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Academic discussion

Review of research in internal-wave and internal-tide deposits of China: Discussion

G. Shanmugam

Department of Earth and Environmental Sciences, The University of Texas at Arlington, Arlington, TX 76019, USA

Abstract This discussion of a review article by Gao *et al.* (2013), published in the *Journal of Palaeogeography* (2(1): 56–65), is aimed at illustrating that interpretations of ten ancient examples in China and one in the central Appalachians (USA) as deep-water deposits of internal waves and internal tides are unsustainable. This critical assessment is based on an in-depth evaluation of oceanographic and sedimentologic data on internal waves and internal tides derived from 332 print and online published works during 1838–January 2013, which include empirical data on the physical characteristics of modern internal waves and internal tides from 51 regions of the world′s oceans (Shanmugam, 2013a). In addition, core and outcrop descriptions of deep-water strata from 35 case studies worldwide carried out by the author during 1974–2011, and a selected number of case studies published by other researchers are evaluated for identifying the sedimentological challenges associated with distinguishing types of bottom-current reworked sands in the ancient sedimentary record. The emerging conclusion is that any interpretation of ancient strata as deposits of internal waves and internal tides is premature.

Key words baroclinic sands, contour currents, deep water, facies models, internal waves, internal tides, pycnoclines, shelf edge

1 Introduction

The topic of internal waves and internal tides is of considerable interest to both oceanographers and sedimentologists worldwide. In this context, the paper by Gao *et al.* (2013) entitled "Review of research in internal-wave and internal-tide deposits of China" is of significance not only for the Chinese readership but also for the international readership. However, their paper suffers from fundamental deficiencies. In pointing out these problems and in advancing the primary mission of the *Journal of Palaeogeography*, which is to promote the communication and cooperation between Chinese and international scholars, I avail this opportunity by offering basic information and explanation.

The article by Gao *et al.* (2013) is the first major review of research on ancient deposits. Therefore, a rigorous scrutiny of the review is imperative. Otherwise, the article will leave an indelible impression that the science of internal waves and internal tides is settled. From an oceanographic viewpoint, it is far from settled (Garrett and Kunze, 2007). From a sedimentological point of view, it is at a crisis stage (Shanmugam, 2008a, 2012a, 2012b, 2013a, 2013b, 2013c, 2013d, 2013e, 2014) in the Thomas Kuhn′s (1996) five stages of scientific revolutions: (1) random observations, (2) first paradigm, (3) crisis, (4) revolution, and (5) normal science.

1.1 Global data sets

Deep-water processes and facies models are full of conflicts (Shanmugam, 2012b). Eventually, all major conflicts

* Corresponding author. E-mail: shanshanmugam@aol.com.
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must be resolved. To this end, the subject of internal waves and internal tides has generated five published debates, including this one, since 2008 (Table 1). Although various sedimentological issues raised in these debates are critical here, Gao *et al.* (2013) have neglected to address them. In particular, a clear understanding of the origin of bottom-current reworked sands (BCRS), which include reworked sands by baroclinic currents (Shanmugam, 2013a), has direct implications for process sedimentology and petroleum geology. In this context, descriptions of deep-water strata from 35 case studies worldwide are considered (Figure 1, Table 1). These global data sets include 7832 meters of conventional cores from 123 wells, representing 32 petroleum fields. Finally, selected modern and ancient case studies of deep-water systems published by other researchers are discussed in illustrating the challenges in distinguishing baroclinic sands (see Section 9). Hopefully, this comprehensive discussion and related reply will motivate others to undertake future research.

1.2 Historical backgrounds

Gao *et al.* (2013) state that "*The study of internal waves has a long history in oceanography which can be traced back to the study of the interfacial wave theory by Stocks in* 1847 (*Munk*, 1981)." But Benjamin Franklin in 1762 was the first one who demonstrated that internal gravity waves on the interface between oil and water have a much longer period than do surface waves with the same wavelength (Phillips, 1974). Early observations of internal waves in nature have been attributed to Russell (1838) and even to earlier Viking times (Ekman, 1904). In the 20th century, the late Dr. John Ralph Apel is considered the "Father" of SEASAT (one of the earliest Earth-observing satellites by NASA) in the use of remote sensing for investigating the physics of internal waves and internal tides (Jackson, 2004).

2 Fundamental concepts

2.1 Baroclinic oceans

The concept of 'Barotropic vs. Baroclinic' is of paramount importance in understanding currents associated with internal waves and internal tides (CIMAS, 2012). This is because these concepts are directly related to developing sedimentological criteria for recognizing ancient deposits. In an oceanographic context, barotropic currents are driven by the slope of the water surface, and these currents are typical of the well-mixed shallower (shelf) part of the ocean (Figure 2). In contrast, baroclinic currents are

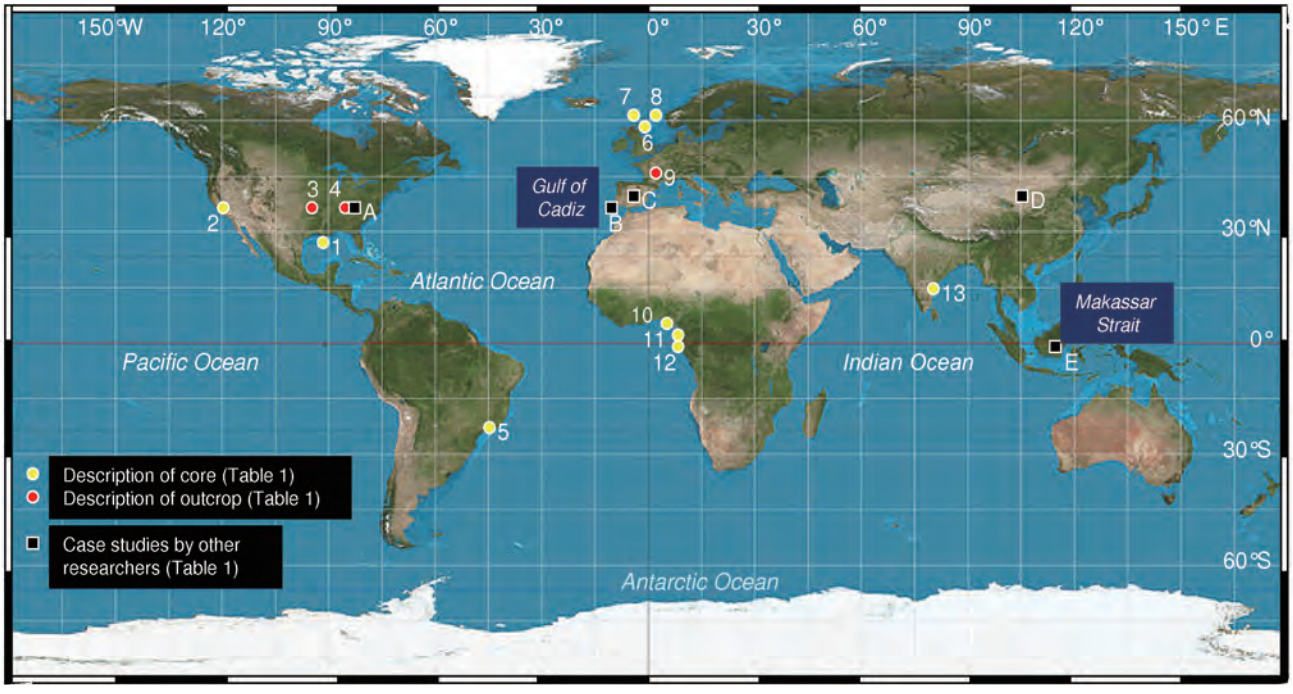

Figure 1 Map showing five case studies (A, B, C, D and E) by other researchers that include the outcrop study of internal-tide deposits in the central Appalachians by Gao and Eriksson (1991). Note locations of case studies of deep-water sandstones by the author. See Table 1 for details of core and outcrop descriptions. Blank world map credit: http://upload.wikimedia.org/wikipedia/commons/8/83/Equirectangular_projection_SW.jpg (accessed April 30, 2014).