 1959; Welder, 1959; and many others). Even archaeology was included in these early studies (McIntire, 1958; Haag, 1958; Gagliano, 1963). The McIntire (1958) study of prehistoric Indian settlements established the first chronology of the switching delta complexes that built the Louisiana coastal plain. Coincident with domestic investigations, studies of foreign areas were also being conducted, such as the study of the Bengal Basin of East Pakistan (Morgan and McIntire, 1959).

In the mid-1950s, legal questions concerning oil-gas revenues and the State of Louisiana–Federal boundary, generally referred to as the Tidelands Issue, prompted the first CSI studies to be funded from sources other than ONR Geography Programs. The State of Louisiana contracted with the Institute to conduct studies of changes in the state's shoreline relevant to the Tidelands Issue. As part of that study, the famous "mudlumps" at the mouth of the Mississippi River's South Pass distributary were investigated (Morgan et al., 1963, 1968) (Fig. 2a). The Tidelands Issue was eventually settled based largely on data collected by CSI researchers. As a result, the state boundary was established well offshore of the coastline. In the 1950s, oil and gas exploration in southern Louisiana was moving from the coastal plain and bays to offshore areas. Moving the state-federal boundary offshore resulted in increased oil and gas revenues for Louisiana. At the same time, private industry (Gulf Oil Corporation), involved in legal issues in the Mississippi Delta, contracted CSI to conduct investigations on the development of the river's subdeltas, specifically West Bay (Figs. 2b and 2c). With the increase in funding for the institute from these two contracts along with the institutional support from ONR, new personnel were hired and Dr. James P. Morgan, a professor in the Geology Department, was appointed Managing Director of CSI.

Following CSI's initial studies, research programs quickly expanded to include beach dynamics, coastal ecology, geochemistry, physical oceanography, and coastal meteorology. Not only did the approach to studying coasts broaden, but also the study sites expanded from a focus on Louisiana to other domestic sites (e.g., McIntire and Morgan, 1963) and the coasts of foreign countries (e.g., Sauer, 1960; Delany 1962; Psuty, 1965; Thom, 1967;

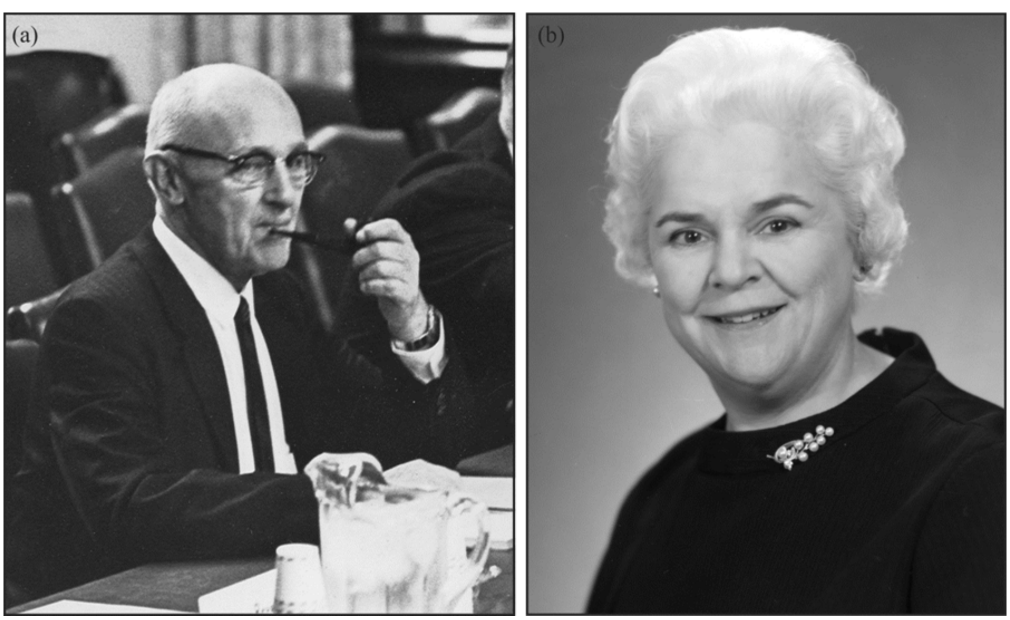


Figure 1. (a) Dr. R. J. Russell, a member of the National Academy of Sciences panel where the need for better coastal information was identified and the idea of a CSI was conceived. (b) Dr. Evelyn Pruitt, former director of the Geography Branch, Office of Naval Research, who funded the formation of CSI at LSU.

Figure 2. (a) Drilling rig preparing to core a mudlump at the mouth of South Pass in the Mississippi River Delta during the 1960–61 drilling program. (b) Dr. James Morgan and students planning drilling sites in West Bay (from left Choule Sonu, James Morgan, James Coleman, unknown student, and Sherwood Gagliano). (c) Dr. James Morgan and graduate student James Coleman reviewing core logs from the West Bay project (circa 1962).

Gagliano and McIntire, 1968; and others). This expansion of the program was made possible through continued institutional funding to CSI by ONR Geography Programs. The institute ran on a limited budget, but more important than the amount of support, was the promise of year-to-year funding. This constant institutional support allowed CSI researchers to follow research themes for multiple years, an invaluable research advantage which would later be fully realized when ONR changed its funding strategy and shifted away from institutional funding to funding individual projects.

The Institute's programs and personnel expanded substantially in the 1960s. Full-time CSI personnel were added as researchers and staff. In the early 1960s, a total of 25 full-time personnel (researchers, field support technicians, illustrators, a photographer, an editor, bookkeepers, and secretaries), plus numerous graduate students and undergraduate student workers, worked for CSI. By this time, CSI was a "self-contained unit" that could start with a research idea, field a data collection project, process the data, and prepare manuscripts for both in-house and professional peer-reviewed publications. Along with the steady improvement of the Institute's capabilities, the research programs broadened to include more foreign sites, largely in response to Navy needs. In addition to deltaic coasts, sandy beaches and carbonate coasts started to receive attention. Barrier islands and beach ridges development in the Gulf Coast (Kwon, 1969), along the Brazilian coast Delaney (1962), and in Mexico (Psuty, 1965) were some of the early studies of sandy coasts. The Institute's initial investigations of carbonate coasts of tropical islands, poorly understood environments during World War II, started in Mauritius (Sauer, 1960; McIntire, 1962; McIntire and Walker 1964) and various sites within the Caribbean region (Russell and McIntire, 1966; Russell, 1959, 1966; Stoddart, 1962a, 1962b). The emphasis of these early reconnaissance-level investigations was on storm effects, geomorphology, lithification of carbonate beaches, and vegetation.

Throughout the 1960s, solid advances were made in understanding details of sediment deposition in various parts of the Mississippi River Delta. Of particular significance were advances recognizing both the stratigraphic relationships and accompanying suites of sedimentary structures plus diagenetic inclusions associated with the delta's major lithofacies units (Coleman and Gagliano, 1965; Coleman, 1966; Coleman et al., 1969; and others). In addition to deltas, beaches were among the first studies to link wave-related processes to consequent geomorphic changes. These investigations were conducted by CSI along the Outer Banks of North Carolina (Dolan, 1965, 1966, 1967). This line of investigation was followed over the next two decades by CSI researchers. Significant advances in understanding sandy coasts were made during this period. The CSI Field Support Group was started during the North Carolina beach study with the hiring of a former navy diver, Norwood Rector.

The 1970s and early 1980s were periods when complex domestic and foreign projects dealing with oceanography, coastal meteorology, and marine geology were fielded. The capabilities of the CSI Field Support Group steadily improved to meet technological challenges associated with fabricating, assembling, and deploying increasingly complex field data collection systems. Personnel were added to deal with a rapidly expanding array of instrumentation. Foreign research projects involved thousands of pounds of scientific instrumentation and other supporting equipment. Until the formation of Homeland Security in response to 9/11, CSI did all of the diplomatic work, shipping arrangements, ship rentals, and other logistics necessary to field a project.

During this time period, CSI developed a truly multidisciplinary approach to coastal research. At the time, this was a trend-setting approach. The initial investigation, the Sea-Air-Land-Interaction Study (SALIS), was conducted on the sandy coast of Santa Rosa Island, Florida (Sonu et al., 1973). At the same time, physical process studies of carbonate reefs and shelves were being conducted (Roberts et al., 1975). Geologically, the variability of world deltas (Coleman and Wright, 1973; Wright et al., 1974) and delta front instability (Prior and Coleman, 1978; Coleman et al., 1983) were topics of primary interest. All of these projects made substantial scientific contributions.

In the mid-1980s, ONR Geography Programs changed its funding format from long-term institutional support, which had sustained CSI for three decades, to project-specific support. The Institute researchers had to quickly respond by acquiring funding from a variety of national and state funding agencies to keep CSI intact. Because of CSI's reputation as an internationally-recognized coastal research unit, the LSU administration advocated salary support for researchers to make sure the unit remained stable through the institutional-to-project funding shift. Under the leadership of LSU Chancellor James Wharton, the LSU Board of Supervisors approved academic positions in the Marine Sciences Department for CSI researchers. Dr. W. G. McIntire (CSI Director) and Institute researchers had helped create the Marine Sciences Department at LSU in 1969. The shift in research support was a major course-changing event in the Institute's history. After the mid-1980s, the Institute's research programs quickly broadened from the original focus primarily on coasts. This change was largely driven by sources of research support, but also by individual research interests. A notable development during the late 1980s was the founding of the Earth

Scan Laboratory within CSI by researcher Oscar Huh. This facility was the first satellite receiving station in the Gulf Coast region.

In the 1990s, CSI researchers continued to diversify their research with large projects involving the physical oceanographic studies of critical sea straits, marine geology of continental shelves and slopes, Loop Current studies in Gulf of Mexico, and a continuation of work on muddy coasts leading the way. Although foreign work continued, for example investigation of the Mahakam Delta (Roberts and Sydow, 1997) and Strait of Bad al Mandab (Murray and Johns, 1997), foreign projects organized and run exclusively by CSI personnel were declining in favor of smaller projects focusing on more local research as well as individual researchers participating in large multi-institutional projects. During this time period, the state agencies in Louisiana became increasingly aware of the important issue of coastal land loss. Although this issue had been worked on by researchers at CSI in the institute's early years, noting the subdelta cycle and constructive versus destructive phases of the delta-switching cycle, funding was becoming available to determine the causes and magnitudes of land loss as well as a continued interest in hurricane impacts.

From 2000 to present, an expansion of Louisiana-based research occurred, driven by the state's need to understand details of the processes responsible for coastal change. To help meet the challenge of collecting physical process data along the Louisiana coast, the CSI Field Support Group designed, fabricated, and deployed an ocean observing system on the inner shelf under the direction of Dr. Gregory Stone. The first station was deployed in late 1998. Others did not became operational until later. These wave-current-surge information systems (WAVCIS) for the first time provided continuous near-real time data from the coast to support both basic and applied research as well as for public and governmental needs (Stone, 2001). In addition to local coastal work, CSI researchers were conducting important field studies of both the Loop Current and deeper currents in the Gulf of Mexico (Inoue et al., 2002). Marine geology studies of the impacts of fluid and gas expulsion processes on the surficial geology of the Gulf's continental slope started in the late 1980s and continued during the 2000s (Roberts, 2001). Numerical modeling of both shallow and deepwater Gulf environments also expanded during this latest chapter in CSI's history (e.g., Welsh and Inoue, 1996).

Major changes in CSI personnel took place in the 2000-present time period. Many of the researchers hired during the peak hiring years of the Institute (1960s and 1970s) retired, moved to other jobs, and natural attrition took others. State funding to universities was cut several times during this time period and vacant CSI positions were not all filled to help meet the cuts required of the School of the Coast and Environment (SC&E), the administrative unit under which the Institute currently resides. In 2010, the faculty lines that for over 50 years had resided in the Institute were moved to the Department of Oceanography and Coastal Sciences. So, new hires became the business of the department faculty rather than CSI. The Institute is moving forward under this new framework. As of 2012, Institute researchers may now be housed in many departments across campus and the CSI Field Support Group operates as a cost center to accommodate more than just CSI work.

The following sections highlight major CSI research areas over its 60-year history and some of the important projects carried out by CSI researchers and related scientific advances.

MAJOR RESEARCH SUBJECTS AND SCIENTIFIC CONTIBUTIONS

River Deltas and Muddy Coasts

The studies for which the Institute is best known, both domestically and internationally, deal with river deltas. Before the Institute was established, Dr. Russell and co-workers conducted important research on the Mississippi Delta (Russell and Howe, 1935; Russell and Russell, 1939; Russell and Fisk, 1942), as well as foreign rivers and delta systems (e.g., Russell, 1942, 1954). The Institute's early deltaic research was concentrated on the Mississippi system and responded directly to questions raised by failed or difficult troop landings during World War II, trafficability-navigability (McIntire et al., 1954) and storm-related coastal changes (Morgan et al., 1958). These first studies were followed by trend-setting investigations of delta stratigraphy (e.g., Coleman and Gagliano, 1964; Coleman et al., 1969) and sedimentary structures of deltaic depositional environments (Coleman and Gagliano 1965; Coleman, 1966). Physical process studies of the salt wedge intruding the Mississippi River distributaries plus expansion and mixing of the effluent plume of river water started in the late 1960s and early 1970s (Wright and Coleman, 1971, 1974).

Following these and many more early delta studies of the Mississippi system, a four-year project, referred to as the Coastal Information Program (CIP) was initiated, to compare deltas worldwide. The program was directed by Dr. J. M. Coleman and graduate student L. D. Wright. Over 200 variables including physical process data from delta receiving basins, were collected on 50 world deltas (Wright et al., 1974; Coleman and Wright, 1975, 1977). This database then formed the basis for field verification studies conducted in the Burdekin (Australia), Klang (Malasia), Ord (Australia), Ebro (Spain), Sao Francisco (Brazil), Ganges-Brahmaputra (Bangladesh), and Senegal (Africa). The delta variability study was the first of its kind. It established principles for comparing delta morphology and sand body geometries based on water-sediment discharge of the river versus physical processes of the receiving basin. These efforts and the investigation of other world deltas after CIP was completed, e.g., the Nile River (Murray et al., 1981), Yellow River (Wright et al., 1990), and Mahakam River (Roberts and Sydow, 2003), and continuing research on the Colville River Delta (Walker, 2002) added significantly to detailed knowledge of deltas other than the Mississippi (Fig. 3). These later delta field studies were multidisciplinary and integrated measurements of the physical process environment with geologic response.

In addition to the delta variability study, Institute researchers developed three major geologic themes for delta work during the late 1970s to mid-1980s: (1) delta front instability, (2) a new Mississippi Delta complex in the making, the Atchafalaya–Wax Lake deltas, and (3) muddy coasts.

Academic researchers from LSU, Texas A&M University, and industry combined efforts to better understand slope failures on the delta front after the loss of Shell's production platform in South Pass Block 70 during Hurricane Camille in 1969. With the commercial availability of side-scan sonar in the early 1970s, it became possible to map the seafloor with swath rather than profile acoustic data. Funding from the Bureau of Land Management supported a field project to employ this relatively new technology to map the entire front of the modern Mississippi River Delta (Coleman et al., 1980). The map resulting from this project and the scientific papers that were developed during and after the mapping (e.g., Prior and Coleman, 1978, 1982; Roberts et al., 1980a) provided another landmark for CSI researchers in the study of modern deltas. This study was very well-received by the geologic community. For the first time, a comprehensive understanding of river-dominated delta front deposition, slope failure, and sediment transport on extremely low slopes (<0.5°) appeared in the scientific literature. These studies of delta front instability changed geologic thinking about how river-dominated deltas prograde and provided industry with new information for planning production platform locations and pipelines.

Starting in 1973 when the Atchafalaya and Wax Lake deltas entered their subaerial phase, it became clear that a new delta complex was developing along the Louisiana coast (Rouse et al.,

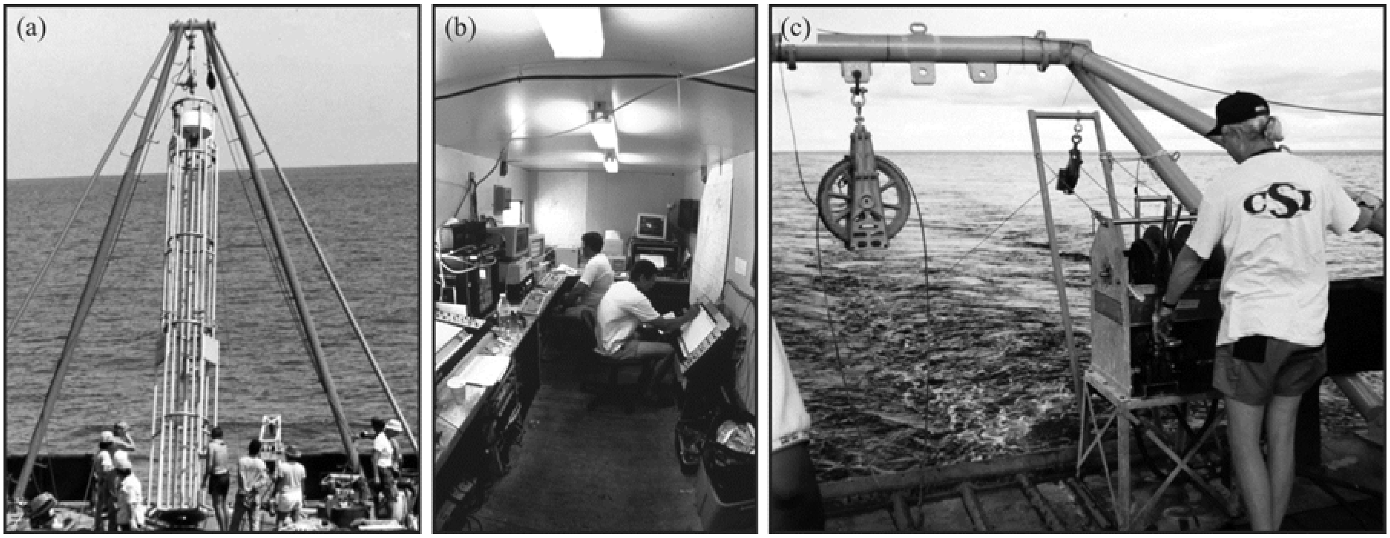


Figure 3. (a) Preparing to take a long vibracore on the shelf seaward of the Mahakam River Delta (1994). (b) Walker Winans and Harry Roberts record high resolution seismic and side-scan sonar data on the continental shelf near the Mahakam River Delta (1993). (c) Floyd DeMers taking a bottom sediment sample on the delta front (1993).

1978). Fundamental studies of stratigraphy and sedimentary facies of a bayhead delta were derived from early investigations of the Atchafalaya Delta (van Heerden and Roberts, 1988; Roberts et al., 1980b; Adams et al., 1982). In the 1990s and more so in the 2000s, when coastal research in Louisiana focused on addressing the State's coastal plain land loss problem, it became increasing clear that river diversions were the most promising solutions. Because the Wax Lake Delta is the result of a man-made diversion of Atchafalaya River water and sediment into Atchafalaya Bay, the delta has become a model for expected results from a river diversion. Work continues on this delta by CSI researchers and many others as Louisiana struggles with the coastal land loss problem. In addition to sediment from river diversions for rebuilding coastal plain land and enhancing wetland plant productivity, sources of sand were sought by the state to rebuild Louisiana's barrier islands, the first line of defense against erosive storm waves. Offshore shoals, Ship Shoal and the Trinity-Tiger Shoal Complex, were initially targeted as available sand resources. Institute personnel were involved in projects designed to locate and evaluate offshore sand resources. The latest of these was a comprehensive study of the Trinity-Tiger shoals (Edrington, 2013).

Because many shorelines adjacent to deltas are mud-rich, research on processes associated with muddy coasts were researched not only along the Louisiana coast (Wells and Roberts, 1981; Kemp and Wells, 1987), but also in Pakistan (Wells and Coleman, 1984), Surinam (Wells and Coleman, 1981), and Korea (Wells et al., 1990; Adams et al., 1990). These studies were some of the first investigations initiated on the physical process-sediment interactions associated with muddy shorelines, which make up a major portion of the world's coasts. In more recent years, ONR has funded a new initiative to investigate the effects of muddy coasts on wave processes along the western Louisiana chenier plain coast. Field measurements collected during these studies will strengthen wave models used over seabeds characterized by cohesive sediments (Sheremet et al., 2002; Sheremet and Stone, 2003). Institute-directed research has clearly shown that muddy inner shelf and coastal environments that have unique fine-grained sediment properties (fluid mud) efficiently extract energy from the incident wave field. Following sediment filling of Atchafalaya Basin and initiation of deltas in Atchafalaya Bay, the shelf opposite Atchafalaya Bay and eastern chenier plain started receiving abundant fine-grained sediment, causing the chenier plain shoreline to prograde (Huh et al., 2001). Researchers from CSI continue to study wave-current interactions with the unique fluid mud bottom along the eastern chenier plain coast (Bentley 2003; Bentley et al., 2006). Active research continues on the chenier plain coast and inner shelf, one of the few prograding Louisiana coasts.

In addition to studies of modern deltas, it became clear from various high resolution seismic datasets that the northern Gulf's shelf margin was constructed largely of shelf-edge deltas formed during periods of falling-to-low sea level. These depositional systems were the sediment source for deepwater slope and basin floor fans. In order to build a better understanding of the lithostatigraphic-chronostratigraphic characteristics of these deltas, a group of academic and industry personnel joined to form the Gulf of Mexico Shelf-Slope Research Consortium (GOMSSRC) and conduct a shelf-edge delta study. Multichannel seismic data and four long cored borings were collected as part of the study. Personnel from CSI played a key role in planning data collection, data processing, and publication of results (e.g., Sydow et al., 1994; Roberts et al., 2004). High quality seismic data collected as part of the study defined a wedge of sand-rich sediment on the outer shelf east of the modern Mississippi River Delta. An entrenched channel network filled with sand and gravel delivered sand to construct the shelf-edge clinoform wedge and transport sediments directly to deepwater environments. Slumping of the delta front also provided a source of sediment for transport to deep downslope sites. At present, the GOMSSRC project is the most detailed study of a shelf-edge delta anywhere in the world. Results provided important links between sea level change, sediment deposition, and stratigraphic response.

Arctic Coasts

Although several coastal types including beaches, barriers, and deltas were studied in the Arctic, the unique nature of the arctic environment sets these studies apart and therefore warrants a separate section in this CSI history. The first major projects in the Arctic under CSI's direction began in 1961. Strategic interest caused ONR (founded in 1946) to be concerned with arctic research. Under ONR sponsorship a laboratory was established at Point Barrow, a laboratory that was instrumental to the success of the CSI research in the Arctic during the 1960s and 1970s. Known as the Arctic Research Laboratory (ARL) and later the

Naval Arctic Research Laboratory (NARL), it was administered by ONR's Human Ecology Branch, whose head was M. C. Shelesnyak. He knew of Evelyn Pruitt's interest in the arctic and assigned her the task of producing a *Naval Arctic Operations Handbook* (Shelesnyak, 1948). The establishment within ONR of a Geography Branch (of which Pruitt was later to become Director) included the transfer of arctic programs to it. Within the new Branch, Pruitt's duties soon expanded both regionally and topically (including coastal science) (Pruitt, 1979; Walker 2006).

The first CSI publication from arctic research was by Smith (1964) which reported on work conducted on ARLIS II (Arctic Research Laboratory Ice Station II). Smith, who had begun work on Fletcher's Ice Island (T–3) while at Dartmouth University, transferred to LSU and CSI in the early 1960s where he continued his research on the geologic/glaciologic history of ice islands.

The two major endeavors of CSI in the arctic were: (1) a study of the Colville River Delta (1961–78) and (2) a broader-based program addressing Alaskan arctic coastal processes and morphology (1971–73) (Walker, 2002). Both programs were funded by ONR with logistical support provided by NARL.

Colville River Delta Research

The motivations for Colville River Delta research were (1) deltas were one of the major coastal landform types to be examined by CSI and (2) knowledge about American arctic deltas would provide details typical of arctic deltas elsewhere.

A reconnaissance survey was made to the essentially uninhabited delta during the summer of 1961 by H. Jesse Walker and H. M. Morgan. While some river depth measurements were made and riverbank stations established, the main accomplishment was the determination of a base camp location at Putu at the head of the delta. During the spring of 1962, two cabins fabricated at NARL in Barrow were hauled 250 kilometers by tractors and sleds across the tundra to Putu, and served as the base of Colville delta research for the next 12 years. Additional equipment (e.g., boat, snowmobiles, and generators) and supplies were transported by twin-engine aircraft, which used the frozen river as a landing strip. During field seasons, detailed studies were made under the inclusive categories of deltaic morphology, hydrology, sedimentology, near shore oceanography, climatology, and cryology.

The first major field season on the delta (March-October 1962) placed emphasis on determining river discharge; dissolved, suspended, and bed load; channel morphology; river ice breakup characteristics; and bank erosion (Fig. 4a). It was found that there is no measurable flow under the ~2 meter thick river-ice during winter and that a saltwater wedge progresses upstream at least 64 kilometers. During breakup, about 70% of the flow is through the main channel with the distributaries carrying the rest. During flood stages, the main channel carries as much as 5.8 x 10^6 tons of suspended sediment and 1.3 x 10^5 tons of dissolved salts. Of the total suspended load, 62% was transported during the two week breakup period (Arnborg et al., 1966, 1967).

Early studies concentrated on cross-sections of the two main channels, longitudinal profiles of the distributaries, and selected river bank profiles while determining erosion rates. Because the delta is within the zone of continuous permafrost, riverbanks are frozen and often support ice wedges. Relatively warm river water flowing against such banks produce thermo-erosional niches, some of which undercut banks by as much as 8 meters, promoting block collapse. The monitoring of bank retreat along selected riverbanks that began in 1961 was continued into the 2000s (Walker and Arnborg, 1966; Walker, 1969; Ritchie and Walker, 1974).

The 1971 and 1973 seasons advanced the research of the previous 10 years and added the collection of data from the oceanic portion of the delta with the use of helicopters. During the breakup flooding period of 1971, 10 days of discharge spread nearly one half of the annual flow over the top of the bottom-fast ice and further seaward beneath the floating sea ice (Walker, 1973a; Walker, 1973b; Hamilton et al., 1974, 1976; Ho and Walker, 1976). Other research during the early 1970s included analyses of the forms and processes of arctic river bars, sediment deposition on sea ice by flood water, offshore island cryology, and arctic deltaic microclimates. Additional studies during the Colville Delta research period treated such subjects as lake morphology and classification, lake tapping and filling, ice-wedge and ice-wedge polygon classification, barchan formation, deltaic dune classification, and perched lake formation.

Early Colville River delta research publications, most under the auspices of the CSI, are available on the LSU website (www.lsu.edu/diglib) under "Colville River Delta" in "collections" (Walker, 2002). Other early studies are summarized in Walker (1983).

Coastal Processes and Morphology

Between May 1971 and June 1973, CSI researchers conducted a study of the variability of physical processes and associated morphological changes of the Alaskan arctic coast (Wiseman et al., 1973) (Fig. 4b). Point Lay on the Chukchi Sea and Pingok Island in the Beaufort Sea were the study sites. Drs. S. A. Hsu and C. D. Walters, Jr. established insight into the surface boundary layer wind structure during the summer and during ice buildup in the winter at Point Lay. They also estimated momentum transfer to the Chukchi Sea. This research and similar work along the Texas coast led to a modification of boundary layer airflow models that were used in the 1970s (Hsu, 1974a, 1974b).

Coincident with boundary layer meteorology studies, nearshore hydrodynamic processes were investigated. Long-period sea level variations, waves, mesoscale coastal currents, and water mass properties were measured. From energy input to the coast, it was determined that one day of storm-driven sediment transport was as much as 142 days of transport under average wave conditions (Wiseman et al., 1973). Also, flushing of coastal lagoons introduced sediment and freshwater into the nearshore system. Lower salinities affected the timing of freeze up along the coast (Wiseman et al., 1974).

Coastal morphology was mapped along 1441 kilometers of arctic coastline. A total of 22 landform provinces were identified. At the same time, more specific beach process-response studies were undertaken to determine contrasting changes during freezeup and breakup conditions (Short and Wiseman, 1974, 1975). Short (1975) also demonstrated the role of offshore standing waves in controlling the patterns of offshore sand bars. Alaskan arctic coastal studies continued until 1976 (Harper and Wiseman, 1977; Owens and Harper, 1977; Harper, 1978) (Fig. 4c). Another two years of arctic research was conducted along the coasts of Svalbard, Norway, an archipelago in the Arctic Ocean (Wiseman et al., 1981). With the exception of work on the Colville Delta by H. J. Walker, the Svalbard project was CSI's last coastal process research thrust in the Arctic.

Later, in the 1980s, CSI researchers and technical support personnel in conjunction with personnel from the Geological Survey of Canada studied fan delta instability and sediment transport processes in arctic and sub-arctic fjords (Fig. 4c). They provided new insight on submarine morphology and gravity-driven transport of delta-front sediment to deepwater depositional settings (e.g., Prior et al., 1987).

Beaches and Nearshore Processes

Among the earliest CSI research projects was an assessment of changes in the sand-rich to mud-rich shorelines of Louisiana by Morgan and Larimore (1957). This work indicated that ero-

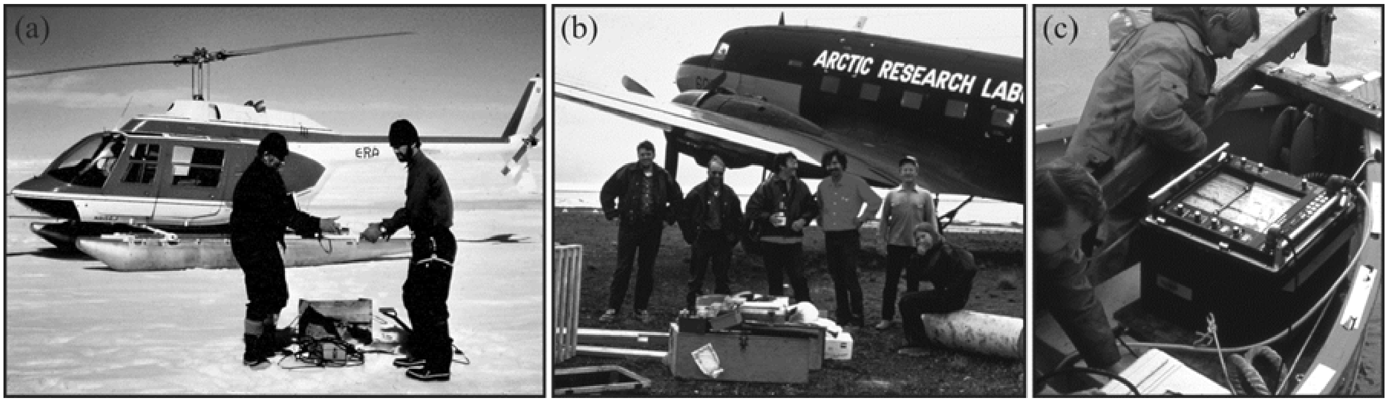


Figure 4. (a) H. J. Walker and L. S. McKenzie augering through the ice in 1971 to take salinity measurements in a Colville River distributary. (b) The CSI arctic research team off-loading supplies from an Arctic Research Laboratory transport plane in 1972 (from left, Walker Winans, William J. Wiseman, John Harper, Larry Rouse, and non-CSI personnel). (c) Brian Bornhold and David Prior acquiring side-scan sonar data from a British Columbia fjord (1987).

sion was prevalent along most of Louisiana's shoreline. At the same time that CSI researchers were focusing primarily on the geomorphology and sedimentology of the Mississippi River Delta and its various coastal environments, research questions were being asked about sandy beaches. In the early 1960s, little was known about the relationships between physical processes and morphological changes along sandy coasts. A study fielded along the Outer Banks of North Carolina was CSI's first instrumented beach study (Dolan, 1965, 1966). This research project documented the summer and winter processes causing changes in beach and shallow nearshore topography. As part of this project, Dolan (1967) was the first researcher to use time-lapse photography to document high frequency changes in beach morphology. The study also required underwater photography. A former navy diver (Norwood Rector) was hired to take underwater movies of sand movement and install instrumentation for the study. Work on the Outer Banks beach study led to the permanent hiring of Rector which started the CSI Field Support Group.

Dr. Choule Sonu, a coastal engineer doing research at Tokyo University, was hired at CSI in 1965 to conduct beach dynamics research. He joined the North Carolina study and instrumented the Outer Banks beach and nearshore areas to document the wave-current processes responsible for short-term changes in beach morphology (Sonu and van Beek, 1971). Using a rhodamine dye tracer, a tethered balloon with camera, and a well-instrumented surf zone (Figs. 5a and 5b), he observed the formation of rhythmic beach topography and associated meandering currents (Sonu, 1969, 1972).

Following the beach work in North Carolina, a landmark study was conducted on the white quartz sand beaches of the Florida Panhandle at Ft. Walton (Sonu et al., 1973). This study was unusual at the time because it involved many disciplines, boundary layer meteorology (S. A. Hsu), currents (S. P. Murray), wave dynamics (J. N. Suhayda), and sediment transport/beach morphology (C. J. Sonu and E. Waddell) in one field data-collection program. This Sea-Air-Land-Interaction Study (SALIS) focused on the sea breeze system and associated beach changes. It was a forward-thinking multidisciplinary approach to beach research that was followed by other research groups and a model for the design of complex beach studies. Beach studies along the Gulf Coast continues after SALIS (e.g., Suhayda and Pettigre, 1977). In this same timeframe (1971–73), CSI researchers studied beach process-response interactions on arctic beaches (Short et al., 1974). See Arctic section of this paper for more details of CSI's arctic coastal research. In the mid-1970s, similar research was conducted on the sandy beach coast near Aracaju, Brazil (Suhayda et al., 1977) (Fig. 5c).

At this same time, researchers at CSI (e.g., C. J. Sonu, L. D. Wright, and A. D. Short) started using the term "morphodynamics" to describe morphological changes in beaches as well as other coastal types in response to their physical process environment. That term is now widely used by coastal researchers worldwide. Its origin can be traced back to CSI work in the 1970s.

Studies of storm impacts along the Louisiana coast extend back to the beginnings of CSI. Morgan et al. (1958) carried out the first comprehensive appraisal of coastal change after Hurricane Audrey which made landfall in Cameron Parish in 1957. Other notable studies include the impacts of Camille in 1969 on the Chandeleur Islands and Mississippi coast (Wright et al., 1970), Hurricane Andrew in 1992 along the Isles Derniers and Timbalier Islands (Stone et al., 1993, 1995), Hurricane Opal in 1995 along the Florida Panhandle (Stone et al., 1996), Hurricane George in 1998 along the south-central Louisiana coast (Stone et al., 1999), hurricanes Isidore and Lili in 2002 (Stone et al., 2003), Hurricane Rita in 2005 (Stone et al., 2007), Hurricane Claudette (Sheremet et al., 2005), and summaries of storm impacts by Stone et al. (2004) and Stone and Orford (2004).

Following studies of coastal change related to hurricanes, a considerable effort has been focused on the importance of winter cold front passages on sediment transport and coastline changes (Huh et al., 1978, 2001; Armbruster and Stone, 2001; Pepper and Stone, 2002; Stone et al., 2004). It has been determined that even though less powerful than tropical storms, cold fronts are much more frequent events (20–30 per year) and therefore may cause more cumulative coastal change.

Carbonate Coasts and Shelves

Reconnaissance-level research started on tropical carbonate coasts early in CSI's history. These studies were initiated by R. J. Russell in the mid-to-late 1950s with an emphasis on determining the variability and origin of beach rock. Russell traveled throughout the Caribbean region making observations related to lithification of carbonate beaches and is credited with originating the term beach rock to describe these products of carbonate beach cementation. His research papers in Russell (1958, 1959, 1962) and Russell and McIntire (1965) chart progress on this subject and represent the first appraisal of beach rock formation (Fig. 6a). It is interesting that his final field project was on Cape Sable at the southern tip of the Florida Peninsula with a focus on groundwater and beach rock (Russell, 1971).

Other early CSI studies along carbonate coasts and on carbonate islands are represented by McIntire (1961) and Sauer

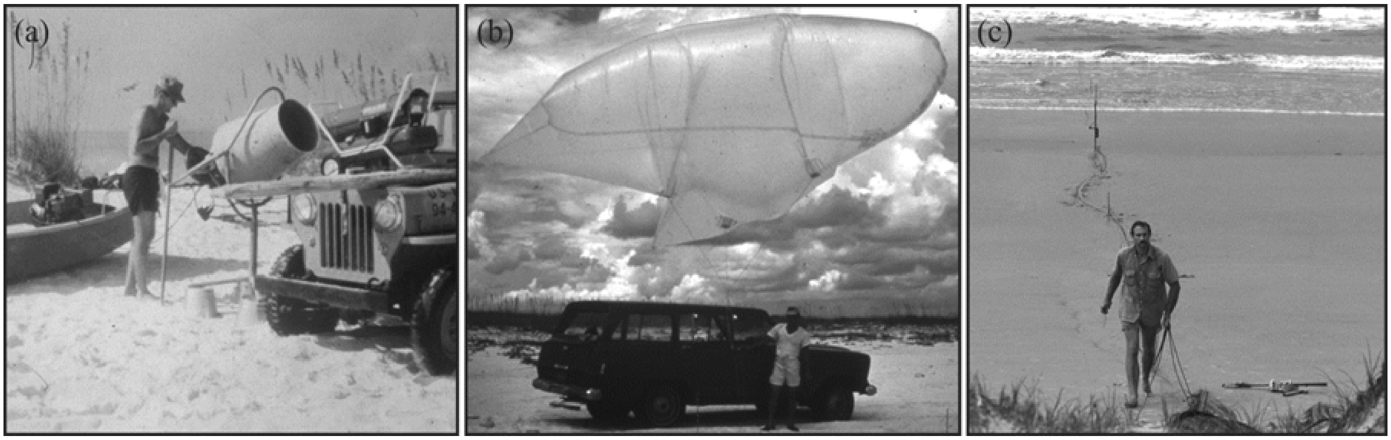


Figure 5. (a) Norwood Rector of the CSI Field Support Group dying sand for an early 1970s sediment tracer experiment along the beach at Ft. Walton, Florida. (b) A tethered balloon used to carry a camera package for photographing rhodamine dye as water circulated through rhythmic beach and nearshore bar morphology in the early 1970s. (c) Joe Suhayda setting up an experiment to measure waves as part of a coastal processes study along a Brazilian beach in 1976.

(1962) on the island of Mauritius in the Indian Ocean. David Stoddart from Cambridge University worked through CSI to start his long career of studying carbonate islands and reefs with an expedition to the atoll reef platforms off British Honduras (Stoddart, 1962a, 1962b). Other sites of early CSI carbonate studies include a reconnaissance of Barbuda (Russell and McIntire, 1966), an appraisal of the coral cap of Barbados (Russell, 1966), a study of Isle de Lobos, Mexico (Rigby and McIntire, 1967), an investigation of the leeward reefs of St. Vincent (Adams, 1968), and initial studies on Grand Cayman Island (Rigby and Roberts, 1976). These early studies were largely reconnaissance-level descriptions of coastal geology-geomorphology and botany. In the mid-1970s, studies of carbonate-dominated areas departed from the geomorphological and botanical approach and followed the process focus already applied to selected deltas and beaches by CSI researchers. Instrumentation of the forereef shelf of Grand Cayman broke new ground in understanding the interaction of ocean processes and reefs (Roberts et al., 1975) (Fig. 6b). These instrumented studies continued in Nicaragua and St. Croix with an emphasis on the waves and currents encountered by shallow reefs that influence their geomorphology and community structure as well as sediment transport and backreef lagoon circulation (Roberts and Suhayda, 1983; Roberts et al., 1992; Lugo-Fernandez et al., 1998a; 1998b). Using satellite remote sensing and field measurements, Walker et al. (1982) and Wilson and Roberts (1992) showed that cold water generation in Florida Bay and on the Bahama Bank produced by cold front passages caused density flows that limited sites of coral growth and delivered sediment to surrounding deep water environments.

Additional studies in mixed carbonate-siliciclastic systems include the investigation of eastern Nicaragua's coast and shelf (Murray et al., 1982), the carbonate platforms of the northern Red Sea (Roberts and Murray, 1984), the Java Sea shelf margin in Indonesia (Roberts et al., 1987), and the most recent investigation of the carbonate shelf opposite the Mahakam Delta of eastern Borneo (Roberts and Sydow, 1997, 2003). In Nicaragua it was found that the shelf within 20 kilometers from the coast was dominated by terrigenous sediment, but the remainder of the shelf was carbonate-dominated with *Halimeda* bioherms at the shelf edge. Similar, but more pervasive bioherms were discovered on the Sunda shelf margin and opposite the Mahakam Delta during the Indonesian studies. The bioherms at the shelf margin in Nicaragua, as well as in Indonesia, developed in zones of upwelling and accounted for immense volumes of biogenically-derived sediment. The bioherms in both Nicaragua and Indonesia were new discoveries. *Halimeda* bioherms were only known to exist behind Australia's Great Barrier Reef at the time of these CSI discoveries. The Mahakam Delta study provided new insight into how siliciclastic and carbonate sediments interfinger in tropical settings and change throughout a late Pleistocene sea-level cycle.

Although not a carbonate province, the continental slope of the northern Gulf of Mexico has thousands of reef-like carbonate buildups and hardgrounds that are the by-products of microbial processes associated with hydrocarbon seeps. Many of these sites are accompanied by densely populated and unusual benthic communities (chemosynthetic) that live on seep products (e.g., methane and hydrogen sulfide). These extensive carbonates and seep communities were unknown in the Gulf until the mid-1980s. In 1988, CSI started a research track to study the impacts of fluid-gas expulsion on the slope. Funding from the National Oceanic and Atmospheric Administration (NOAA) and the Mineral Managements Service (MMS) supported much of this research which used 3D seismic to find sites of hydrocarbon seepage-venting and submersibles (e.g., *Johnson Sea-Link* and *ALVIN*) and remotely operated vehicles (ROVs) (e.g., Woods Hole Oceanographic Institution's *Jason*) to observe and sample the seafloor (Fig. 6c). Research on seeps has changed our concepts of the seafloor of the slope and added needed detail about the geology of the slope for industries operating in the deepwater Gulf. Institute directed work on this subject can be found in Roberts et al. (1990) and Roberts (2001, 2010).

Physical Oceanography and Coastal Meteorology

Early in the Institute's history (mid-to-late 1960s), it became apparent that a more comprehensive approach was needed to understand the physical processes responsible for coastal change. Although projects in the late 1950s and early 1960s were multidisciplinary, in-house expertise in physical oceanography and meteorology was needed in order to expand and refine many of the research fronts initially explored by CSI investigators, as well as to start new research initiatives. To meet this need, programs in shallow water oceanography and coastal meteorology were started.

In 1967, University of Chicago–trained Steve Murray was hired to initiate a program in coastal currents. Soon afterward (1969), a University of Texas graduate, S. A. Hsu, was added to direct a research program in coastal meteorology. By 1971, it was clear that at least two additional researchers were needed to create a critical mass in physical oceanography and to meet the

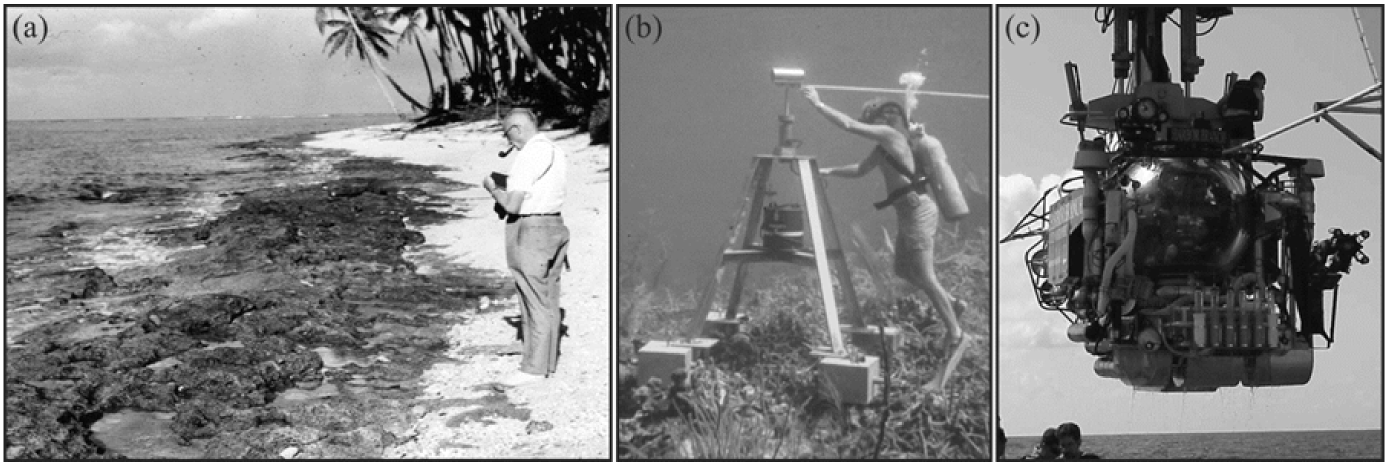


Figure 6. (a) R. J. Russell in 1965 taking notes on an outcrop of beachrock in Barbuda. (b) Norwood Rector adjusting a current meter placed in the forereef environment, Grand Cayman Island (1974). (c) The *Johnson Sea-Link* research submersible used extensively by CSI researchers in the late 1980s to 2000s to study sites of hydrocarbon seepage-venting on the continental slope, northern Gulf of Mexico.

needs of a new arctic research program that was on the horizon. In that year, a physical oceanographer from Johns Hopkins and the Chesapeake Bay Institute, Bill Wiseman, was added to work in the Arctic, as well as on general estuarine and shelf circulation problems. With the addition of a Scripps Institute of Oceanography researcher trained in wave dynamics, Joe Suhayda, CSI had its first team of oceanographers to work in parallel with researchers working on sedimentology, beach dynamics, and coastal geomorphology. Later, another oceanographer, Charles Adams from Florida State University, was hired to conduct boundary layer research. During this era, air-sea-land interaction studies took center stage with the initial study on the sea breeze and its impact on coastal waves, currents, and beach response (Sonu et al., 1973). As highlighted in Beach and Nearshore Processes section of this CSI history, the sea breeze study was multidisciplinary and trend-setting. Coincident with the sea breeze study, S. A. Hsu established the theoretical foundation for the process of eolian sand transport (Hsu, 1971), a subject he refined throughout his tenure at CSI. Also, physical oceanographic work started on the Louisiana inner shelf (Murray, 1972). Hsu continued work on coastal meteorology by investigating shear stress and wind stability over the coastal ocean and at air-coast interfaces (Hsu, 1974a, 1974b). Fundamental advances in our understanding of eolian sediment transport dynamics in the coastal zone were made during these years (Fig. 7a).

Expansion of the CSI research staff to conduct instrumented and field-oriented oceanographic and meteorological research made it necessary to expand technical support capabilities within the institute. In 1968, Rodney Fredericks was hired as an electronics technician to join Norwood Rector and establish a Field Support Group within CSI. After returning from active duty in the Navy (January 1970–October 1972), Fredericks became the Field Support Group Coordinator. Under his supervision, the CSI Field Support Group expanded its capabilities to design and fabricate complex instrumentation and deployment systems. This in-house capability gave CSI researchers a great advantage in competing for research funding.

During the mid-to-late 1970s, shallow water oceanography studies along the Gulf Coast (Murray, 1975; Wiseman et al., 1976) and in the Arctic (Wiseman et al., 1974) expanded. At the same time, foreign projects with the focus on coastal oceanography were begun. The first was a study of the Guayas estuary of Ecuador (Murray et al., 1976). Later, a first time study of circulation on the Nile Delta shelf and an initial investigation of the eastern shelf of Nicaragua (Murray et al., 1982) were conducted by CSI researchers. These two studies are still the primary resources for understanding the oceanography of these two sites. During the late 1970s, CSI also initiated a program to study sea straits with ONR support. This program continued for nearly 20 years under the direction of Dr. Murray and is covered in this paper under a separate heading.

Through the 1980s and 1990s, much of the Institute's activity in physical oceanography and meteorology shifted toward the Gulf of Mexico. By 1988, S. A. Hsu published his book entitled "Coastal Meteorology" highlighting the results of both foreign and domestic studies conducted through CSI (Hsu, 1988). This book established coastal meteorology as a scientific discipline and brought well-deserved attention to Hsu's research and the work of the Institute. Study of effluent from the Mississippi River and flow on the inner shelf of Louisiana and Texas received thorough attention during this period (Chuang and Wiseman, 1983; Wiseman and Dinnel, 1988; Dinnel et al., 1997; Wiseman et al., 1997).

In 1991, CSI received a multimillion grant from the then Minerals Management Service (MMS) for a multi-disciplinary study of the Mississippi-Atchafalaya Coastal Plume (MACP). This study joined CSI scientists with researchers from Texas A&M University, the University of Maine, the Virginia Institute of Marine Science, the University of Washington, the Louisiana Universities Marine Consortium, and the Coastal Ecology and Coastal Fisheries institutes of LSU, as well as the Aquatic Toxicology Laboratory. A comprehensive report (Murray, 1998; Murray et al., 1998) provided a treasure house of data and vastly increased understanding of processes active in the targeted areas of (1) remote sensing, (2) physical oceanography, (3) sediment flux, (4) benthic boundary layer dynamics, (5) light and nutrients, (6) hypoxia and pigments, (7) phytoplankton, (8) zooplankton, and (9) pollutant chemistry. For example, a detailed analysis of velocity and thermohaline properties from 5 cruises in different seasons, from near the Mississippi River Delta all the way into Texas, provided a new understanding of the MACP as an integral unit with predictable seasonal and spatial variability controlled largely by wind forcing and river discharges (Murray et al., 1998). The close and detailed response of the coastal current off western Louisiana to wind forcing, on scales of several days to seasonal, was directly determined from current meters deployed over 2 years and the data analyzed in Jarosz and Murray (2005). Markedly different dynamical characteristics between the winter downcoast regime and the summer upcoast regime were confirmed.

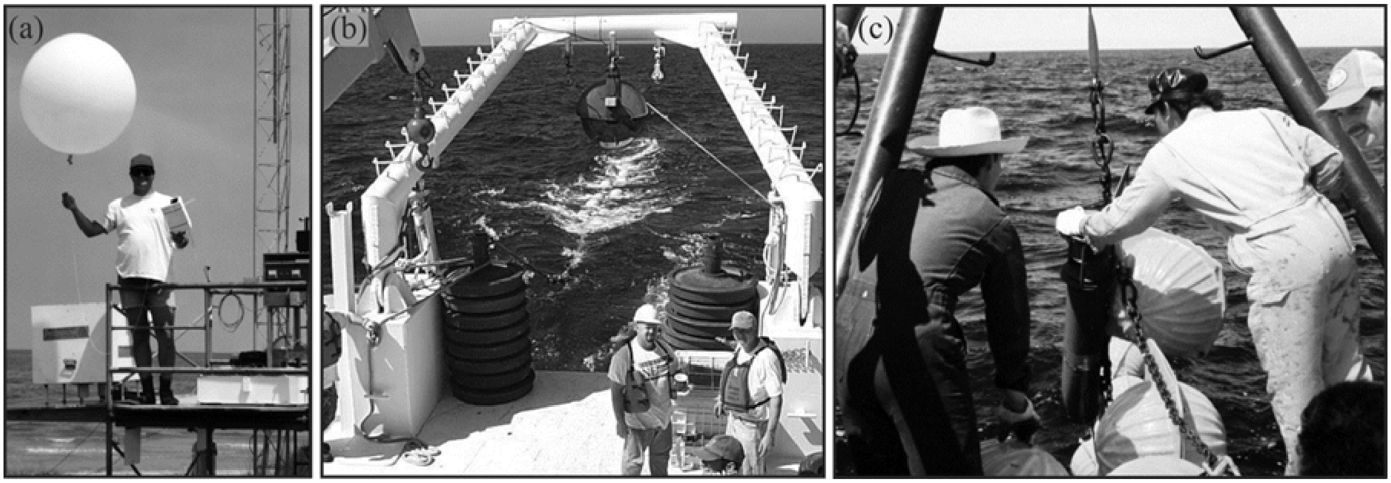


Figure 7. (a) Bill Gibson of the CSI Field Support Group launching an atmospheric profiling package at an instrumented site designed to measure air quality and study the boundary layer physics of sand transport on a Louisiana barrier island (1995). (b) The CSI Field Support Group preparing to deploy a current meter mooring in the deepwater area of the northern Gulf of Mexico continental slope in 2000. (c) Rod Fredericks, CSI Field Support Group in 1986, preparing the deck crew for deploying a mooring in the Lombok Strait, Indonesia.

Through this variety of regional northern Gulf of Mexico studies, Institute researchers developed the first integrated and detailed description of the physical oceanography of the inner and middle shelf, with particular focus on the Mississippi and Atchafalaya river plumes and the highly-stratified coastal currents that represent their downstream extensions. These descriptions include statistics of seasonal variations in current and stratification, volumes of fresh water and their relationship to river discharge, and the response of these patterns to external forcing on time scales from hours to months. These analyses continue to serve as the basis for further studies of the region today.

At the same time that the inner shelf work was being conducted, research extended to incorporate the transport, mixing and stirring processes that connect the waters of the inner shelf with those of Louisiana's highly productive estuaries (Wiseman et al., 1990a, 1990b). Associated modeling studies have illuminated the manner in which coastal trapping leads to chaotic and efficient dispersion (Inoue and Wiseman, 2000).

In the early 1990s, the Institute also started a serious research thrust in numerical modeling of deep ocean processes under the direction of Masa Inoue and Susan Welsh. One of the first studies dealt with modeling the upper layer circulation in the Indo-Pacific region (Inoue and Welsh, 1991). Later modeling studies focused on the Gulf of Mexico with particular attention placed on the Loop Current and its eddies (Welsh and Inoue, 1996). A deepwater mooring program funded by the MMS made great progress in understanding both the dynamics of the Loop Current and the deep Gulf circulation below the Loop Current and its eddies (Welsh and Inoue, 2000) (Fig. 7b).

With the retirements of S. P. Murray, W. J. Wiseman, Jr., C. E. Adams, and M. Inoue, the complex data collection projects in physical oceanography in the deepwater Gulf of Mexico and foreign areas dramatically decreased. Institute researchers presently concentrate much of their physical oceanographic research on shallow water environments of the Louisiana coastal zone. A new generation of studies is now being conducted in subjects such as storm surge (Li et al., 2009), the impacts of cold front passage on estuaries of the Louisiana coastal plain (Li et al., 2008; Li, 2013), and other local investigations.

Sea Strait Program

In response to interest from the ONR, CSI began a program in the early 1980s focused on the dynamical oceanography of sea straits. With the knowledge of coastal dynamics already developed at the Institute by oceanographer Bill Wiseman, Steve Murray led an expansion to understand the role of more complex coastal topography exhibited by sea straits on coastal circulation. So began a long program in the Middle East, where the straits of Jubal and Tiran at the entrances to the gulfs of Suez and Aqaba in the northern Red Sea were instrumented. Primary modes of circulation and a surprisingly strong inverse estuarine circulation were quantitatively described for the first time (Murray et al., 1984). Work off the Mediterranean coast of Egypt in this same time frame lead to the discovery of a strong topographic eddy controlling sand bank evolution off the Damietta Nile promontory (Murray et al., 1981), an important effect suspected to be associated with the catastrophic coastal erosion emanating from the Aswan Dam closure.

Subsequently, the sea straits program was awarded funding to tackle the much larger problem of the strength, variability, and the forcing of the Lombok Strait, a major connection between the Indian and Pacific oceans through the Indonesian Archipelago. Despite extremely rigorous environmental, logistical, and political conditions, analysis of project data discovered what came to be known as the Indonesian Throughflow (ITF), a major transport of low salinity water from the Pacific to the Indian Ocean with strong seasonal variability driven by the large scale reversal of the western Pacific monsoon (Murray and Arief, 1988; Arief and Murray, 1996). The ITF was subsequently studied by numerous other scientists from many countries as it proved to be a key element in the global ocean circulation with important climatic implications (Fig. 7c).

Work continued in the western Pacific when another important ocean chokepoint was instrumented and studied for the first time (Murray et al., 1995), when the CSI Sea Straits Team was funded to investigate the transport characteristics of the Vitiaz Strait off eastern New Guinea. Measurement of the strength, temporal, and cross-sectional variability of this major but little known low latitude western boundary current was determined over an entire annual cycle. Acquiring these logistically difficult datasets to identify this boundary current was a major program accomplishment.

In the late 1990s, the straits program returned to the Middle Eastern seas when the group addressed the world class problem of the dynamics of flow in the Bab al Mandab Strait at the entrance to the Red Sea and thus to the Suez Canal. Extensive instrumentation for measurement of currents and tidal heights extending over 2 years led to a series of papers quantitatively determining for the first time the seasonal modulation of the two and three layer exchange flow that characterizes the strait (Murray and Johns, 1997), the exchanges of heat and fresh water between the Red Sea and the Gulf of Aden (Sofianos et al., 2002), and the observed characteristics of the tidal currents (Jarosz et al., 2005a). A further study successfully used numerical modeling techniques to simulate the tidal currents and tidal heights in this topographically and dynamical complex region (Jarosz et al., 2005b). The field observations in all of these geopolitically and scientifically important straits have proved to be an essential element in validating and calibrating numerical models of non-accessible regions.

During this era of straits research, the CSI Field Support Group under the direction of Rodney Fredericks gained a reputation as being composed of highly professional technical personnel that could consistently get a high rate of data return from deepwater moorings. This technology and experience paid dividends for other CSI researchers, who have deployed deepwater projects in the Gulf of Mexico.

Satellite Remote Sensing

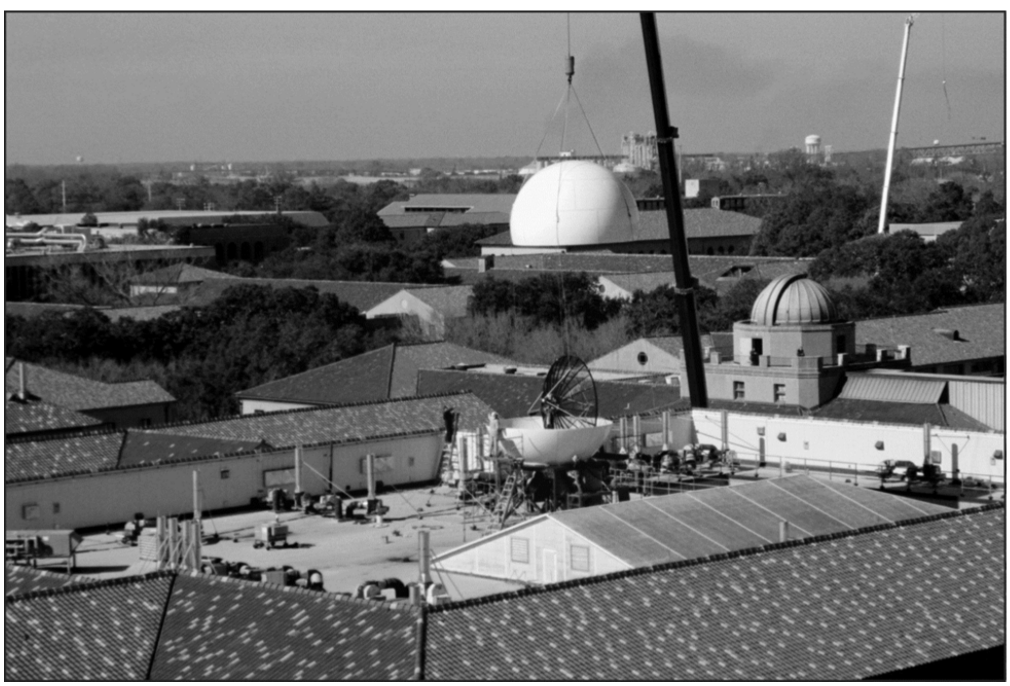
In 1976, Dr. Oscar Huh joined the research faculty at CSI to start a program in remote sensing. His experience with classified Defense Department satellite data at the Naval Research Lab in Washington, D.C., emphasized the exceptional value of satellite imagery to oceanographic studies. With the development of CSI's physical oceanography program, there was a critical need to place ship-based and site-specific buoy data into a larger spatial context. Satellite-based remote sensing data were beginning to fill that need by the late 1970s (Huh et al., 1978). However, access to satellite data was a cumbersome process and sometimes datasets could not be obtained in a temporal framework to fit the schedule of data acquisition in the field. To make satellite data more accessible to CSI researchers and others with a need for imagery, Dr. Huh founded the Earth Scan Laboratory (ESL) in 1988 with a grant from the Louisiana Education Quality Support Fund (LEQSF). At this time, ESL was the first satellite receiving station in the Gulf Coast region and the first state-funded university-based station in the nation.

The ESL receives, processes, and disseminates via its website (www.esl.lsu.edu), and archives satellite data. Initially, the ESL system received data from the NOAA polar orbiting environmental satellites (POES). In 1995, the capability to capture and process data from the geostationary satellite GOES-East was obtained through funding from the Louisiana Office of Homeland Security and Emergency Preparedness. Data from GOES-East, repeated every 30 minutes, enables CSI researchers to track and study hurricanes across the tropical Atlantic and into the Gulf of Mexico, as well as rapidly changing oceanic features such as the Loop Current and its eddies. A hardware and software enhancement in 1996 allowed for acquisition and processing of Orbview-2 SeaWiFS ocean color data for the study of chlorophyll-a in water and vegetation changes on land. Following Dr. Huh's retirement in 2003, Dr. Nan Walker was appointed director of ESL.

The Louisiana Technology Innovation Fund made possible the acquisition of a 4.4 meter tracking antenna in 2001 enabling the real-time reception of satellite data at very high data rates, 150 times faster than previous ESL antennas. Data acquisition from higher-resolution earth environmental satellites, (e.g., Terra-1 and Aqua-2 carrying the MODIS sensor) provided daily coverage of the Gulf of Mexico and adjacent water and land areas. These new sensors were designed to enable researchers to detect and quantify, with greater accuracy and frequency, the components of the atmosphere, oceans, and land masses. By 2002, ESL antennas were receiving data streams from six unique satellite systems on a daily basis: NOAA AVHRR, GOES-East GVAR, Orbview-2 SeaWiFS, Terra-1 and Aqua-1 MODIS, Oceansat-1 OCM, and Radarsat-1 SAR (Fig. 8).

The ESL facility provides a wide range of environmental satellite measurements that have applications in many fields of research and education including emergency response and management, land use and vegetation changes, oceanography, meteorology, land-water interface changes, veterinary medicine, public health, and engineering to name a few. In 2014, the ESL made additional upgrades to its x-band antenna, receiver, and computers to capture and process data from NASA's Visible Infrared Imaging Radiometer Suite (VIIRS), one of several sensors carried by the Suomi NPP polar-orbiting satellite. This new data stream provides further improvements in spatial resolution yielding finer details of oceanic temperature, color, and reflec-

Figure 8. Installation of an antenna on top of the Howe-Russell Geoscience Complex Building (LSU) for receiving data from x-band satellite systems in support of the Earth Scan Laboratory.



tance, and also a variety of atmospheric parameters. In addition to satellite data received through ESL, other forms of remotely sensed data are used by CSI researchers. For example, DeWitt Braud who joined CSI in 2004, was instrumental in processing and mosaicing light detection and ranging (LiDAR) data for the entire state of Louisiana. He also was responsible for development of a state-wide Louisiana GIS DVD that is currently being widely used by academic, government agencies, and industry.

Since its founding, the ESL has been a consistent source of satellite data for studies in oceanography (e.g., Walker and Hammack, 2000; Walker et al., 2005; D'Sa and DiMarco, 2009; D'Sa et al., 2011), meteorology (Hsu, 1998, 2013), and land gain and land loss in the Mississippi and other world deltas (Rouse et al., 1978; Huh et al., 2001; Coleman et al., 2008), as well as shoreline change, coastal plain flooding, vegetation changes, inner shelf hypoxia (Walker and Rabalais, 2006), and storm-induced barrier island changes (Stone et al., 2003). As Louisiana faces the 21st century, satellite data and the ESL will certainly play critical roles in monitoring changes such as coastal plain land loss and hypoxia of shallow inner shelf waters off the Louisiana coast. Remotely sensed satellite data will be used extensively to evaluate the effectiveness of human efforts to reverse land loss and hypoxia in the face of rising sea level, a reduction in Mississippi River sediment to fill growing accommodation space, and continued nutrient-rich river discharge.

THE FUTURE

In late 2012, CSI reorganized and expanded its faculty base, with support from the LSU Office of Research and Economic Development. Faculty with coastal interests now resides in many departments across campus and CSI is the central organization that focuses interdisciplinary coastal research at LSU. The Institute's research centers on coastal geology, engineering, and oceanography with emphasis on deltaic, shelf, and slope sedimentary environments. A well-equipped field support group helps organize and deploy complex field data collection projects. The goal is to continue to develop fundamental scientific knowledge, engineering principles, and coastal management guidelines for deltaic and other coastal types. With 60 years of fundamental science contributions that have led to a better understanding of deltas, as well as other coastal types, the new CSI has a strong foundation on which to build.

ACKNOWLEDGMENTS

We gratefully acknowledge the Office of Naval Research and Dr. Evelyn Pruitt, former head of Geography Programs, for providing initial support that started the Coastal Studies Institute at LSU. Long-term institutional support from ONR was the foundation for many landmark studies and research accomplishments over the first three decades of CSI history. The investment ONR made in coastal research through CSI continues to pay scientific and educational dividends. Members of the Field Support Group, graduate students, and staff not mentioned specifically in this abbreviated history certainly played significant roles in the Institute's success. We also thank LSU for recognizing CSI as an independent unit within the School of Geoscience and providing academic positions for CSI researchers when ONR shifted from institutional to specific project support. The complex data collection projects started in the 1970s and continued to present could not have been fielded without the excellent technical assistance of the CSI Field Support Group. Their expertise in designing, fabricating, and deploying data collection systems has been the foundation for many trend-setting research accomplishments.

REFERENCES CITED

Adams, C. E. Jr., J. T. Wells, and J. M. Coleman, 1982, Sediment transport on the central Louisiana continental shelf—Implications for the developing Atchafalaya River delta: Contributions to Marine Science, v. 25, p. 133–143.

Adams, C. E., J. T. Wells, and V. Park, 1990, Internal hydraulics of a sediment-stratified flow: Marine Geology, v. 95, p. 131–145.

Adams, R. D., 1968, The Leeward reefs of St. Vincent, West Indies: Journal of Geology, v. 76, p. 587–595.

Arief, D., and S. P. Murray, 1996, Low frequency fluctuations in the Indonesian Throughflow through Lombok Strait: Journal of Geophysical Research, v. 101, p. 12455–12464.

Armbruster, C. K. and G. W. Stone, 2001, Beach and nearshore responses during winter cold front passages along a sheltered, micro-tidal coast: North Shore Santa Rosa Island, Florida: Geoscience and Man, v. 32, School of Geoscience, Louisiana State University, Baton Rouge, p. 277–290.

Arnborg, L., H. Walker, and J. Peippo, 1966, Water discharge in the Colville River Alaska, 1962: *Geografiska Annaler*, v. 48 (Series A), p. 195–210.

Arnborg, L., H. Walker, and J. Peippo, 1967, Suspended load in the Colville River, Alaska, 1962: *Geografiska Annaler*, v. 49 (Series A), p. 131–134.

Bentley, S. J., 2003, Wave-current dispersal of fine-grained fluvial sediments across continental shelves: The significance of hyperpycnal plumes, *in* E. D. Scott, A. H. Bouma, and W. R. Bryant, eds., Siltstones, mudstones and shales: Depositional processes and characteristics: Society for Sedimentary Geology (Tulsa, Oklahoma) / Gulf Coast Association of Geological Societies (Austin, Texas), p. 35–48.

Bentley, S. J., A. Sheremet, and J. M. Jaeger, 2006, Preservation potential of event layers on continental shelves: A model and observations: Continental Shelf Research, v. 26, p. 2108–2124.

Chamberlain, J. L., 1959, Influence of Hurricane Aubrey on the coastal marsh of southwestern Louisiana: Louisiana State University Coastal Studies Institute Technical Report 10, Part B, Baton Rouge, 38 p.

Chuang, W. S. and W. J. Wiseman, Jr., 1983, Coastal sea level response to frontal passages on the Louisiana-Texas shelf: Journal of Geophysical Research, v. 88, p. 2615–2620.

Coleman, J. M., 1966, Ecological changes in a massive freshwater clay sequence: Gulf Coast Association of Geological Societies Transactions, v. 16, p. 159–174.

Coleman, J. M., and S. M. Gagliano, 1964, Cyclic sedimentation in the Mississippi River deltaic plain: Gulf Coast Association of Geological Societies Transactions, v. 14, p. 67–80.

Coleman, J. M., and S. M. Gagliano, 1965, Sedimentary structures: Mississippi River Deltaic Plain, *in* G. V. Middleton, Primary sedimentary structures and their hydrodynamic interpretation: American Association of Petroleum Geologists Special Publication 12, Tulsa, Oklahoma, p. 133–148.

Coleman, J. M., S. M. Gagliano, and J. P. Morgan, 1969, Mississippi River subdeltas: Natural models of deltaic sedimentation: Louisiana State University Coastal Studies Institute Bulletin 3, Baton Rouge, p. 23–27.

Coleman, J. M., and L. D. Wright, 1973, Variability of modern river deltas: Gulf Coast Association of Geological Societies Transactions, v. 23, p. 33–36.

Coleman, J. M., and L. D. Wright, 1975, Modern river deltas: Variability of processes and sand bodies, *in* M. L. Broussard, ed., Deltas: Models for exploration: Houston Geological Society, Texas, p. 99–149.

Coleman, J. M., and L. D. Wright, 1977, Research techniques in deltas, proceedings, symposium on research techniques in coastal environments (Russell Symposium): Geoscience and Man, v. 18, School of Geoscience, Louisiana State University, p. 35–51.

Coleman, J. M., D. B. Prior, and L. E. Garrison, 1980, Subaqueous sediment instabilities in the offshore Mississippi River Delta: U.S. Department of Interior, Bureau of Land Management Open File Report 80–01, New Orleans, Louisiana, 60 p.

Coleman, J. M., D. B. Prior, and J. F. Lindsay, 1983, Deltaic influences on shelfedge instability processes, *in* D. J. Stanley and G. T. Moore, eds., The shelfbreak: Critical interface on continental margins: Society of Economic Paleontologists and Mineralogists Special Publication 33, Tulsa, Oklahoma, p. 121–137.

Coleman, J. M., O. K. Huh, and D. H. Braud, 2008, Wetland loss in world deltas: Journal of Coastal Research, v. 24, p. 1–14.

Delaney, P. J. V., 1962, Quaternary geologic history of the coastal plain of Rio Grande do Sul, Brazil: Louisiana State University Coastal Studies Institute Technical Report 18, Part A, Baton Rouge, 63 p.

Dinnel, S. P., W. J. Wiseman, Jr., and L. J. Rouse Jr., 1997, Coastal currents in the northern Gulf of Mexico: U.S. Department of the Interior Minerals Management Service, OCS Study MMS 97–0005, Gulf of Mexico OCS Region, New Orleans, Louisiana, 113 p.

Dolan, R., 1965, Seasonal variations in beach profiles along the outer banks of North Carolina: Shore and Beach, October issue, p. 1–5.

Dolan, R., 1966, Beach changes on the outer banks of North Carolina: Annals Association of American Geographers, v. 56, p. 699–711.

Dolan, R., 1967, Photographic beach measurements: Sedimentology, p. 77–80.

D'Sa, E. J., and S. F. DiMarco, 2009, Seasonal variability and controls on chromophoric dissolved organic matter in a large river-dominated coastal margin: Limnology and Oceanography, v. 54, p. 2233–2242.

D'Sa, E. J., M. Korobkin, and D. S. Ko, 2011, Effects of Hurricane Ike on the Louisiana-Texas coast from satellite and model data: Remote Sensing Letters, v. 2, p. 11–19.

Edington, C. H., 2013, Depositional history of the Trinity-Tiger shoals region: A transgressed delta complex of the middle Holocene Mississippi Delta: Ph.D. Dissertation, Louisiana State University, Baton Rouge, 402 p.

Gagliano, S. M., 1963, A survey of preceramic occupations in portions of south Louisiana and south Mississippi: Louisiana State University Coastal Studies Institute Technical Report 16, Part E, Baton Rouge, p. 105–132.

Gagliano, S. M., and W. G. McIntire, 1968, Reports on the Mekong River Delta: Louisiana State University Coastal Studies Institute Technical Report 57, Baton Rouge, 143 p.

Haag, W. G., 1958, The archeology of coastal North Carolina: Louisiana State University Coastal Studies Institute Technical Report 2, Baton Rouge, 136 p.

Hamilton, R., C. Ho, and H. Walker, 1974, Breakup flooding and nutrient source of Colville River Delta during 1973, *in* J. C. Sater and J. E. Reed, eds., The coast and shelf of the Beaufort Sea: Arctic Institute of North America, Calgary, Alberta, Canada, p. 637–648.

Hamilton, R., C. Ho, and H. Walker, 1976, Contributions of suspended and dissolved substances to the Arctic Ocean during breakup of the Coleman River, Alaska: Louisiana State University Coastal Studies Institute Technical Report 203, Baton Rouge, 30 p.

Harper, J. R., 1978, Coastal erosion rates along the Chukchi Sea coast near Barrow, Alaska: Arctic, v. 31, p. 428–433.

Harper, J. R., and W. J. Wiseman, Jr., 1977, Temporal variations of surface roughness over a tundra surface: Journal of Geophysical Research, v. 82, p. 3495–3497.

Ho, C., and H. Walker, 1976, Contribution of nutrients from sediments and interstitial water to the Colville River system, Alaska: *Geografiska Annaler*, v. 58 (Series A), p. 41–54.

Hsu, S. A., 1971, Wind stress in eolian sand transport: Journal of Geophysical Research, v. 76, p. 8684–8686.

Hsu, S. A., 1974a, On the log-linear wind profile and the relationship between shear stress and stability characteristics over the sea: Boundary-Layer Meteorology, v. 6, p. 509–514.

Hsu, S. A., 1974b, Experimental results of the drag-coefficient estimates for air-coast interfaces: Boundary-Layer Meteorology, v. 6, p. 505–507.

Hsu, S. A., 1988, Coastal meteorology: Academic Press, London, U.K., 260 p.

Hsu, S. A., 1998, A relationship between the Bowen ratio and sea-air temperature difference under unstable conditions at sea: Journal of Physical Oceanography, v. 28, p. 2222–2226.

Hsu, S. A., 2013, Mississippi River flow reversal during Hurricane Isaac in 2012: A physical explanation: Mariners Weather Log, v. 57, p. 5–11.

Huh, O. K., W. J. Wiseman Jr., and L. J. Rouse, 1978, Winter cycle of sea surface thermal patterns, northeast Gulf of Mexico: Journal of Geophysical Research, v. 83, p. 4523–4529.

Huh, O. K., N. Walker, and C. Moeller, 2001, Sedimentation along the eastern Chenier Plain coast: Downdrift impacts of a delta complex shift: Journal of Coastal Research, v. 17, p. 72–81.

Inoue, M., and S. E. Welsh, 1991, Modeling seasonal variability in wind-driven upper-layer circulation in the Indo-Pacific region: Journal of Physical Oceanography, v. 23, p. 1411–1436.

Inoue, M., and W. J. Wiseman Jr., 2000, Transport, mixing and stirring processes in a Louisiana Estuary: A model study: Estuarine, Coastal and Shelf Science, v. 50, p. 449–466.

Inoue, M., S. E. Welsh, L. Rouse, and E. Weeks, 2002, Observations of deep water manifestation of loop current and loop current rings in the eastern Gulf of Mexico: EOS, Transactions of the American Geophysical Union, v. 52, p. 321.

Jarosz, E., and S. P. Murray, 2005, Velocity and transport characteristics of the Louisiana-Texas Coastal Current, *in* W. Sturges III and A. Lugo-Fernandez, eds., Circulation in the Gulf of Mexico: Observations and models: American Geophysical Union Geophysical Monograph Series 161, Washington, D.C., p. 143–156.

Jarosz, E., S. P. Murray, and M. Inoue, 2005a, Observations on the characteristics of tides in the Bab al Mandab Strait: Journal of Geophysical Research, v. 110, p. 1–17.

Jarosz, E., A. Blain, S. P. Murray, and M. Inoue, 2005b, Barotropic tides in the Bab el Mandab Strait—Numerical simulations: Continental Shelf Research, v. 25, p. 1225–1247.

Kemp, G. P., and J. T. Wells, 1987, Observations of shallow water waves over a fluid-mud bottom: Implications to sediment transport: Coastal Sediments '87, p. 363–378.

Kwon, H. J., 1969, Barrier islands of the northern Gulf of Mexico coast: Sedimentation source and development: Louisiana State University Coastal Studies Institute Technical Report 25, Baton Rouge, 51 p.

Li, C., 2013, Subtidal water flux through a multi-inlet system: Observations before and during a cold front event and numerical experiments: Journal of Geophysical Research: Oceans, v. 118, p. 1–16.

Li, C., N. Walker, A. Hou, I. Georgiou, H. Roberts, E. Laws, J. McCorquodale, E. Weeks, X. Li, and J. Crocket, 2008, Circulation plumes in Lake Pontchartrain estuary under wind straining: Estuarine, Coastal, and Shelf Sciences, v. 80, p. 161–172.

Li, C., E. Weeks, and J. Rego, 2009, In situ measurements of saltwater flux through tidal passes of Lake Pontchartrain estuary by hurricanes Gustav and Ike in September 2008: Geophysical Research Letters, v. 36, L19609, doi:10.1029/2009GL039802.

Lugo-Fernandez, A., H. H. Roberts, W. J. Wiseman, Jr., and B. Carter, 1998a, Water levels and currents of tidal and infragravity periods at Tague Reef, St. Croix (USVI): Coral Reefs, v. 17, p. 343–349.

Lugo-Fernandez, A., H. H. Roberts, and J. N. Suhayda, 1998b, Wave transformations across a Caribbean funging-barrier coral reef: Continental Shelf Research, v. 18, p. 1099–1124.

McIntire, W. G., 1954, Trafficability and navigability of delta-type coastal (Louisiana coast marshes): Louisiana State University Coastal Studies Institute Report ONR Project N7 35608, Task Order NR388–002, Baton Rouge, 66 p.

McIntire, W. G., 1958, Prehistoric Indian settlements of the changing Mississippi River Delta: Louisiana State University Coastal Studies Institute Technical Report 1, Baton Rouge, 127 p.

McIntire, W. G., 1961, Mauritius: River-mouth terraces and present eustatic sea stand: *Zeitschrift für Geomorphologie* (Supplement), v. 3, p. 39–49.

McIntire, W. G., 1962, Mauritius: River-mouth terraces and present eustatic sea stand: Annals of Geomorphology, Supplement, v. 3, p. 39–47.

McIntire, W. G., L. G. Nichols, J. P. Morgan, R. J. Russell, J. R. Van Lopik, and R. Cuthrell, 1954, Trafficability and navigability of delta-type coasts trafficability and navigability of Louisiana coastal marshes: Louisiana State University Coastal Studies Institute Technical Report 1–7, Baton Rouge.

McIntire, W. G., and J. P. Morgan, 1963, Recent geomorphic history of Plum Island, Massachusetts and adjacent coasts: Louisiana State University Coastal Studies Institute Technical Report 8, Baton Rouge, 43 p.

McIntire, W. G., and H. J. Walker, 1964, Tropical cyclones and coastal morphology in Mauritius: Annals of the Association of American Geographers, v. 54, p. 582–596.

Morgan, J. P., 1963, Louisiana's changing shoreline: Louisiana State University Coastal Studies Institute Technical Report 16, Part D, Baton Rouge, p. 66–78.

Morgan, J. P., and P. B. Larimore, 1957, Changes in the Louisiana shoreline: Gulf Coast Association of Geological Societies Transactions, v. 7, p. 303–310.

Morgan, J. P., L. G. Nichols, and M. Wright, 1958, Morphological effects of Hurricane Audrey on the Louisiana coast: Louisiana State University Coastal Studies Institute Technical Report 10, Baton Rouge, 53 p.

Morgan, J. P., and W. G. McIntire, 1959, Quaternary geology of the Bengal Basin, 56 p., 1956. (Republished as Quaternary geology of the Bengal Basin, East Pakistan and India: Geological Society of America Bulletin, v. 70, p. 319–342.

Morgan, J. P., J. M. Coleman, and S. M. Gagliano, 1963, Mudlumps at the mouth of South Pass, Mississippi River; sedimentology, paleontology structure, origin, and relation to deltaic processes: Louisiana State University Coastal Studies Institute Technical Report 10, Baton Rouge, 190 p.

Morgan, J. P., J. M. Coleman, and S. M. Gagliano, 1968, Mudlumps: diapiric structures in Mississippi delta sediments, *in* J. Braunstein and D. O'Brien, eds., Diapirism and diapirs: American Association of Petroleum Geologists Memoir 8, Tulsa, Oklahoma, p. 145–161

Murray, S. P., 1972, Observations on wind, tidal, and density-driven currents in the vicinity of the Mississippi River Delta, *in* D. J. Swift, D. B. Duane, and D. H. Pilkey, eds., Shelf sediment transport: Dowden, Hutchinson, and Ross, Stroudsburg, Pennsylvania, p. 127–142.

Murray, S. P., 1975, Trajectories and speeds of wind-driven currents near the coast: Journal of Physical Oceanography, v. 5, p. 347–360.

Murray S. P., 1998, An observational study of the Mississippi-Atchafalaya coastal plume—Final report: U.S. Department of the Interior Minerals Management Service OCS Study MMS 98 –0040, Gulf of Mexico OCS Region, New Orleans, Louisiana, 513 p.

Murray, S. P., and D. Arief, 1988, Throughflow into the Indian Ocean through the Lombok Strait, Jan. 1985–Jan.1986: Nature, v. 333, p. 444–447.

Murray, S. P., and W. Johns, 1997, Direct observations of seasonal exchange through the Bab al Mandab Strait: Geophysical Research Letters, v. 24, p. 2557–2560.

Murray, S. P., D. Conlon, A. Siripong, and J. Santoro, 1976, Circulation and salinity distribution in the Rio Guayas Estuary, Ecuador: Estuarine Research, v. 2, p. 345–363.

Murray, S. P., J. M. Coleman, and H. H. Roberts, 1981, Accelerated currents and sediment transport off the Damietta Nile promontory: Nature, v. 293, p. 51–54.

Murray, S. P., S. A. Hsu, H. H. Roberts, E. H. Owens, and R. L. Crout, 1982, Physical processes and sedimentation on a broad, shallow bank: Estuarine, Coastal, and Shelf Science, v. 14, p. 135–157.

Murray, S. P., A. Hecht, and A. Babcock, 1984, On the mean flow in the Tiran Strait in Winter. Journal of Marine Research, v. 52, p. 265–287.

Murray, S. P., E. Lindstrom, J. Kindle, and E. Weeks, 1995, Transport through the Vitiaz Strait: World Ocean Circulation Experiment (WOCE) Notes, v. 7, p. 21–23.

Murray, S. P., E. Jarosz, and E. Weeks, 1998, Physical oceanographic observations of the Coastal Plume, *in* An observational study of the Mississippi-Atchafalaya coastal plume—Final report: U.S. Department of the Interior Minerals Management Service OCS Study MMS 98–0040, Gulf of Mexico OCS Region, New Orleans, Louisiana, p. 5–102.

Owens, E. H., and J. R. Harper, 1977, Frost-table and thaw depths in the littoral zone near Peard Bay, Alaska: Arctic, v. 30, p. 155–168.

Pepper, D. A., and G. W. Stone, 2002, Atmospheric forcing of fine sand transport on a low-energy inner shelf: South-central Louisiana, USA: Geo-Marine Letters, v. 22, p. 23–31.

Prior, D. B., and J. M. Coleman, 1978, Submarine landslides on the Mississippi River delta-front slope: Geoscience and Man, v. 19, School of Geoscience, Louisiana State University, Baton Rouge, p. 41–53.

Prior, D. B., and J. M. Coleman, 1982, Submarine slope instability, Mississippi River—Side-scan sonar mosaics: Proceedings, Oceanology International, Brighton, England, U.K., March 1982, 15 p.

Prior, D. B., B. D. Bornhold, W. J. Wiseman Jr., and D. R. Lowe, 1987, Turbidity current activity in a British Columbia fjord: Science, v. 237, p. 1330–1333.

Pruitt, E., 1979, The office of naval research and geography: Annals of the Association of American Geographers, v. 69, p. 103–108.

Psuty, N. P., 1965, Beach-ridge development in Tabasco, Mexico: Annals of the Association of American Geographers, v. 55, p. 112–124.

Rigby, J. K., and W. G. McIntire, 1967, The Isle de Lobos and associated reefs: Brigham Young University Geology Studies, v. 13, Provo, Utah, p. 3–46.

Rigby, J. K., and H. H. Roberts, 1976, Geology, reefs, and marine communities of Grand Cayman Island, British West Indies, *in* J. K. Rigby and E. Shaw, eds., Grand Cayman Island: Geology, sediments, and marine communities: Brigham Young University, Geology Series Special Publication 4, Provo, Utah, p. 1–96.

Ritchie, W., and H. Walker, 1974, Riverbank forms of the Colville River delta, *in* J. C. Sater and J. E. Reed, eds., The coast and shelf of the Beaufort Sea: Arctic Institute of North America, Calgary, Alberta, Canada, p. 545–562.

Roberts, H. H., 2001, Fluid and gas expulsion on the northern Gulf of Mexico continental slope-Mud-prone to mineral-prone responses, *in* C. K. Paull and W. P. Dillon, eds., Natural gas hydrates: Occurrence, distribution, and dynamics: American Geophysical Union Geophysical Monograph 124, Washington, D.C., p. 131–143.

Roberts, H. H., 2010, Gulf of Mexico cold seeps: Deep-Sea Research–Part II, Special Issue, p. 1835–2060.

Roberts, H. H., S. P. Murray, and J. N. Suhayda, 1975, Physical processes in a fringing reef system: Journal of Marine Research, v. 33, p. 233–260.

Roberts, H. H., J. N. Suhayda, and J. M. Coleman, 1980a, Sediment deformation and transport on low-angle slopes: Mississippi River Delta, *in* D. R. Coates and J. D. Vitek, eds., Thresholds in Geomorphology: Dowden and Culver, Stroudsburg, Pennsylvania, p. 131–167.

Roberts, H. H., R. D. Adams, and R. H. W. Cunningham, 1980b, Evolution of sand-dominant subaerial phase, Atchafalaya Delta, Louisiana: American Association of Petroleum Geologists Bulletin, v. 64, p. 264–279.

Roberts, H. H., and J. N. Suhayda, 1983, Wave-current interactions on a shallow reef (Nicaragua, Central America): Coral Reefs, v. 1, p. 209–214.

Roberts, H. H., and S. P. Murray, 1984, Developing carbonate platforms: Southern Gulf of Suez, northern Red Sea: Marine Geology, v. 59, p. 165–185.

Roberts, H. H., C. V. Phipps, and L. Effendi, 1987, *Halimeda* bioherms of the eastern Java Sea, Indonesia: Geology, v. 15, p. 371–374.

Roberts, H. H., P. Aharon, R. Carney, J. Larkin, and R. Sassen, 1990, Seafloor responses to hydrocarbon seeps, Louisiana continental slope: Geo-Marine Letters, v. 10, p. 232–243.

Roberts, H. H., P. A. Wilson, and A. Lugo-Fernandez, 1992, Biological and geological responses to physical processes: Examples from modern reef systems of the Caribbean-Atlantic: Continental Shelf Research, v. 12, p. 809–834.

Roberts, H. H., and J. Sydow, 1997, Siliciclastic-carbonate interactions in a tropical deltaic setting: Mahakam Delta of East Kalimantan (Indonesia): Proceedings of the 8th International Coral Reef Symposium, v. 2, Balboa, Panama, p. 1773–1778.

Roberts, H. H., and J. Sydow, 2003, Late Quaternary stratigraphy and sedimentology of the offshore Mahakam Delta, East Kalimantan (Indonesia): Society of Economic Paleontologists and Mineralogists Special Publication 76, Tulsa, Oklahoma, p. 125–145.

Roberts, H. H., R. Fillon, B. Kohl, J. Robalin, and J. Sydow, 2004, Depositional architecture of the Lagniappe (Mobile River) Delta: Sediment characteristics, timing of depositional events, and temporal relationship with adjacent shelf-edge deltas, *in* J. B. Anderson and R. Fillon, eds., Late Quaternary stratigraphic evolution of the northern Gulf of Mexico Basin: Society for Sedimentary Geology Special Publication 79, Tulsa, Oklahoma, p. 141–186.

Rouse, L. J., Jr., H. H. Roberts, and R. H. W. Cunningham, 1978, Satellite observation of the subaerial growth of the Atchafalaya delta, Louisiana: Geology, v. 6, p. 405–408.

Russell, R. J., 1942, Geomorphology of the Rhone Delta: Association of American Geographers Annals, v. 32, p. 149–254.

Russell, R. J., 1954, Alluvial morphology of Anatolian rivers: Annals of the Association of American Geographers, v. 44, p. 363–391.

Russell, R. J., 1958, Preliminary notes on Caribbean beach rock: Louisiana State University Coastal Studies Institute Technical Report 11, Part A, Baton Rouge, 16 p.

Russell, R. J., 1959, Caribbean beach rock observations: *Zeitschrift für Geomorpholigie*, v. 3, p. 227–236.

Russell, R. J., 1962, Origin of beach rock: *Zeitschrift für Geomorphologie*, v. 6, p. 1–16.

Russell, R. J., 1966, Coral cap of Barbados: Journal of the Royal Netherlands Geographical Society, p. 298–302.

Russell, R. J., 1971, Beaches and ground water of Cape Sable, Florida, during extreme drought: Louisiana State University Coastal Studies Institute Technical Report 103, Baton Rouge, 18 p.

Russell, R. J., and H. V. Howe, 1935, Cheniers of southwestern Louisiana: Geography Reviews, v. 25, p. 449–461.

Russell, R. J., and R. D. Russell, 1939, Mississippi River Delta sedimentation, *in* P. D. Trask, ed., Recent marine sediments: A symposium: Thomas Murray and Company, London, U.K., p. 153–177.

Russell, R. J., and H. N. Fisk, 1942, Isostatic effects of Mississippi River Delta sedimentation: 7th International Union Geodesy and General Assembly, Washington, D.C., 1939, p. 56–59.

Russell, R. J., and W. G. McIntire, 1965, Southern hemisphere beach rock: The Geographical Review, v. 55, p. 17–45.

Russell, R. J., and W. G. McIntire, 1966, Barbuda reconnaissance: Louisiana State University Coastal Studies Institute Technical Report 16, Baton Rouge, 53 p.

Sauer, J. D., 1960, Coastal plant geography of Mauritius: Louisiana State University Coastal Studies Institute Technical Report 15, Part A., Baton Rouge, 153 p.

Sauer, J. D., 1962, Effects of recent tropical cyclones on the coastal vegetation of Mauritius: Journal of Ecology, v. 50, p. 275–290.

Shelesnyak, M. C., 1948, Scientists move to northern frontiers: Monthly Research Report of the Office of Naval Research, Washington, D.C., p. 1–11.

Sheremet, A., G. W. Stone, N. D. Walker, and H. H. Roberts, 2002, The influence of fine-grained sediments on wave propagation, west Louisiana coast: Gulf Coast Association of Geological Societies Transactions, v. 52, p. 899–905.

Sheremet, A., and G. W. Stone, 2003, Wave dissipation due to heterogeneous sediments on the inner Louisiana shelf: Book of Abstracts of the 5th International Symposium on Coastal Engineering and Science of Coastal Sediment Processes, Clearwater Beach, Florida, p. 120–121.

Sheremet, A., A. J. Mehta, B. Liu, and G. W. Stone, 2005, Wave-sediment interaction on a muddy inner shelf during Hurricane Claudette: Estuarine, Coastal, and Shelf Science, v. 63, p. 225–233.

Short, A. D., 1975, Offshore bars along the Alaskan arctic coast: Journal of Geology, v. 83, p. 209–221.

Short, A. D., J. M., Coleman, and L. D. Wright, 1974, Beach dynamics and nearshore morphology of the Beaufort Sea Coast, Alaska, *in* J. C. Sater and J. E. Reed, eds., The coast and shelf of the Beaufort Sea: Arctic Institute of North America, Calgary, Alberta, Canada, p. 477–488.

Short, A. D., and W. J. Wiseman, Jr., 1974, Freezeup processes on arctic beaches: Arctic, v. 27, p. 215–224.

Short, A. D., and W. J. Wiseman, Jr., 1975, Coastal breakup in the Alaskan arctic: Geological Society of America Bulletin, v. 86, p. 199–202.

Smith, D., 1964, Ice lithologies and structure of Ice Island Arlis II: Louisiana State University Coastal Studies Institute Technical Report 21, Baton Rouge, 38 p.

Sofianos, S. S., W. E. Johns, and S. P. Murray, 2002, Heat and freshwater budgets in the Red Sea from direct observations at Bab al Mandeb: Deep Sea Research, Part II, v. 49, p. 1323–1340.

Sonu, C. J., 1969, Tethered balloon for study of coastal dynamics: Proceedings, Symposium on Earth Observations from Balloons, American Society of Photogrammetry, Washington, D.C., February6–7, p. 92–102.

Sonu, C. J., 1972, Field observations of nearshore circulation and meandering currents: Journal of Geophysical Research, v. 77, 18, p. 3232–3247.

Sonu, C. J., 1973, Three-dimensional beach changes: Journal of Geology, v. 81, p. 42–64.

Sonu, C. J., and J. L. van Beek, 1971, Systematic beach changes on the outer banks, North Carolina: Journal of Geology, v. 79, p. 416–425.

Sonu, C. J., S. P. Murray, S. A. Hsu, J. N. Suhayda, and E. Waddell, 1973, Sea breeze and coastal processes: EOS, Transactions of the American Geophysical Union, v. 54, p. 820–833.

Stoddart, D. R., 1962a, Three Caribbean atolls: Turneffe Islands, Lighthouse Reef, and Glover's Reef, British Honduras: Louisiana State University Coastal Studies Institute Technical Report 11, Part G, Baton Rouge, 151 p.

Stoddart, D. R., 1962b, Catastrophic storm effects on the British Honduras reefs and cays: Nature, v. 196, p. 512–515.

Stone, G. W., 2001, A new wave-current online information system for oil spill contingency planning (WAVCIS): Proceedings of the 24th Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, Edmonton, Canada, p. 401–425.

Stone, G. W., J. Grymes, K. Steyer, S. Underwood, K. Robbins, and R. A. Muller, 1993, A chronologic overview of climatological and hydrological aspects associated with Hurricane Andrew and its morphological effects along the Louisiana coast, U.S.A.: Journal of the American Shore and Beach Preservation Association, v. 61, p. 2–12.

Stone, G. W., J. P. Xu, and X. P. Zhang, 1995, Estimation of the wave field during Hurricane Andrew and morphological impacts along the Louisiana coast, *in* G. W. Stone and C. W. Finkl, eds., Impacts of Hurricane Andrew on the coastal zones of Florida and Louisiana: August 22–26, 1992: Journal of Coastal Research, v. 21, Special Issue, p. 234–253.

Stone, G. W., J. M. Grymes, C. A. Armbruster, and O. K. Huh, 1996, Overview and impacts of Hurricane Opal on the Florida Coast: EOS, Transactions of the American Geophysical Union, v. 77, p. 551–553.

Stone, G. W., P. Wang, D. A. Pepper, J. M. Grymes, H. H. Roberts, X. P. Zhang, S. A. Hsu, and O. K. Huh, 1999, Researchers begin to unravel the significance of hurricanes on the Northern Gulf of Mexico Coast: EOS, Transactions of the American Geophysical Union, 80, p. 301–305.

Stone, G. W., A. Sheremet, X. Zhang, and D. Braud, 2003, Coastal land loss and wave-surge predictions during hurricanes in coastal Louisiana: Implications for the oil and gas industry, Louisiana Department of Natural Resources, U.S. Geological Survey, and Minerals Management Service, Final Project Report, 61 p.

Stone, G. W., A. Sheremet, X. Zhang, Q. He, B. Liu, and B. Strong, 2003, Landfall of two tropical systems seven days apart along south central Louisiana: Book of Abstracts of the 5th International Symposium on Coastal Engineering and Science of Coastal Sediment Processes, Clearwater Beach, Florida, p. 333–332

Stone, G. W., and J. D. Orford, 2004, Stone and their significance in coastal morpho-sedimentary dynamics: Marine Geology, v. 210, p. 1–5.

Stone, G. W., B. Liu, D. A. Pepper, and P. Wang, 2004, The importance of extratropical and tropical cyclones on the short term evolution of barrier islands along the northern Gulf of Mexico: Marine Geology, v. 210, p. 63–78.

Stone, G. W., F. Jose, and W. Guidroz, 2007, Impacts of Hurricane Rita along the southwest Louisiana coast: Water Resources IMPACT, v. 9, p. 14–16.

Suhayda, J. N., and N. R. Pettigre, 1977, Observations of wave height and wave celerity in the surf zone: Journal of Geophysical Research, v. 82, p. 1419–1424.

Suhayda, J. N., S. A. Hsu, H. H. Roberts, and A. D. Short, 1977, Documentation and analysis of coastal processes, northeast coast of Brazil: Louisiana State University Coastal Studies Institute Technical Report 238, Baton Rouge, 98 p.

Sydow, J. C., H. H. Roberts, A. H. Bouma, and R. Winn, 1992, Constructional subcomponents of a shelf-edge delta, northeast Gulf of Mexico: Gulf Coast Association of Geological Societies Transactions, v. 42, p. 717–726.

Sydow, J., and H. H. Roberts, 1994, Stratigraphic framework of a late Pleistocene shelf-edge delta, northeast Gulf of Mexico: American Association of Petroleum Geologists Bulletin, v. 78, p. 1276–1312.

Thom, B. G., 1967, Mangrove ecology and deltaic morphology: Tabasco, Mexico: Journal of Ecology, v. 55, p. 301–343.

Van Heerden, I., and H. H. Roberts, 1988, Facies development of the Atchafalaya Delta, Louisiana: A modern bayhead delta: American Association of Petroleum Geologists Bulletin, v. 72, p. 439–453.

Walker, H. J, 1969, Some aspects of erosion and sedimentation in an arctic delta during breakup: Proceedings of a Symposium on *Hydrologie des Deltas,Association International d'Hydrologie Scientifique*, Bucharest, Romania, p. 209–219.

Walker, H. J., 1973a, Spring discharge of an arctic river determined from salinity measurements beneath sea ice: Water Resources Research, v. 9, p. 474–480.

Walker, H. J., 1973b, The nature of the seawater-freshwater interface during breakup in the Colville River Delta, Alaska, *in* Proceedings of the 2nd International Conference on Permafrost, Yakutsk, Russia: National Academy of Sciences, Washington, D.C., p. 473–476.

Walker, H. J., 1983, Guidebook to permafrost and related features of the Colville River Delta, Alaska: Guidebook 2 of the 4th International Conference on Permafrost, Fairbanks, Alaska, 34 p.

Walker, H. J., 2002, Arctic research at the Louisiana State University: Witness the Arctic, The Arctic Research Consortium of the United States, Spring 2002, p. 1–4.

Walker, H. J., 2006, Evelyn Lord Pruitt, 1918–2000: Annals of the Association of American Geographers, v. 96, p. 432–439.

Walker, H. J., and J. Arnborg, 1966, Permafrost and ice-wedge effect on riverbank erosion, *in* Permafrost: Proceedings of the an international conference: National Academy of Sciences / National Research Council Publication 1287, Washington, D.C., p. 164–171.

Walker, N. D., H. H. Roberts, L. J. Rouse, Jr., and O. K. Huh, 1982, thermal history of reef-associated environments during a record cold-air outbreak event: Coral Reefs, v. 1, p. 83–87.

Walker, N. D., and A. B. Hammack, 2000, Impacts of winter storms on circulation and sediment transport: Atchafalaya-Vermillion Bay region, Louisiana: Journal of Coastal Research, v. 16, p. 996–1010.

Walker, N. D., W. Wiseman Jr., L. Rouse, and A Babin, 2005, Effects of river discharge, wind stress, and slope eddies on circulation of the Mississippi River plume, Louisiana: Journal of Coastal Research, v. 21, p. 1228–1244.

Walker, N. D., and N. N. Rabalais, 2006, Relationships among satellite chlorophyll a, river inputs and hypoxia on the Louisiana continental shelf, Gulf of Mexico: Estuaries and Coasts, v. 9, p. 1–13.

Welder, F. A., 1959, Processes of deltaic sedimentation in the lower Mississippi River: Louisiana State University Coastal Studies Institute Technical Report 12, Baton Rouge, 90 p.

Wells, J. T., and H. H. Roberts, 1981, Fluid mud dynamics and shoreline stabilization: Louisiana Chenier Plain: Proceedings of the 17th International Coastal Engineering Conference, Sydney, Australia, March, 23–28, p. 1382–1401.

Wells, J. T., and J. M. Coleman, 1981, Physical processes and fine-grained sediment dynamics, coast of Surinam, South America, Journal of Sedimentary Petrology, v. 51, p. 1053–1068.

Wells, J. T., and J. M. Coleman, 1984, Deltaic morphology and sedimentology, with special reference to the Indus River Delta, *in* B. U. Haq and J. D. Milliman, eds., Marine geology and oceanography of Arabian Sea and coastal Pakistan: Van Nostrand Reinhold, New York, New York, p. 85–100.

Wells, J. T., C. E. Adams, Jr., Yong-Ahn Park, and E. W. Frankenberg, 1990, Morphology, sedimentology and tidal channel processes on a high-tide-range mudflat, west coast of South Korea: Marine Geology, v. 95, p. 111–130.

Welsh, S. E., and M. Inoue, 1996, Numerical simulation of the Gulf of Mexico under present and glacial conditions: U.S. Department of the Interior Minerals Management Service OCS Study 96–0067, Gulf of Mexico Outer Continental Shelf Region, New Orleans, Louisiana, 146 p.

Welsh, S. E., and M. Inoue, 2000, Loop Current rings and the deep circulation in the Gulf of Mexico: Journal of Geophysical Research: Oceans, v. 105, p. 16951–16959.

Wilson, P. A., and H. H. Roberts, 1992, Carbonate periplatform sedimentation by density flows: A mechanism for rapid off-bank transport and vertical flux of shoal water fines: Geology, v. 20, p. 713–716.

Wiseman, W. J., Jr., J. M. Coleman, A. Gregory, S. A. Hsu, A. D. Short, J. N. Suhayda, C. D. Walters, and L. D. Wright, 1973, Alaskan arctic coastal process and morphology: Louisiana State University Coastal Studies Institute Technical Report 149, Baton Rouge, 171 p.

Wiseman, W. J., Jr., J. N. Suhayda, S. A. Hsu, and C. D. Walters, Jr., 1974, Characteristics of the nearshore oceanographic environment of Arctic Alaska, *in* J. C. Sater and J. E. Reed, eds., The coast and shelf of the Beaufort Sea: Arctic Institute of North America, Calgary, Alberta, Canada, p. 49–63.

Wiseman, W. J., Jr., J. M. Bane, S. P. Murray, and M. W. Tubman, 1976, Small-scale temperature and salinity structure over the inner shelf west of the Mississippi River Delta: *Memoires Societe Royals des Sciences de Liege*, 6th Series, v. 10, p. 277–285.

Wiseman, W. J., Jr., E. H. Owens, and J. Kahn, 1981, Temporal and spatial variability of ice-foot morphology: *Geografiska Annaler*, v. 63A, p. 69–80.

Wiseman, W. J., Jr. and S. P. Dinnel, 1988, Shelf currents near the mouth of the Mississippi River: Journal of Physical Oceanography, v. 18, p. 1287–1291.

Wiseman, W. J., Jr., E. M. Swenson, and F. J. Kelly, 1990a, Control of estuarine salinities by coastal ocean salinity: Coastal and Estuarine Studies, v. 38, p. 184–193.

Wiseman, W. J., Jr., E. M. Swenson, and J. Power, 1990b, Salinity trends in Louisiana estuaries: Estuaries, v. 13, p. 265–271.

Wiseman, W. J., Jr., N. N. Rabalais, R. E. Turner, S. P. Dinnel, and A. MacNaughton, 1997, Seasonal and interannual variability within the Louisiana Coastal Current: Stratification and hypoxia: Journal of Marine Systems, v. 12, p. 237–248.

Wright, L. D., F. J. Swaye, and J. M. Coleman, 1970, Effects of Hurricane Camille on the landscape of the Breton-Chandeleur Island chain and the eastern portion of the lower Mississippi delta: Louisiana State University Coastal Studies Institute Technical Report 76, Baton Rouge, 34 p.

Wright, L. D., and J. M. Coleman, 1971, Effluent expansion and interfacial mixing in the presence of a salt wedge, Mississippi River Delta: Journal of Geophysical Research, v. 76, p. 8649–8661.

Wright, L. D., and J. M. Coleman, 1974, Mississippi River mouth processes: Effluent dynamics and morphologic development: Journal of Geology, v. 82, p. 751–778.

Wright, L. D., J. M. Coleman, and M. W. Erickson, 1974, Analysis of major river systems and their deltas: Morphologic and process comparisons: Louisiana State University Coastal Studies Institute Technical Report 156, Baton Rouge, 114 p.

Wright, L. D., W. J. Wiseman, Jr., Z. S. Yang, B. D. Bornhold, G. H. Keller, D. B. Prior, and J. N. Suhayda, 1990, Processes of marine dispersal and depositional of suspended silts off the mouth of the modern Huanghe (Yellow River): Continental Shelf Research, v. 10, p. 1–40.