



## Introduction

These maps present the inferred distribution of natural gas hydrate within the sediments of the eastern United States continental margin (Relative Economic Zone) in the offshore region from Georgia to New Jersey (fig. 1). The maps, which were created on the basis of seismic interpretation, represent the first attempt to map volume estimates for gas hydrate. Gas hydrate forms a large reservoir for methane in oceanic sediments. Hydrate breakdown probably is a controlling factor for sea-floor landfills, and its presence has significant effect on the acoustic velocity of sea floor sediments. A gas hydrate is a crystalline solid in which the gas molecules are much more loosely surrounded by a cage of water molecules. This is similar to ice, except that the crystalline structure is stabilized by the guest gas molecules within the cage of water molecules. Many gases have molecular sizes suitable for sea floor hydrate, including such naturally occurring gases as carbon dioxide, hydrogen sulfide, and several low-carbon-number hydrocarbons, but most common gas hydrates that have been analyzed are those of methane. Gas hydrates are stable at the temperatures and pressures that occur in ocean-floor sediments at water depths greater than about 500 m, and at these pressures they are as stable as temperatures above those for ice stability. Gas hydrates also are stable in association with permafrost in the polar regions, both in offshore and onshore sediments. In deep-sea sediments, where temperature normally increases downward, a temperature eventually is reached at which hydrate is unstable, even though the pressure continues to increase with depth. Thus a zone within the sediments will exist in which gas hydrate is potentially stable from the sea floor down to a depth at which the gas-hydrate phase boundary is reached, commonly several hundred to a thousand meters below the sea floor. If gas (methane) saturation exists within this zone, gas hydrate will form. Over a small area, the base of the hydrate stability zone within the sediments will approximately parallel the sea floor at any particular water depth (equivalent to a slight pressure value) because the thermal gradient within a restricted area is generally fairly constant, that is, the isotherms (surface of constant temperature) will tend to parallel the sea floor. Over larger areas, the thermal field may be distorted and even the pressure field and the chemistry of pore water may vary unpredictably, all of which factors affect the phase stability of hydrate. Therefore the variation in depth to the base of the gas-hydrate stability zone can indicate a gas-hydrate sub-bottom contour.

## Recognition of Gas Hydrates in Sediments by Remote-Sensing Methods: Seismic-Reflection Profiles

Although gas hydrate has been recognized in drill-core logs, its presence over large areas can be detected much more efficiently by acoustical methods, using seismic-reflection profiles (Tubolke and others, 1977; Shipley and others, 1979; Dillon and Paul, 1983; Collins and Watkins, 1985; Miller and others, 1991; Rowe and Gormez, 1993). The calculated effect of gas-hydrate concentration on the amplitude of seismic reflections is demonstrated by the series of synthetic seismograms in figure 3, and maps indicating the distribution of hydrate, created on the basis of seismic-reflection data, are presented as figures 4, 5, and 6. Hydrate has a very strong effect on acoustic reflections because it has a high acoustic velocity (approximately 3.5 km/s) about twice that of sea-floor sediments. Since 1980, and thus concentration of grains by hydrate produces a high-velocity deposit due to the mixing of hydrate with the sediment. Sediment below the hydrate-concentrated zone, if water saturated, have lower velocities (water velocity is about 1.5 km/s), and gas is trapped in the sediment below the hydrate-concentrated zone, which is lower (even with just a few percent of gas; Brand, 1960). Because reflection strength at an interface is a function of the change in acoustic impedance, which is the product of velocity times density, the base of the hydrate-concentrated zone produces a very strong reflection. The reflection is also sharply defined, because the phase boundary is a distinct line to hydrate occurrence, whereas the top of hydrate within the sediments has no such precisely defined boundary. It may be difficult and very irregular; it does not produce a sharp reflection. Because the base of the gas-hydrate stability zone occurs at an approximately uniform subbottom depth throughout any small area, the well-defined seismic reflection from the base of the zone roughly parallels the sea floor. It is called the "bottom simulating reflector," or BSR. The BSR is characteristic of hydrate-bearing sediments. Once the hydrate concentrations for the near-bottom sediments of the southeastern United States were estimated from results of scientific drilling (Dillon, Ewing and others, 1972; Sheridan, Gradstein and others, 1982). Once the hydrate concentrations for the six multichannel seismic profiles were calculated, variations in concentration of hydrate could be correlated with the measured blanking. This relation then was used to estimate the proportion of hydrate in the vertical-incidence, two-channel profiles for use in the calculation of velocity and amplitude effects.

The relation of blanking to hydrate concentration is not considered to be precise, so in estimating hydrate volumes from seismic profiles we divided the effect into only three blanking classes. Class boundaries were selected at amplitude reductions of 6 decibels. To illustrate how the presence of increased amounts of gas hydrate content in sediments affects seismic reflections, and to show the three classes of blanking, we modeled a series of synthetic seismograms (fig. 3). In order to simulate a seismogram for non-concentrated sediments, 200 random velocities in the porosity range of 50-70 percent (similar to the range in the literature) were generated and the corresponding velocities and densities were computed. We then computationally "replaced" non-hydrated sediment with varying amounts of a representative hydrate-concentrated sediment (hydrate concentration 27.5 percent, porosity 57.5 percent) and an average hydrate profile was applied. In figure 3, the effect of blanking of increasing proportions of gas-hydrate content, figure 3 shows a series of synthetic seismograms, in which the representative hydrate-concentrated sediment replaces non-hydrate-bearing sediment in proportions of 0, 25, 50, 60, 70, 80, and 90 percent. The blanking classes are shown. The characteristics of gas-hydrate-concentrated sediments within these classes are indicated in table 1.

**Table 1.** Properties of the blanking classes of gas hydrate in the vertical-incidence sediments.

|                                     | Class I   | Class II   | Class III |
|-------------------------------------|-----------|------------|-----------|
| Median reflectance                  | <0.024    | 0.05-0.025 | >0.05     |
| Bulk volume of hydrate (percent)    | 12-16     | 8-12       | 0-8       |
| Average volume of hydrate (percent) | 14        | 10         | 4         |
| Range in interval velocity (km/s)   | 1.94-0.02 | 1.85-1.94  | 1.71-1.85 |

**Data Collection and Processing**

The majority of the seismic-reflection data used in this study were collected during five cruises of the research vessel (RV) *Farwell* conducted between February and May 1987, which were intended primarily to gather data for the study of gas hydrate in the southeastern United States.

**Table 2.** Estimated hydrate and gas volumes and carbon mass in selected areas, indicated by diagonal hatching in figure 4.

| Location      | Area (km <sup>2</sup> ) | Hydrate (TCF)         | Methane (Gg)         | Methane (TCF) | Carbon (Gg) |
|---------------|-------------------------|-----------------------|----------------------|---------------|-------------|
| Large polygon | 20,200                  | 4.87x10 <sup>10</sup> | 7.8x10 <sup>10</sup> | 2750          | 42.3        |
| 30-m contour  | 3,050                   | 1.12x10 <sup>10</sup> | 1.8x10 <sup>10</sup> | 630           | 9.7         |

**Figure 6.** A map of the depth of the BSR below the sea floor. The interval from the sea floor down to the BSR represents the zone in which gas hydrate is stable. This map, like figures 4 and 5, was created using the seismic data and the interpretation of blanking classes. The depth of the BSR at any given point was calculated by identifying the thickness in seismic time of the deposits of each class and multiplying the time thickness of each class by a characteristic velocity associated with that class (table 1). The thicknesses were then summed to get the total depth to the base of the gas hydrate. Velocities used were as follows: Class I, 2 km/s; Class II, 1.9 km/s; and Class III, 1.8 km/s. Because gas hydrate is stable to higher temperatures as pressure increases and because pressure increases as water depth increases, the base of hydrate stability might be expected to extend deeper into the sediments as water depth increases. This assumes that pressure change depends only on change of water depth, and that the thermal and chemical gradients are constant. This simple model thickening of the gas-hydrate stability zone does not occur, however. Clearly, the structure of the gas-hydrate zone is far more complicated than anticipated and this is effected by factors other than pressure alone (Dillon and others, 1993, 1994).

**Figure 3.** Synthetic seismograms showing the calculated effect from left to right of the increase of hydrate content on reflection amplitudes. The reduction in amplitude, which apparently is caused by concentration of reflecting layers by gas hydrate, is known as "blanking". Blanking class boundaries are indicated. Class I represents the greatest concentration of hydrate (see table 1).

**Figure 5.** Isopach map showing thickness of pure gas hydrate of the seismic Class I in the sediments of the U.S. Atlantic continental margin. Class I is interpreted to represent the most concentrated hydrate accumulations on the basis of blanking effect on seismic reflections. This effect is the reduction in amplitude of seismic reflections (known as "blanking") that is demonstrated using synthetic seismograms in figure 3. Hydrate concentrations in Class I deposits probably range from 12 to 16 percent of the bulk volume. The estimated hydrate amounts from all classes (I, II, and III) were summed to create figure 4.

**Figure 6.** A map of the depth of the BSR below the sea floor. The interval from the sea floor down to the BSR represents the zone in which gas hydrate is stable. This map, like figures 4 and 5, was created using the seismic data and the interpretation of blanking classes. The depth of the BSR at any given point was calculated by identifying the thickness in seismic time of the deposits of each class and multiplying the time thickness of each class by a characteristic velocity associated with that class (table 1). The thicknesses were then summed to get the total depth to the base of the gas hydrate. Velocities used were as follows: Class I, 2 km/s; Class II, 1.9 km/s; and Class III, 1.8 km/s. Because gas hydrate is stable to higher temperatures as pressure increases and because pressure increases as water depth increases, the base of hydrate stability might be expected to extend deeper into the sediments as water depth increases. This assumes that pressure change depends only on change of water depth, and that the thermal and chemical gradients are constant. This simple model thickening of the gas-hydrate stability zone does not occur, however. Clearly, the structure of the gas-hydrate zone is far more complicated than anticipated and this is effected by factors other than pressure alone (Dillon and others, 1993, 1994).

**Conclusions**

These maps represent the first effort to estimate the volume of gas hydrate and amount of the gas-hydrate zone over a significant region. Thus they are an important early step in analyzing the significance of gas hydrate as a possible energy resource, as a control on sea-floor stability, and as a possible reservoir of a greenhouse gas, methane.

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MAPS SHOWING GAS-HYDRATE DISTRIBUTION  
OFF THE EAST COAST OF THE UNITED STATES

By

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