GSA/AEG Growth Fault Symposium - March 16, 2004

Morning Session

8:00 - 8:30	Welcome and Introduction Chris Beal and Bob Traylor, co-chairs Thoughts on Tectonic Reasons for Active Coastal Faulting and Subsidence Bob Traylor
8:30 - 9:00	Faults and Other Geohazards, Northern Gulf of Mexico Kerry Campbell
9:00 - 9:30	Growth Faults in Upper Triassic Deltaic Sediments, Edge Island, Svalbard Archipelago, Arctic Ocean, Norway Marc Edwards
9:30 - 10:00	The Relationship Between Third- and Fourth-Order Sequences and Growth Fault Development—Frio Formation, South Texas Ursula Hammes
10:00 - 10:30	Break and Posters
10:30 - 11:00	Are Surface Faults Activated by Subsidence Induced by Groundwater Pumpage? Carl Norman
11:00 - 11:30	Structural Characteristics of Active Normal Faults in South Louisiana: Implications for Their Origin and Public Policy Roy Dokka
11:30 - 12:00	Earthquakes, Faults, Subsidence and Land Loss in South Louisiana and South Texas Sherwood "Woody" Gagliano
12:00 - 1:00	Lunch

Afternoon Session

1:00 - 1:30	Inferred Fracture Patterns Within Overlapping Normal Fault Zones from Shallow, High-Resolution Gravity, Seismic, and Laser Altimetry (Lidar) Data Sets: Neotectonics along Northern Gulf of Mexico Coast, Louisiana, USA Juan Lorenzo
1:30 - 2:00	Geodetic Evidence of Active Faulting in Southwest Louisiana Jordan Heltz
2:00 - 2:30	The Inter-relationships of Growth Faults and Geologic Hazards, Their Origins, Economic Impact and Methods of Investigation in the Houston, Texas Area Michael D. Campbell
2:30 - 3:00	Geophysical Methods of Investigation of Growth Faults in the Houston, Texas Area Mustafa Saribudak
3:00 - 3:30	Standards for Fault Detection Studies Bill Elsbury
3:30 - 3:45	Break
3:45 - 5:00	Panel Discussion

FAULTS AND OTHER GEOHAZARDS, NORTHERN GULF OF MEXICO

Kerry J. CAMPBELL, Fugro GeoServices, Inc., Houston, TX

Faults and other seafloor and shallow geological features and related processes are potentially hazardous to oil and gas exploration, development, and production activities in the northern Gulf of Mexico. Various types of geophysical survey data and images derived therefrom will be used to give an overview of these features as they exist today on the outer continental shelf and continental slope. Emphasis is on showing examples of several types of faults, including large, regional, down-to-the-basin growth faults that extend to depths of thousands of feet; both reverse and normal faults that commonly terminate at salt bodies and result directly from salt movement; shallow "bulldozer" (reverse) faults peripheral to large landslide deposits; and small "consolidation" faults in sediments overlying thick landslide deposits. Rates of offset apparently have varied from very slow, more-or-less-continuous offset over long periods of time on regional growth faults, to episodes of sudden failure along some faults caused by salt movement. Faulting (as well as other processes) was most pronounced and widespread during periods of sea-level lowstand. With sea-level rise, and decreasing amounts of sediment being supplied to offshore areas underlain by thick sediment and plastic salt, fault activity has slowly decreased in general with time, but many faults appear to still be active today. This paper provides an overview perspective of these active or recently active faults, and may help others to better understand the potential engineering significance of similar faults underlying the coastal plain. Other conditions that will be discussed include: large landslides, gas hydrates, and shallow over-pressures and the potential for shallow-water-flow. Brief descriptions of the geophysical survey tools used to characterize faults will be incorporated in the presentation, along with mention of specific engineering concerns resulting from offshore geologic conditions.

Kerry J. Campbell, P.G.
Manager, Geoscience Consulting Services
Fugro GeoServices, Inc.
6100 Hillcroft
Houston, TX 77081
kcampbell@fugro.com
Office Phone & Voice Mail: 713-369-5805
Cell Phone (no voice mail): 281-794-2429
Fax: 713-369-5811

THE INTER-RELATIONSHIPS OF GROWTH FAULTS AND GEOLOGIC HAZARDS, THEIR ORIGINS, ECONOMIC IMPACT AND METHODS OF INVESTIGATION IN THE HOUSTON, TEXAS AREA

Michael D. CAMPBELL, P.G., P.H., Mustafa Saribudak, Ph.D., and M. David Campbell, P.G.

The Houston area, and the Gulf Coast in general, is laced by numerous growth faults, many of which occur along certain regional trends, that are, by definition, geological hazards costing millions of dollars in repairs to damaged house slabs, building-support structures, highways and associated foundations, water-supply wells and pipelines, oil and gas wells and pipelines, and other anthropogenic structures. Although these faults at depth have created significant reservoirs of oil and gas, sulfur, uranium, and geothermal energy, they also provide pathways for radionuclides (^{226}Ra and ^{222}Rn) and hydrocarbons to migrate from great depths upward into Houston's ground-water supplies within the Evangeline and Chicot Aquifers. Such faults continue to affect the Houston environs as a geologic hazard although they have gone unrecognized for decades since the U.S.G.S. budgets for mapping the faults in the Houston area were cut in the late 1970s. Houston's home-building industry has since flourished in fault-prone areas unsuitable for building. We review the origins and characteristics of growth faults, their apparent relation to salt domes and subsidence, and the nature of the damage and economic impact that has occurred over the past 25 years. To characterize these faults, we present a few case histories employing a special application of Ground-Penetrating Radar (GPR) over some of these faults that are below, and sheltered from, the otherwise high-moisture soils occurring in and around the Houston, Texas area.

Michael D. Campbell, P.G., P.H., Principal Hydrogeologist,
M. D. Campbell and Associates
1810 Elmen
Houston, Texas 77019
(http://www.mdcampbell.com)
mdc@mdcampbell.com
713/807-0021

Mustafa Saribudak, Ph.D., Principal Geophysicist
Environmental Geophysics Associates
Spring, Texas
(http://www.environgeophysics.com)

M. David Campbell, P.G., Project Hydrogeologist
M. D. Campbell and Associates
Houston, Texas

STRUCTURAL CHARACTERISTICS OF ACTIVE NORMAL FAULTS IN SOUTH LOUISIANA: IMPLICATIONS FOR THEIR ORIGIN AND PUBLIC POLICY

Roy K. DOKKA, Center for GeoInformatics and Department of Civil & Environmental Engineering, Louisiana State University, Baton Rouge, LA 70803.

Strategies for analysis of active faulting have been developed mainly from studies in arid to semi-arid regions and depend on the creation and preservation of fault-related landforms. South Louisiana's subtropical climatic conditions, the weak nature of the surface materials cut by faults, and the apparent continuous motion on faults do not promote creation of characteristic landforms. Although normal faults in the region are well known from subsurface studies, and are suspected to be active based on the disruption of built structures, the lack of fault kinematics data has hampered our understanding of mechanics and dynamics of faulting. This has led to misconceptions on the causes of faulting (natural vs. human-induced) and a general lack of awareness of the public safety and property damage hazard posed by the faults. A methodology that combined high-resolution topographic mapping using LIDAR technology, geodetic leveling, analysis of subsurface data, and field observations has been successful in recognizing important characteristics of faults of the region: 1) Active faults are generally not exposed and are marked by fault-line scarps, not surface breaks. Kinematics evidence is, thus, essential to prove activity; 2) Current slip rates range from a few mm/yr to over 1 cm/yr; 3) Faults move episodically at time-scales of days to months; 4) Surface deformation associated with faults is limited to areas of hanging wall deformation (roll-overs, and antithetic faults); 5) Stratigraphic analysis suggests that some faults have been active sporadically since the Jurassic. Each period of faulting has coincided with times of sediment loading along the coast. Loading has had the effect of: a) activating long-standing, weak crustal scale faults such as the Tepetate-Baton Rouge system; b) creating a gravitationally unstable mass (Mississippi River delta) that is collapsing under its own weight into the Gulf of Mexico basin and; c) activating the flow of deep seated salt that promotes faulting.

Dr. Roy K. Dokka
Fruehan Endowed Professor of Engineering
Director, Louisiana Spatial Reference Center and Center for GeoInformatics
Louisiana State University
Baton Rouge, LA 70803
rkdokka@c4g.lsu.edu
Voice: 225-578-2975
FAX: 225-578-4502

GROWTH FAULTS IN UPPER TRIASSIC DELTAIC SEDIMENTS, EDGE ISLAND, SVALBARD ARCHIPELAGO, ARCTIC OCEAN, NORWAY

Marc EDWARDS, Marc Edwards Consulting, Houston TX

Growth faults, rollovers, and shale anticlines affecting Upper Triassic deltaic coarsening-upward sequences are excellently exposed in coastal cliffs on Edgeoya in southeast Svalbard. Study of photographs of the cliffs shows fault configuration, reservoir variations, and internal features of shale anticlines.

On downthrown blocks, the strata were tilted and rollovers were formed. Beneath the concave-upward growth faults, shale anticlines developed and relative uplift of the upthrown block resulted in erosion of some of the newly deposited sands. Subsequent shale deposition formed a local angular unconformity.

The faulting may have been initiated by a combination of (1) denser sands overlying less dense clays with excess pore-fluid pressure, (2) a southward prodelta slope and/or regional paleoslope, and (3) differential loading associated with deltaic progradation.

These structures serve as a model for the larger Gulf Coast and Nigerian structures and provide criteria for the recognition of growth faulting in other exposures of ancient deltaic sediments.

Marc Edwards
Marc Edwards Consulting
5430 Dumfries
Houston TX 77096
marc@marcedwards.com
713-728-4215

STANDARDS FOR FAULT DETECTION STUDIES
By Bill R. ELSBURY, P.E. and Robert P. Ringholz, P. E.

There are two levels of investigation that may be used to evaluate the possibility of faulting: reconnaissance (called Phase I by some) and detailed (also called Phase II). A reconnaissance study usually consists of surface faulting literature review, review of subsurface geology, interpretation of aerial photographs, interpretation of topographic maps, and personal observations. When properly applied, these methods can provide a realistic evaluation of the risk of faulting. Examples will be given to demonstrate the need for the consideration of all five methods by a skilled practitioner. A reconnaissance study can result in three possible answers: (a) a fault is present, (b) the risk is low enough that further study is not warranted, or (c) a more detailed study is needed. A detailed study usually consists of drilling and electric logging boreholes (most commonly about 300 ft deep) along a line that crosses the risks identified in a reconnaissance. In some cases, acquisition and interpretation of the logs of oil and gas explorations will demonstrate that a fault identified by the subsurface maps is blind at great depth or will reinforce the need for site-specific borings. Water wells are usually too far apart for their logs to be useful. Shallow explorations, such as geotechnical borings and ground penetrating radar can occasionally detect a known fault, but they cannot be relied upon to demonstrate the absence of faulting, and their use for this purpose can be seriously misleading.

Bill Elsbury, P.E.
Sr. Geotechnical Consultant
Fugro South
PO Box 740010
Houston TX 77274
belsbury@sprynet.com
713/778-5520

Robert P. Ringholz, P. E.
Chief Engineer
Fugro South
Houston TX
bringholz@fugro.com
713/369-5450

EARTHQUAKES, FAULTS, SUBSIDENCE AND LAND LOSS IN SOUTH LOUISIANA AND SOUTH TEXAS

Sherwood M. GAGLIANO, Coastal Environments Inc, Baton Rouge, LA

"Unusual water disturbances" and seiches, with waves up to 2 m that occurred during a 30-minute period in confined streams and water bodies across South Louisiana and South Texas during the Alaskan earthquake of 27 March 1964, have now been correlated with regional listric growth faults. Although the faults are geologically old, tide gauge records and geomorphic signatures indicate that some, if not most, of the segments affected by the remote earthquake exhibited accelerated vertical movement during and after the event. Fault movement in turn, was a cause of twentieth century coastal land loss in the region.

Other remote earthquakes have caused seiches at some of the same locales as the 1964 Alaskan earthquake. Epicenters of historic local earthquakes also correlate with the listric growth faults.

Effects of shock waves from remote earthquakes, locations of local epicenters, and modern subsidence and land loss will be examined within the context of the linked regional tectonic framework.

Gagliano, Sherwood M.
Coastal Environments, Inc
1260 Main St
Baton Rouge LA 70802-4657
sgagliano@coastalenv.com
225/383-7455

THE RELATIONSHIP BETWEEN THIRD- AND FOURTH-ORDER SEQUENCES AND GROWTH FAULT DEVELOPMENT—FRIO FORMATION, SOUTH TEXAS

Ursula HAMMES, Frank Brown, Bob Loucks, and Ramon Trevino, Bureau of Economic Geology, Jackson School of Geosciences, The Univ of Texas at Austin, Austin, TX

Subregional 3-D seismic volumes and wireline logs permitted definition of second- to fifth-order (~10 my–10 ky) Frio and Anahuac (Oligocene) sequences, systems tracts, and associated syntectonics within and across growth-faulted subbasins. Third- and most fourth-order sequences were correlated within several subregional wireline-log and seismic networks. Third-order cycles correlate across subbasins, whereas higher frequency cycles solely correlate within subbasins. Typically, growth faults develop because of sediment loading during third-order relative sea-level lowstands. However, in some instances fourth-order lowstands also generate syndepositional faulting. Postdepositional faults often nucleate above preexisting structural weakness related to older growth faults. Lithostratigraphic Frio and Anahuac strata comprise six chronostratigraphic, third-order depositional sequences and many fourth- and fifth-order sequences. Except for incised-valley fills, lowstand tracts comprise off-shelf systems deposited within active, growth-faulted, intraslope subbasins. Maximum Anahuac flooding provided a regional, dated marker to which latest published ages of sequence surfaces were calibrated. Maximum flooding surfaces and type 1 unconformities are essentially isochronous, but sand-rich lithofacies are mostly diachronous. Seaward, lowstand sedimentary wedges and superposed shelves become younger. Entrenched rivers supplied sediments via ephemeral deltas for gravity transport to basin floors and slope fans. Eventually, overloaded lowstand depocenters initiated gravity faulting, mobilized mud, and, hence, produced younger faulted, shale-withdrawal subbasins. Diminished faulting permitted lowstand deltas to extend shelf edges basinward until the deltaic ramps were anchored at the basinward margin of buried subjacent shale ridges. These shale buttresses stabilized the upper continental slope and shelf edge. During a later cycle, highstand shorelines prograded basinward over the shallow, lowstand ramps. On-shelf regression eventually stalled by increasing accommodation space near the continental shelf edge, establishing another depocenter and intraslope subbasin. These cycles not only span third-order sequences but also occur at higher frequency scales displaying all or part of the third-order facies successions.

Ursula Hammes
Bureau of Economic Geology
Jackson School of Geosciences
The Univ of Texas at Austin
Austin TX 78713
ursula.hammes@beg.utexas.edu
512/471-1891

GEODETIC EVIDENCE OF ACTIVE FAULTING IN SOUTHWEST LOUISIANA

Jordan O. HELTZ, Center for Geo Informatics, Louisiana State University, Baton Rouge, LA 70803, and, Roy K. Dokka, Center for Geo Informatics, Department of Civil & Environmental Engineering, Louisiana State University, Baton Rouge, LA 70803

Benchmark velocities derived from analysis of first-order geodetic leveling lines from the National Geodetic Survey and tide gauge data from the National Oceanic and Atmospheric Administration have provided new insight into the activity of known faults in southwest Louisiana. Because of an emerging consensus that faulting could play a major role in the subsidence and subsequent land loss of coastal Louisiana, a better understanding of fault motion is essential to the success of coastal restoration. The majority of faults in south Louisiana (1) strike generally east to west, (2) are relatively steep near the surface (~ 70 degrees) but become shallower at depth, (3) and are normal growth faults, where the hanging block is downthrown and faulting takes place contemporaneously with sediment deposition. Consequently, faults in coastal Louisiana often show little or no surface expression and therefore have been mapped primarily with subsurface data by petroleum geologists working with seismic imagery and oil well boring logs.

A comparison of benchmark elevations from the 1960's and 1980's has shown that slip rates along normal faults in southwest Louisiana range from about 2 mm/yr to as much as 6 mm/yr. These rates can be updated with respect to current elevations by taking short-term GPS observations on benchmarks adjacent to fault traces. It is concluded that episodic fault movement has occurred in Louisiana throughout recent geologic history and using historical leveling data in concert with present day GPS observations should provide a better understanding of the nature of this movement.

Jordan O. Heltz
Center for Geo Informatics
Louisiana State University
Baton Rouge LA 70803
jheltz1@lsu.edu
225/229-5035

INFERRED FRACTURE PATTERNS WITHIN OVERLAPPING NORMAL FAULT ZONES FROM SHALLOW, HIGH-RESOLUTION GRAVITY, SEISMIC, AND LASER ALTIMETRY (LIDAR) DATA SETS: NEOTECTONICS ALONG NORTHERN GULF OF MEXICO COAST, LOUISIANA, USA

Juan M. LORENZO (1), Jeffrey T Landrum (2), Carrie Cazes (1), Carroll Westbrook (1), and Ivor Van Heerden, (3), (1) Louisiana State Univ, E235 Howe-Russell, Baton Rouge, LA 70803-4101, (2) Dept. Geology and Geophysics, Louisiana State University, Howe-Russell Building, E235, Baton Rouge, LA 70803, (3) LSU Hurricane Center, Louisiana State Univ, Suite 3221 CEBA Building, Baton Rouge, LA 70803

Holocene, normal fault reactivation of Tertiary growth faults at and south of ~30.5 degrees, Louisiana generates linear, arcuate and splayed surface fault traces with overlap zones hundreds of meters to 10 km wide. Within overlap zones, detailed surface and subsurface data provide snapshots of the different stages of complex fault deformation within soft sediments, and aid in developing kinematic models for fracture growth and orientation. Based on high-resolution seismic data (80-300 Hz, 1.5 m CDP spacing) and gravity (+/- .01 mGal per measurement error) simple interpreted cross-sections highlight a (1) broad ~100-m-wide brecciated fault zone and(2) antithetic reverse secondary faulting. LiDAR DEM's (at least ~25 cm vertical accuracy) available from the Louisiana Oil Spill Coordinator's Office, show reorientation of Holocene meander belts with older regional stream directions changing from NW-SE to N-S directions over time in response to growth and breaching of structural ramps in overlap zones. We infer that during normal fault growth, within overlap zone, both E-W as well as ~N-S striking fractures interact to produce 'chocolate-tablet' fracture sets which divert surface drainage and complicate subsurface fluid pathways. We recommend 3-D seismic data seismic anisotropy measurements for P and S waves to test and confirm subsurface orientations.

Lorenzo, Juan M.
Louisiana State Univ
E235 Howe-Russell Bldg
Baton Rouge LA 70803-4101
juan@geol.lsu.edu
225/578-4249

ARE SURFACE FAULTS ACTIVATED BY SUBSIDENCE INDUCED BY GROUNDWATER PUMPAGE?

Carl E. NORMAN, Houston, TX

In the 1920's it became apparent that high-volume production of shallow petroleum caused ground surface subsidence in the Houston Metropolitan Area. By the late 1960's the subsidence contours extended over most of the metropolitan area, and geologists observed that most known active faults were within the subsidence basin. This led to the notion that groundwater pumpage also activated previously dormant faults. That notion has become so deeply entrenched that many accept it for fact, and even begin to assume that present controls on pumpage will render the faults inactive. This presentation challenges that notion on grounds that it: 1) fails to account for active faults located where groundwater is produced in insignificant amounts; 2) fails to account for fault activity prior to man's residence in the Gulf Coastal Plain; 3) is not based on a formal, testable scientific theory for the mechanism of faulting; 4) is not in accord with the firmly established principle of effective stress, which, over 7 decades, has been proven repeatedly in laboratory and field experiments; 5) attributes movements on faults that extend to depths over 20,000 feet to soil compaction at depths less than 2000 feet.

Data from fault displacement monitoring over the past 18 years provide additional concerns that the mechanism of fault movement cannot be attributed to a single, simple process.

Carl E. Norman
12625 Memorial Drive #77
Houston TX 77024
DOD895@aol.com
713/461-7420

GEOPHYSICAL METHODS OF INVESTIGATION OF GROWTH FAULTS IN THE HOUSTON, TEXAS AREA

Mustafa SARIBUDAK, Ph.D., Principal Geophysicist, Environmental Geophysics Associates, Spring, Texas

The land surface in the Gulf Coast area is cut with active surface faults. Movement of these faults, only a few inches per decade, can cause structural damage to highways, industrial buildings, residential houses, and railroads, etc.

Common methods that have been used in identifying these faults are: 1) recognition of fault lineation by studying the aerial photographs; 2) obtaining subsurface borehole data on downthrown and upthrown sides of the fault: 3) associated geophysical logging data along with borehole data; and 4) utilizing geophysical methods.

The first three investigation techniques are the most common ones so far applied to the study of faults in the Gulf Coast area. Geophysical methods are randomly used to determine the locations and parameters of these faults. Available results from these surveys are mixed, and thus geophysical techniques were not recognized as primary tools in fault studies.

However, in the last ten years there have been remarkable technical advances in the manufacturing of geophysical instruments. Data quality has been increased by continuous data collection. The data have been processed and interpreted by better software packages, which have resulted in highly visual mappings and cross-sections.

With these points in mind, conductivity, magnetic, resistivity imaging, and induced polarization methods have been applied to several known faults in the Houston area. Results so far available from two locations indicate that geophysical techniques may be used as a primary tool in fault studies along with other traditional techniques.

Mustafa Saribudak, Ph.D.
Principal Geophysicist
Environmental Geophysics Associates (www.environgeophysics.com)
9211 Colony Pond Dr
Spring TX 77379
ega@pdq.net
281/370-7066

SYMPOSIUM INTRODUCTION AND THOUGHTS ON TECTONIC REASONS FOR ACTIVE COASTAL FAULTING AND SUBSIDENCE

Robert "Bob" J. Traylor, Texas Commission on Environmental Quality, Austin, Texas 78753

The symposium is a beginning. Hopefully, it will lead to future research symposia with more specific issue focus. Coastal faulting and subsidence are not new geohazard topics. Consequently, a lot is taken for granted in the geological literature and considerable "dogma" is embedded in that literature. New research and thinking are emerging from the ever increasing cultural demand to better understand and evaluate the related geohazards of coastal faulting and subsidence. The time has come to air controversies and flesh out the geologic dogma. In that effort, having a symposium which combines the practicing geoscientist (AEG) with the academic geoscientist (GSA) is an appropriate beginning.

Depositional tectonism on passive margins, such as the Gulf Coast, has and continues to be a leading interest of the petroleum industry for the obvious reasons of petroleum exploration and production. Little has been done to connect what is well known in the subsurface to the surface geohazard expression of active faulting and subsidence. Also much has been documented in surface faulting and subsidence studies without the perspective of the deep subsurface.

Four major tectonic factors enter into the complex formula for coastal faulting and subsidence. First is the loading deltaic wedge itself. Its most effective tectonic setting is low-stand deposition onto high-stand shales at the self margin. The next two factors are dominant players - salt tectonism and geopressure from clay diagenesis. Ignoring the plastic whimsy of the Jurassic Louann Salt is impossible, as it underlaid most of the Paleo-Gulf Basin. Deltaic loading of salt is the geologic equivalent of stepping on a "banana peel." The rapidly accommodating salt scoots out from under the delta wedge as diapirs, ridges, and slope pillow structures. The geopressured glide plane from clay diagenesis of the high-stand shales is the "great skate board" of depositional tectonics. Like salt, geopressured shales provide the geologic setting for prolonged instability with continued fault movement to the surface and coastal subsidence long after the initiating deltaic event. Overburden compaction is the last and perhaps least of the factors. The much touted subsidence from localized, near-surface ground water withdrawal is quite minimal in the overall geological subsidence budget and certainly has no relationship to fault movement. Blaming coastal subsidence on petroleum production is rank speculation, which professes a genuine misunderstanding of reservoir fluid dynamics and the tectonic reasons for subsidence.

Robert "Bob" J. Traylor
Surface Casing Team
Texas Commission on Environmental Quality
PO Box 13087
Austin TX 78711-3087
rtraylor@tceq.state.tx.us
Voice: 512/239-0520
FAX: 512/239-1003