Coincident sediment slump/clathrate complexes on the U.S. Atlantic continental slope

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ABSTRACT

High-resolution seismic reflection data recorded on the continental slope off the east coast of the United States have revealed instances of sediment mass movement (slumps) which appear to occur above clathrate accumulations. The slumping is believed to be related to the liberation of free gas by clathrate decomposition and consequent weakening of unconsolidated sediments above the clathrate. Pleistocene sea-level lowering and/or post-Pleistocene bottom water temperature increases may have had a significant role in this process.

INTRODUCTION

High-resolution seismic reflection profiles collected in an attempt to define the extent and nature of mass movements on selected areas of the United States east coast continental slope have revealed what appears to be sediment slumps overlying clathrate deposits. The coincident locations of the slumps and clathrate deposits and the existence of similar slump/clathrate complexes in other areas seems to verify the prediction of McIver [1] that release of gas from clathrates may be a factor in mass movements. This paper attempts to show that the features discussed are indeed slumps and clathrates and to explore possible relationships between the two.

THE SLUMPS

Figure 1 shows the locations of the two slump/clathrate complexes discussed herein. A considerable amount of data has been collected over the slump at location A and this example is discussed in more detail. Only a single profile (Fig. 2) was recorded over the feature at location B.

The notch in the seafloor sediments (Fig. 3) is, for several reasons, interpreted as a slump scar. An outline drawing of the failed block is shown in Figure 4 and reveals it to be arcuate in plan view. A migration calculation performed on the data to collapse the diffraction resulting from the edge effect at the top of the slump scar reveals the scar to be sharp, well defined, and slightly concave (L. K. Good, pers. comm., 1980). The results of this calculation and the records presented in Figure 3 also show the near-surface reflections to be cleanly truncated by the escarpment. Additional evidence for interpreting the feature as a slump is the distortion of sediments at the foot of the failed block (Fig. 3). Such distortion is thought to be typical of many marine mass movements [2].

A problem in interpreting slumps, particularly on the steeper parts of the continental slope which have been extensively incised by canyons and tributary channels, is the superposition of side echoes from nearby rough topography on the normal incidence data. Side echoes can produce features on reflection profiles which appear to be slumps but are actually artifacts of the recording process. The absence of such three-dimensional effects considerably reduces interpretational ambiguities. The seafloor is quite smooth and slopes gently seaward with a gradient of about 2°, which would tend to eliminate generation of unwanted side echoes.

THE CLATHRATE DEPOSITS

Gas in sediments can take various physical forms, one of which is a clathrate. A clathrate (or gas hydrate) is an icelike crystalline lattice of water molecules in which gas molecules are physically contained under the proper conditions of

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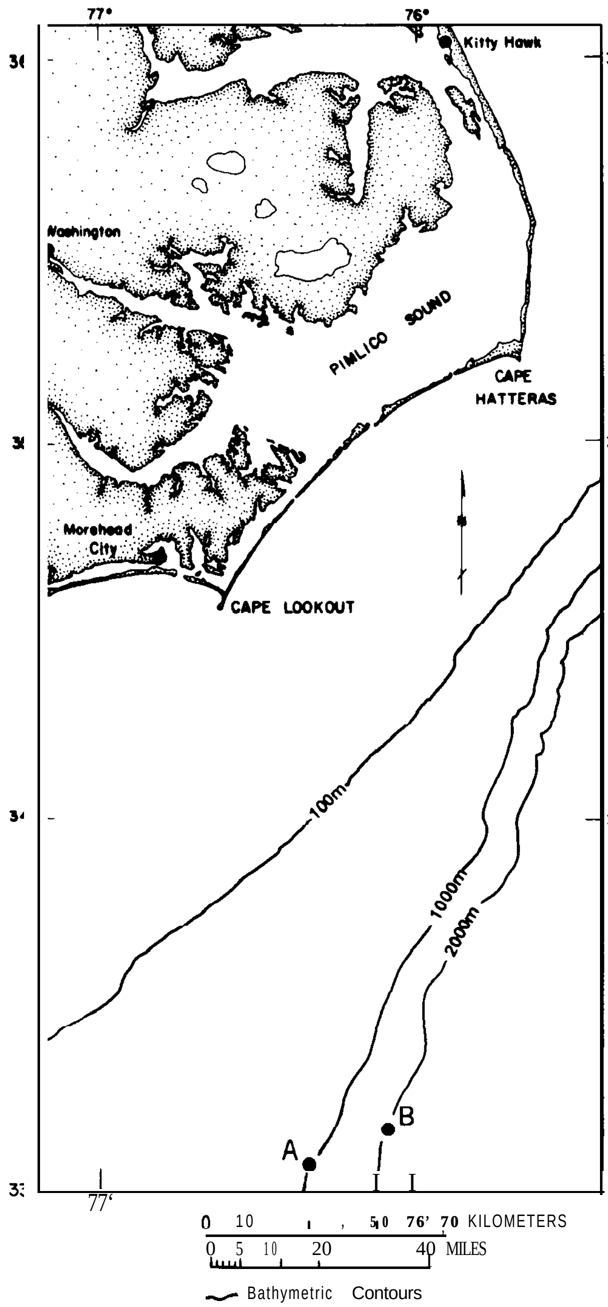


Figure 1. Map showing location of slump/clathrate complexes.

temperature and pressure [3]. Clathrates are rather common constituents of deep water (> 1000 m) sediments. They are detectable on seismic reflection profiles because of the large acoustic impedance contrast (due to a pronounced velocity inversion) at the lower surface. Like any diagenetic horizon, clathrates can cross bedding planes, which further increases the chance of detecting them on reflection data. A sequence of short, high-amplitude, reversely dipping reflectors can be seen in the profiles on the left side of Figure 3 at about 250 ms subbottom under the slump in about 950 m water depth.

Because a clathrate can function as an efficient gas seal [1], these reflectors have been interpreted as bright spots resulting from free gas under the clathrate. Although the clathrate base does not produce a strong reflector in these particular profiles, the bright spots are truncated at a consistent point along their length, and so a line drawn through the up-dip end points of the bright spots (Fig. 2B) roughly parallels the seafloor (as would be expected if the line defined the clathrate base). The bottom simulating reflector (BSR) interpreted as the clathrate base in Figure 3 is remarkably similar to that of Figure 3.

The subbottom depth of the clathrate base shown in Figure 2 is considerably deeper than that shown in Figure 3, which is entirely consistent with the pressure/temperature relations which govern clathrate formation. Using a velocity of 2 km/sec for the clathrate-cemented sediments above the BSR, the seafloor to BSR depth is about 250 m for the clathrate shown in Figure 3 and 480 m for that in Figure 2. The respective water depths are about 950 and 2600 m. These BSR depth/water depths compare favorably to those

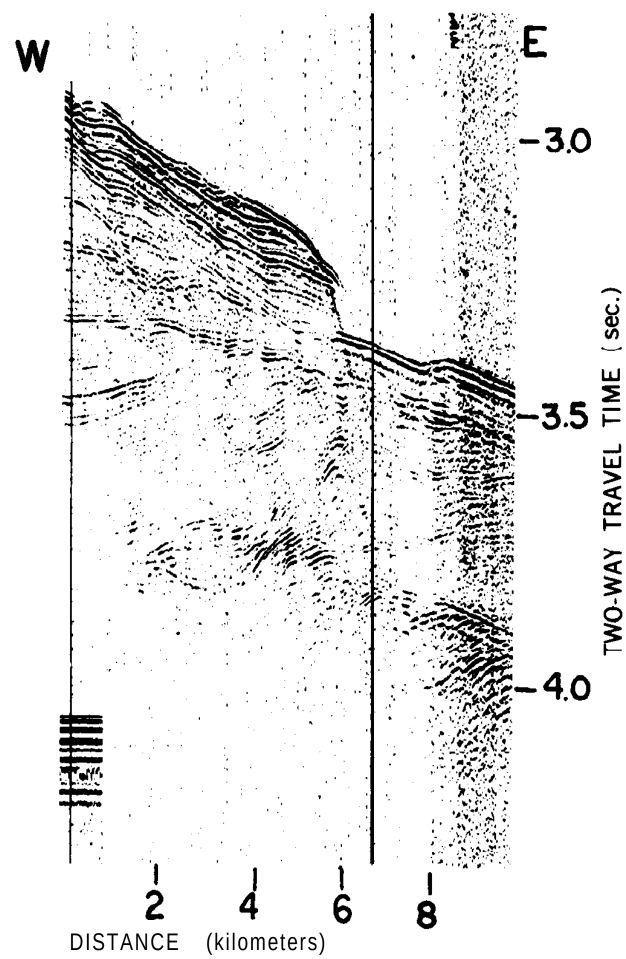
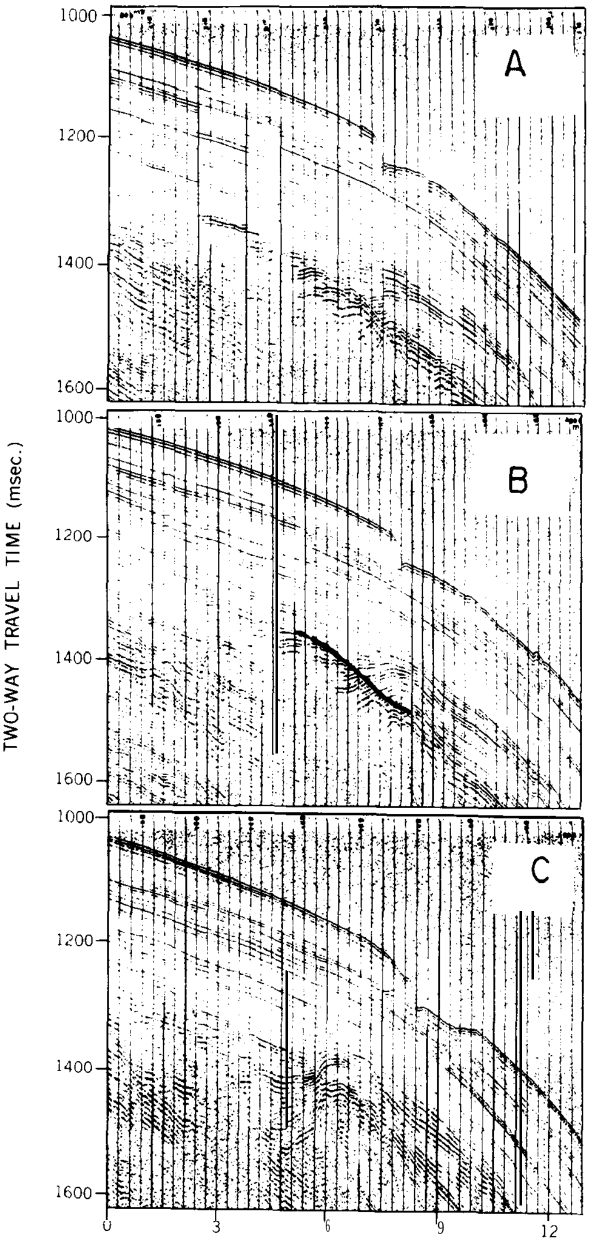


Figure 2. Seismic reflection profile of a suspected slump/clathrate complex (B, Fig. 1). Vertical exaggeration X20.



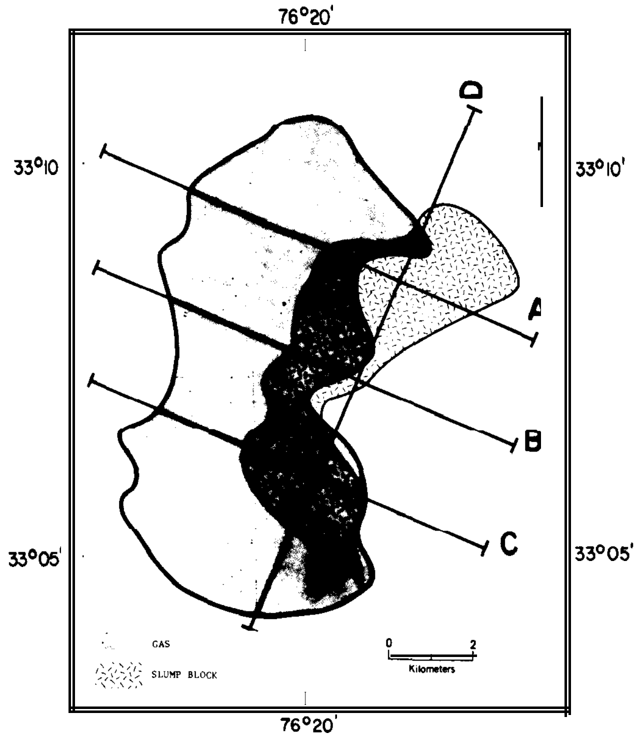


Figure 4. Schematic map drawn from profiles in Figure 2 showing the areal extent of the slump block and clathrate accumulation (A, Fig. 1) on Figure 1. The slump scar (NW edge of the failed block) nearly defines the long axis of the clathrate deposit.

for other areas empirically determined by Shipley and others [4].

DISCUSSION

The two slumps appear to be underlain by clathrates. The superposition suggests a cause-and-effect relationship. Upward migration of gas liberated by clathrate decomposition

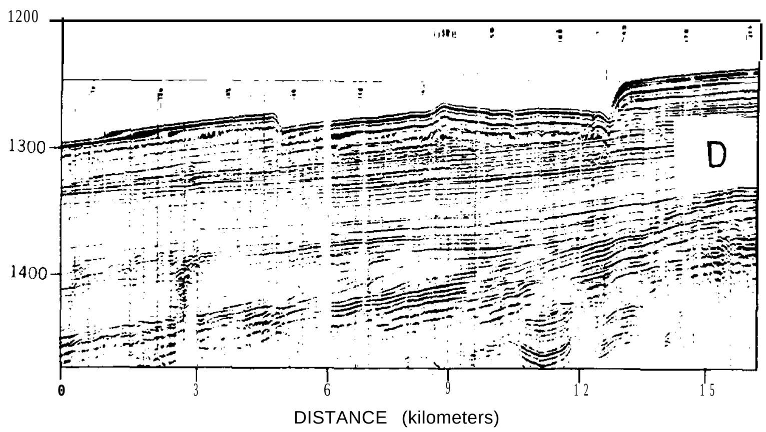


Figure 3. Seismic reflection profiles across a slump/clathrate complex (A, Fig. I). Track coverage is shown on Figure 4. The base of the suspected clathrate has been indicated by the solid line shown on the center dip profile, Vertical exaggeration X15.

may have weakened the overlying unconsolidated sediments to the point of failure, resulting in the slumps shown in Figures 2 and 3.

The precise mechanisms involved in this process are still unclear, but several possibilities suggest themselves. Clathrates contain large quantities of gas per unit volume [1]. The inverse relationship between sediment shear strength and interstitial gas content is well established [5,6] and it seems likely that if gas were freed from the clathrate source the overlying sediments would be significantly weakened. (Upward migration of free gas from a source beneath the clathrate is thought to be unlikely, given the efficiency of clathrates as a seal.)

The precise age of the failures is not known, but there appears to be very little postfailure sediment over the slumps (the limit of resolution of our seismic system is about 10 m). This suggests that the mass movement may have been relatively recent, perhaps Pleistocene. Pleistocene events such as the sea-level change [l] or the post-Pleistocene bottom water temperature increase [about l°C in this area (N. J. Shackleton, pers. comm., 1980)] may have been significant in destabilizing (melting) the clathrate horizon's upper surface. The consequent release of free gas and water may have triggered the failure of marginally stable sediments at some point above the solid (clathrate) zone.

CONCLUSIONS

These data appear to empirically support the prediction of McIver [l] that clathrate decomposition can trigger mass movement of unconsolidated sediments. This process may be involved in some, although certainly not all. instances of relatively recent sediment failure on the continental slope.

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