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STUDY TITLE: Deepwater Program: Understanding the Processes that Maintain the Oxygen Levels in the Deep Gulf of Mexico

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SPONSORING OCS REGION: Gulf of Mexico

APPLICABLE PLANNING AREAS: Western, Central, and Eastern Gulf of Mexico

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BACKGROUND: With the increase of oil and gas activities in the deepwater Gulf of Mexico, the Minerals Management Service (MMS), Gulf of Mexico Outer Continental Shelf Region, seeks a greater understanding of the environment in Gulf waters deeper than 400 m to aid in making decisions about the protection of the marine environment. Because discharges of oil or gas can consume oxygen during their degradation, this study considers what is known about the distribution of oxygen and processes that control it, what the information gaps might be, and how those gaps might be filled. This summary presents the main results of the Dissolved Oxygen Study.

OBJECTIVES: The objective of this study is to understand the types and rates of processes occurring in the deep Gulf of Mexico that affect the levels of oxygen in the deepwater and the balance that maintains this level.

DESCRIPTION: The study area is that part of the Gulf of Mexico in water depths ≥ 400 m. Vertically, it extends from the sea surface to sea floor. The four project components were: (1) conduct a data search, synthesis, and reanalysis of available historical oxygen data collected from water depths greater than 400 m throughout the entire Gulf of Mexico basin (note 200 m was used to encompass the entire area offshore of the shelf

edge); (2) develop a simple box model that describes the sources and sinks of oxygen in the deep Gulf and that can be used to evaluate inputs from oil and gas activities, using parameters and constants determined from item 1; (3) identify data gaps including an evaluation of the quality of the data and how representative they are of the Gulf's basin environment; and (4) propose methods for filling the data gaps which could include field work.

An inventory of dissolved oxygen data sets was compiled, and as many of these data sets as possible were obtained from MMS, the National Oceanographic Data Center, other Federal and State agencies, national laboratories, universities, Mexican institutions, and the private sector. When available, the temperature and salinity data associated with the oxygen data also were obtained and assembled into the database. Data were processed for quality assurance/quality control (QA/QC). Data were compiled into a digital database on CD-ROM. Dissolved oxygen data basically fall into two types: 1) discrete values from iodometric analysis of water samples collected from Niskin or Nansen bottles, or 2) continuous values from polarographic oxygen sensors or other sensors mounted on CTD/STD packages. Both data types were assembled. The number of stations with discrete oxygen data is approximately 3,600 from over 200 cruises. There are about 1,400 CTD casts with oxygen sensor data, but the data quality is unknown. Results of the data reanalysis, box model study, gaps identification, and recommendations are presented in the Study Results section below.

SIGNIFICANT CONCLUSIONS: The dissolved oxygen database, covering the period 1922-2001, is adequate to study basin-scale distributions in the Gulf of Mexico, but not local distributions or anthropogenic effects thereon. Sources of dissolved oxygen are air-sea exchanges at the sea surface and local contributions from photosynthesis in the photic zone (the upper 100-200 m). For deeper waters, the major source is transport of relatively dense, oxygen-rich water masses through the Yucatan Channel into the Gulf interior. The major sink of oxygen in the Gulf at all depths is oxidation of organic matter. Because the deep waters are well-ventilated by transport processes, the Gulf of Mexico Basin is in no danger of becoming anoxic due either to natural processes, oil and gas production, or other anthropogenic effects. Decreased oxygen levels, however, could occur in localized areas. Comparison of data sets by decade indicates there has not been any discernible change in the vertical or horizontal distribution of dissolved oxygen, suggesting that the transport mechanisms that replenish the oxygen are adequate to balance the oxygen consumption from decay of organic matter, including that from oil seeps and anthropogenic sources. A study of the effects of specific anthropogenic activities on local dissolved oxygen concentrations is recommended to determine the extent, nature, and significance of any such localized effects. The mechanisms that transport oxygen-rich water masses from the Yucatan Channel into the Gulf interior at depths greater than approximately 1,000 m are not well-understood, and a study to determine these Gulf-wide processes would be useful for studies of pollutant transports at depth.

STUDY RESULTS: The Gulf of Mexico is a semi-enclosed sea with two ports. The major inflow port is at the Yucatan Channel, which has a sill depth that is deep enough (~2,000 m) to allow the transport of relatively dense, oxygen-rich deep source waters

from the Atlantic Ocean into the Gulf from the Caribbean Sea. The Loop Current brings these waters in. The major outflow port at the Florida Straits is shallow enough (~800 m) that the deeper, oxygen rich waters can mix into the interior of the Gulf, rather than flowing directly out with the Loop Current.

The sources of dissolved oxygen in the upper waters (~100-200 m) in the Gulf of Mexico are from exchanges with the atmosphere everywhere at the sea surface, mixing mainly by wind and wave action, and local contributions from photosynthesis in the photic zone. The source of dissolved oxygen to the deep waters is the transport and mixing of relatively dense, oxygen-rich water masses into the Gulf of Mexico from the Caribbean Sea through the Yucatan Channel. There is no water mass formation in the Gulf of Mexico to replenish the deep oxygen concentrations. The major sink of oxygen in the Gulf, as elsewhere in the world's oceans, is oxidation of organic matter. The organic matter consists of detritus from living organisms, natural hydrocarbon seeps that are prevalent in the Gulf, continental detritus washed into the ocean through river runoff, and anthropogenic inputs. The rate of oxygen consumption by organic material has not been measured in the Gulf of Mexico.

The oxygen minimum zone, which generally is found in the Gulf between 300-700 m, is derived from two mechanisms. First, the Tropical Atlantic Central Water with the oxygen minimum at its core brings in waters that are depleted from processes occurring outside the Gulf. The decay of organic matter that occurs in the Gulf itself augments this minimum by the same processes. The productivity of the Gulf is not high enough to create extreme oxygen minimum zones such as seen elsewhere.

Data analysis suggests Gulf waters ≥ 1500 m may have slightly different oxygen values in three different regions: southeastern Gulf with mean O_2 concentrations of $4.99 \text{ mL}\cdot\text{L}^{-1}$, northern Gulf with a mean of $4.95 \text{ mL}\cdot\text{L}^{-1}$, and southwestern Gulf with mean of $4.87 \text{ mL}\cdot\text{L}^{-1}$. However, the quality of the data is variable enough that this finding is not definitive. Comparison of data sets from the 1970s with those from 2000/2001 and comparison of decadal mean oxygen profiles indicate there has not been any discernible change in the vertical or horizontal distribution of dissolved oxygen in the Gulf. This suggests that transport mechanisms that replenish oxygen are adequate to balance oxygen consumption from decay of organic matter, including that from oil seeps and anthropogenic sources.

Data sets available are not adequate to study the details of the effects of shelf-deep ocean exchanges on the oxygen levels. However, they do show no water mass is formed on the shelves. There are no shelf waters dense enough to sink to depth into the deep ocean of the Gulf and so to provide a source of ventilation for the deep waters. Any direct shelf-deep ocean exchanges will impact only the upper waters. Transport of organic matter off the shelf, particularly in the region of the Mississippi River Delta, could have local effects on the oxygen concentrations in the deep Gulf only if the material sinks to depth before decaying. But, the database is not adequate to assess this likely local effect.

Although the natural leakage of hydrocarbons, estimated at 140,000±60,000 tonnes per year, has been occurring for millions of years, dissolved oxygen concentrations throughout the water column have been stable over the period during which measurements are available and no significant large-scale perturbations in the oxygen content of deep Gulf waters have been observed to result from this input. However, localized low oxygen conditions are reported to occur within a few centimeters of the sediments and, hence, oxygen concentrations at the sediment-water interface may be depleted at the seeps or associated brine pools. The oxygen database is not adequate to assess associated local effects. Because they require access to oxygenated waters, the presence of chemosynthetic communities at seep sites is additional evidence of ventilation of deepest Gulf waters.

Anthropogenic sources of hydrocarbons to the Gulf are reported at annual estimates of 2000 tonnes from extraction, 1,600 tonnes from transportation, and 6,800 tonnes from consumption. Complete oxidation of the U.S. Gulf oil and gas reserves, which are on the order of 10 billion barrels, would consume <1% of the standing oxygen supply. By comparison annual discharges from extraction would consume 0.000001% of the standing oxygen supply. These effects are not significant alterations of the oxygen supply. Catastrophic oil spills can introduce hydrocarbons at 2-3 times the rate of natural seeps, but such an input will not significantly alter the oxygen supply. There may be local effects from anthropogenic discharges, but the oxygen database is not adequate to assess them.

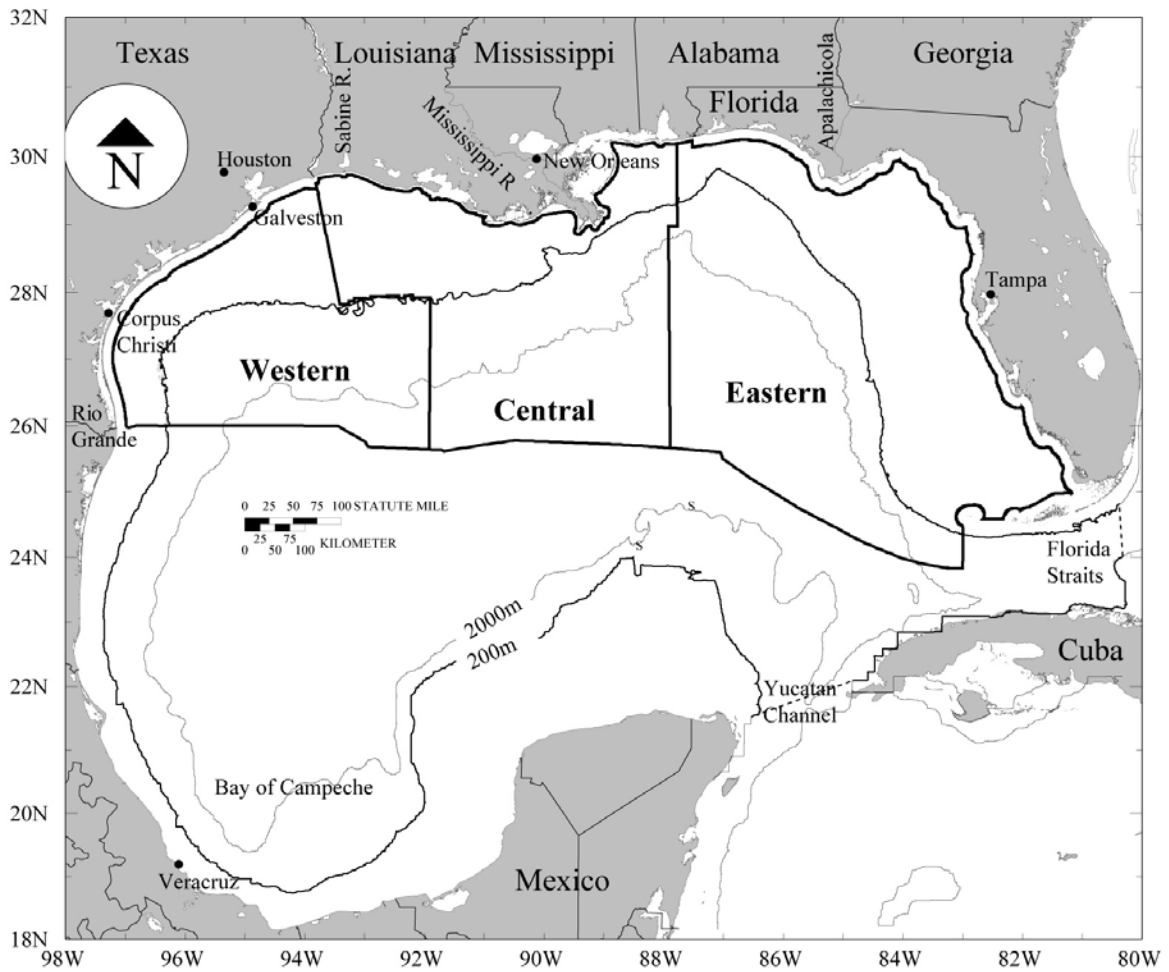
To determine whether anthropogenic activities are locally affecting dissolved oxygen levels will require local monitoring of dissolved oxygen concentrations at discharge sites. A study designed to assess the nature and extent of the effects on dissolved oxygen concentrations of discharges at selected sites of oil and gas exploration and production operations in the deepwater Gulf is recommended. Local environmental conditions, such as currents, waves, temperature, salinity, nutrients, carbon, particulate matter, and other chemical properties, should be monitored at the selected locations to allow determination of the importance of the various complex of factors involved and to provide information that would allow development of an oil spill model that could assess possible effects on dissolved oxygen of a hypothetical subsurface blowout.

STUDY PRODUCTS: Jochens, A. E., L. C. Bender, S. F. DiMarco, J. W. Morse, M. C. Kennicutt II, M. K. Howard, and W. D. Nowlin, Jr.. 2005. Understanding the Processes that Maintain the Oxygen Levels in the Deep Gulf of Mexico: Synthesis Report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2005-032. 142 pp.

Jochens, A. E., M. K. Howard, and S. F. DiMarco. 2004. Recent observations of water properties in the Gulf of Mexico. Contributed presentation, 27 January 2004. AGU Ocean Ocean Sciences 2004, Portland, OR, 25-30 January 2004. *Eos, Trans. AGU*, 84(52), Ocean Sciences Meeting Supplement, Abstract OS31F-01, OS75-76.

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CD-ROM, Dissolved Oxygen Data Base for the Gulf of Mexico. 2005. Deepwater Program: Understanding the Processes that Maintain the Oxygen Levels in the Deep Gulf of Mexico.



Study area, with MMS OCS regions, for the Dissolved Oxygen Study is the Gulf of Mexico in water depths > 200 m.