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ScienceDirect

Russian Geology and Geophysics 59 (2018) 268–275

RUSSIAN GEOLOGY AND GEOPHYSICS

www.elsevier.com/locate/rgg

Seismic stratigraphy of the Upper Quaternary deposits on the northeastern slope of the Ceará Rise (*Central Atlantic*)

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Received 21 December 2016; received in revised form 27 July 2017; accepted 17 August 2017

Abstract

This study is focused on interpretation of ultrahigh-resolution seismoacoustic data from the northeastern slope of the Ceará Rise (Central Atlantic) acquired using the *SES 2000 deep* parametric narrow-beam subbottom profiler during cruise 35 of RV *Akademik Ioffe* in 2011. The geologic nature of most of the detected reflectors is constrained by correlation of the results of seismoacoustic profiling with core data collected in frame of the Ocean Drilling Program (ODP site 929A-E). Detailed seismostratigraphic study of the Upper Quaternary deposits in the study area has implications for better understanding of the role of gravity flows and bottom currents in sedimentation on the NE slope of the rise for the past 1.2 Myr.

Keywords: seismic profiling; contourites; turbidites; bottom currents; reflectors; Ocean Drilling Program

Introduction

Ultrahigh-resolution seismoacoustic profiling was carried out during six cruises of RVs *Akademik Vavilov* and *Akademik Ioffe* (2009–2012) for detailed seismostratigraphic study of Neogene–Quaternary sediments in the Atlantic Ocean. The routes passed through sites of the international Ocean Drilling Program, ODP (Levchenko, 2014; Levchenko and Murdmaa, 2012, 2013; Levchenko et al., 2014; Murdmaa et al., 2012). Seismic profile acquired in cruise 35 of RV *Akademik Ioffe* (2011) crossed through ODP sites 929 and 925 on the slope and top of the Ceará Rise (Levchenko et al., 2014) drilled in 1994 during ODP Leg 154 (RV *JOIDES Resolution*) to study the Cenozoic sedimentation history, including circulation of deep and surface waters, deposition environments, and water chemistry in the Western Atlantic (Curry et al., 1995). In order to demonstrate the feasibility of a paleoceanographic drilling leg in the area a detailed seismic survey was carried out during cruise EW9209 of the RV *Maurice Ewing* in 1992. The seismic studies included 30 Hz single-channel seismic profiling with air guns and 3.5 kHz seismoacoustic survey with the *Atlas Hydrosweep* echosounder (Mountain and Curry, 1995). This work continued the studies that began in the 1970s during Legs 14 and 39 of the Deep Sea Drilling Project, onboard the drilling vessel *Glomar Challenger* (Hayes et al., 1972; Perch-Nielsen et al., 1977).

According to results of predrilling seismic survey the Ceará Rise sediments were divided into three acoustic units (Mountain and Curry, 1995). The shallowest unit, up to 260 ms or 194 m thick, has distinct acoustic stratification with five to eight prolonged and semiprolonged parallel reflectors. Of special interest is a reflector Red (conventional name) distinguishable in almost all profiles at the depth 100–120 ms (70–85 m below the ocean-floor surface). The reflector nearest to the surface at site 929 is at ~45 mbsf. Reflector Blue separates the shallowest unit from the middle one showing a discontinuously hummocky character throughout. Reflector Purple distinguishable at 700 mbsf divides the middle and deepest units. The latter is characterized by lateral continuity of strong internal reflectors that are generally affected by basaltic basement irregularities. Reflector Orange at a depth of 900 mbsf overlies additional sedimentary units infilling local basement lows; in other places, it appears to rest very close to basement; and on local basement peaks it appears to be absent (Mountain and Curry, 1995). Reflectors Purple and Blue presumably mark long hiatuses in the Middle–Late Eocene and in the Late Miocene, respectively, and reflector Red has a Pleistocene age (Mountain and Curry, 1995).

The resolution of the single-channel seismic data is too low for detailed seismostratigraphic study of Upper Quaternary sediments on the Ceará Rise, while the *Atlas Hydrosweep* data

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1068-7971/$ - see front matter © 2018, V.S. Sobolev IGM, Siberian Branch of the RAS. Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.rgg.2018.03.005

(Mountain and Curry, 1995) remain almost unprocessed and unpublished.

This work if focused on correlation between high-resolution seismic and core data from ODP site 929A-E, that was carried out in order to gain insights into the geological nature of the reflectors and study the upper Quaternary stratigraphy of the Ceará Rise.

Geomorphology of the Ceará Rise, sedimentary geology, and deep-water circulation

The Ceará Rise is an N–S aseismic ridge in the western equatorial Atlantic, more than 500 km long and 100 km wide. It is asymmetric in cross section with its slopes in excess of 5.7° and 1.4° along the southwestern and northeastern sides, respectively (Perch-Nielsen et al., 1977). The minimum water depth at the rise is 2600 m, against 4000 m and 4600 m on the Ceará and Para abyssal plains, respectively (Fig. 1*a*). In the west, the rise is bounded by the fan of the Amazon River, the main local source of sediments, which has its mouth 800 km far from the study area.

Sediment thickness over the basaltic basement of the Ceará Rise exceeds 1000 m (Curry et al., 1995). Boreholes drilled in this area recovered alternating layers of clay, calcareous ooze, chalk, and marl of Maastrichtian to Holocene age (Perch-Nielsen et al., 1977). Thickness of Quaternary sediments is about 85–100 m (Bickert et al., 1997).

This study embraces the northeastern slope of the Ceará Rise at water depth range from 4100 to 4600 m. Five boreholes (A to E) were drilled at site 929 at water depths 4355.6–4357.6 m—below the present calcite lysocline level at ~4200 m (Curry and Cullen, 1997). The drilled Quaternary sediments are about 87 m thick and consist of bioturbated clay with variable amount of foraminifera and coccolith that correlate with $CaCO_3$ contents varying from 0 to 60% (Curry and Cullen, 1997). A number of 1–3 cm thick silt layers, showing normal grain size grading in smear-slides studied onboard and probably of turbiditic origin, were revealed in the upper 45 m of the recovered section (Curry et al., 1995). The upper part of the section also contains <0.5 cm thick yellowish-brown iron oxide layers in zones of gradual color change (Curry et al., 1995).

Bottom circulation in this part of the Atlantic is mainly controlled by currents of the Antarctic Bottom Water (AABW) and North Atlantic Deep Water (NADW), with their boundary corresponding to the isosurface of the potential density $\sigma_4 = 45.90$ kg/m^3 and the potential temperature $\theta = 1.8$ °C (Rhein et al., 1995). In the Ceará Rise region, the boundary is at a depth of 4100 m. The colder and heavier AABW underlying the generally southward flowing NADW moves northward and forms a system of cyclonic gyres (Mauritzen et al., 2002). One gyre extended along the Mid-Atlantic Ridge embraces the northern part of the rise (Fig. 1*b*).

The modern velocity of AABW flow is less than 10 cm/s (Hall et al., 1997; Whitehead and Worthington, 1982). How-

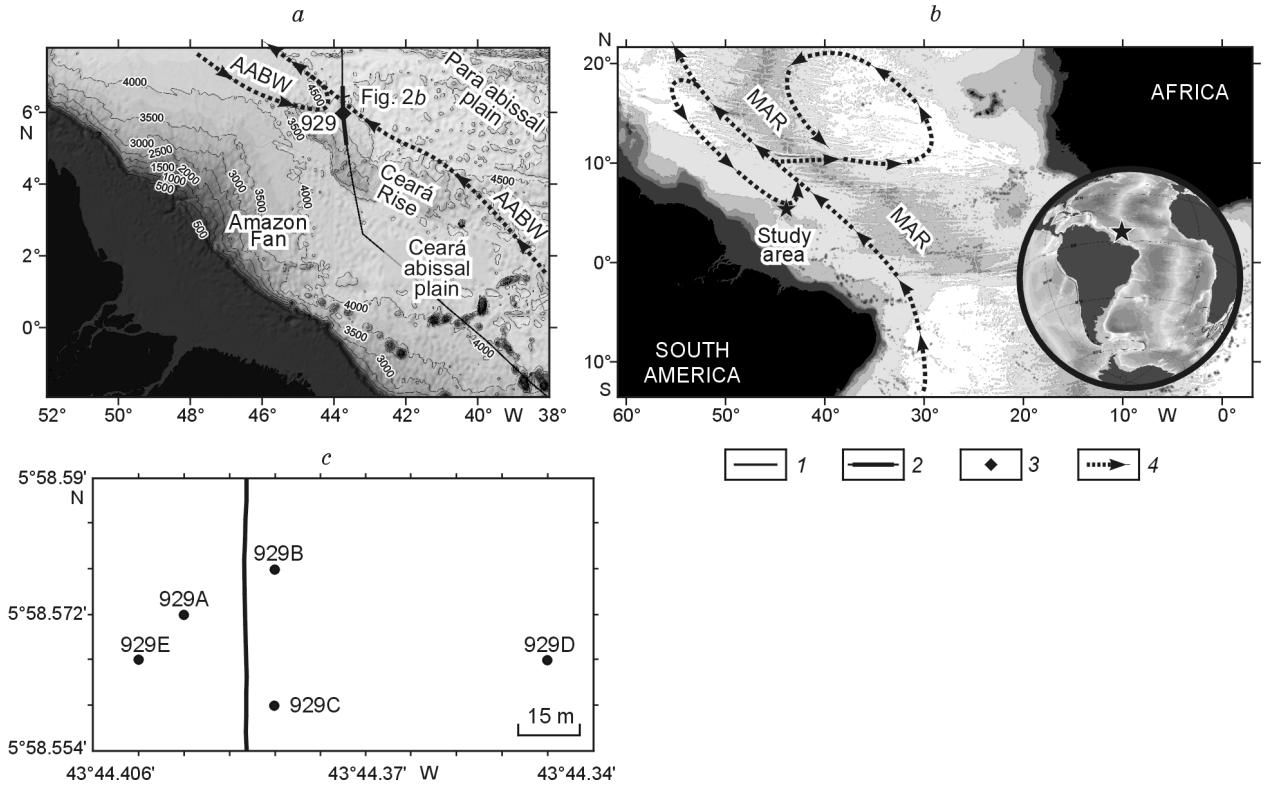

Fig. 1. Bathymetry of the study area (*a*); circulation of the Antactic Bottom Water in the Central Atlantic (*b*); location of ODP site 929A–E (*c*). *1*, ship track of RV *Akademik Ioffe*, cruise 35 (2011); *2*, fragment of *SES 2000 deep* seismic profile discussed in text; *3*, drilling site 929; *4*, AABW flow direction. MAR, Mid-Atlantic Ridge.