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Variability in Cenozoic sedimentation and paleo-water depths of the Weddell Sea basin related to pre-glacial and glacial conditions of Antarctica

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ABSTRACT

The Weddell Sea basin is of particular significance for understanding climate processes, including the generation of ocean water masses and their influence on ocean circulation as well as the dynamics of the Antarctic ice sheets. The sedimentary record, preserved below the basin floor, serves as an archive of the pre-glacial to glacial development of these processes, which were accompanied by tectonic processes in its early glacial phase. Three multichannel seismic reflection transects, in total nearly 5000 km long, are used to interpret horizons and define a seismostratigraphic model for the basin. We expand this initial stratigraphic model to the greater Weddell Sea region through a network of more than 200 additional seismic lines. Information from few boreholes is used to constrain sediment ages in this stratigraphy, supported by magnetic anomalies indicating decreasing oceanic basement ages from southeast to northwest. Using these constraints, we calculate grids to depict the depths, thicknesses and sedimentation rates of pre-glacial (145–34 Ma), transitional (34–15 Ma) and full-glacial (15 Ma to present) units. These grids allow us to compare the sedimentary regimes of the pre-glacially dominated and glacially dominated stages of Weddell Sea history. The pre-glacial deposition with thicknesses of up to 5 km was controlled by the tectonic evolution and sea-floor spreading history interacting with terrigenous sediment supply. The transitional unit shows a relatively high sedimentation rate and has thicknesses of up to 3 km, which may attribute to an early formation of the East Antarctic Ice Sheet, which was partly advanced to the coast or even inner shelf. The main deposition center of the full-glacial unit lies in front of the Filchner-Ronne Ice Shelf and has sedimentation rates of up to 140–200 m/Myr, which infers that ice sheets grounded on the middle to the outer shelf and that bottom-water currents strongly impacted the sedimentation. We further calculate paleobathymetric grids at 15 Ma, 34 Ma, and 120 Ma by using a backstripping technique. Our results provide constraints for an improved understanding of the paleo-ice sheet dynamics and paleoclimate conditions of the Weddell Sea region.

1. Introduction

The breakup of Gondwana and the subsequent opening of the Southern Ocean basins coincided with changes in global ocean circulation and climatic conditions (Jokat et al., 2003) and first-order changes in water mass distribution and marine sedimentation pattern (Brown et al., 2006). Changes in the widths and depths of oceanic gateways and in regional bathymetry influenced ocean current transport and overturning circulation. At present, the Weddell Sea Embayment, at the very southern part of the Atlantic sector of the Southern Ocean, is of particular significance for the generation of deep and bottom-water masses (Orsi et al., 1999; Foldvik et al., 2004). The clockwise rotating Weddell Gyre is responsible for the exchange and mixing of Antarctic Deep Water with the global circulation system as well as for the transport of Antarctic ice to the Atlantic Ocean through the so-called iceberg alley (Anderson and Andrews, 1999).

Various studies have shown that sedimentary processes in the Weddell Sea basin were strongly influenced by ice sheet dynamics and by ocean circulation (e.g., Jokat et al., 1996; Rogenhagen and Jokat, 2000). At its southern margins, repeated ice advances and retreats sculpted the landscape of the continental shelf and transported sediments to the continental slope and rise (Anderson, 1999). Farther offshore, ocean-current related sedimentation transport processes have produced extensive contourite channel-levee deposits (Weber et al., 1994; Michels et al., 2002). Previous seismostratigraphic studies of the Weddell Sea focused mostly on local scales. Miller et al. (1990) proposed a seismostratigraphic model for the eastern margin of the Weddell Sea. They introduced seven horizons (Fig. 2C). A large hiatus was found at Ocean Drilling Project (ODP) site 693 at the Eocene–Oligocene boundary.

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Kuvaas and Kristoffersen (1991) studied the Crary Fan and its channel-levee complex in the southern Weddell Sea. Maldonado et al. (2003, 2005) worked on contourite drifts that result from the interaction of the ACC and Weddell Gyre in the northwestern Weddell Sea. Rogenhagen et al. (2004) improved and expanded Miller et al.'s (1990) study area to the southeastern Weddell Sea by adding new seismic data and calculated sediment thicknesses. Anderson and Wellner (2011) focused on the James Ross Basin and Joinville Plateau in the northwestern Weddell Sea and provided constraints on the ice sheet evolution of the eastern margin of the Antarctic Peninsula based on seismic profiles and shallow boreholes (SHALDRIL). Lindeque et al. (2013) interpreted a long northwest–southeast seismic transect across the southern Scotia Sea and Weddell Sea (Fig. 1, transect B) and proposed a modified seismic horizon stratigraphy based on it.

In this study, we analyze all existing seismic profiles of the Weddell Sea region and attempt to synthesize a unified stratigraphic model by integrating previously published local models with modifications in some cases. We calculate sediment depth, isopach and sedimentation rate grids for the entire basin from pre-glacial to full glacial times. Sediment thicknesses and volumes are estimated from basin-wide seismic horizon correlations using drill sites for stratigraphic control. We applied a backstripping method in order to analyze the subsidence history and paleobathymetry. The gridded maps are then used to discuss sediment transport and deposition processes corresponding to terrigenous sediment supply, as well as past ice sheet dynamics and ocean circulation of the Weddell Sea basin.

2. Regional setting and antarctic glacial history

The Weddell Sea basin experienced more than 180 million years of tectonic, paleoceanographic and paleoclimate history, spanning from its rifting as part of Mesozoic Gondwana break-up to the present (Dalziel and Grunow, 1992; Dalziel, 2007; König and Jokat, 2010). It is bounded to the east by the high-elevation Dronning Maud Land and the East Antarctic Ice Sheet (EAIS), to the west by the mountainous Antarctic Peninsula and its ice sheet (APIS), and to the south by the vast Filchner-Ronne Ice Shelf, which is fed by large ice-streams from both the EAIS and the West Antarctic Ice Sheet (WAIS) (Fig. 1).

Antarctica's glacial history has been investigated using seismic and coring/drill records of marine sediments, glaciomorphological studies, ice cores, and numerical models of paleoclimate and ice sheet dynamics (e.g., Naish et al., 2001; Zachos et al., 2001; DeConto and Pollard, 2003a,

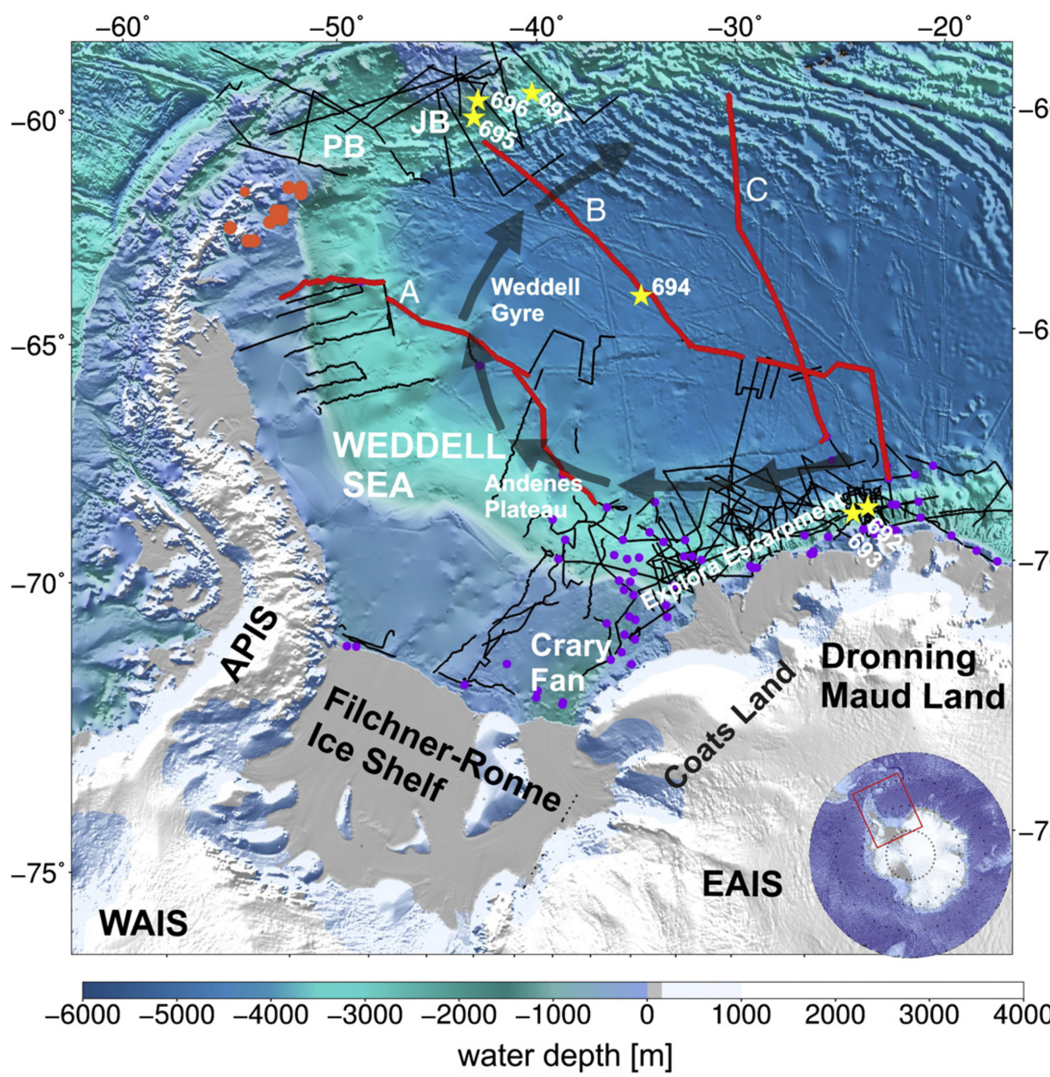

Fig. 1. General overview of the Weddell Sea basin with the network of seismic profiles from the Antarctic Seismic Data Library System (SDLS) and three long transects (thick red lines, marked A, B, C) initially used and described in the text. Background image: global seafloor topography grid (Arndt et al., 2013) merged with ETPO1 Global Relief Model (Amante and Eakins, 2009). APIS: Antarctica Peninsula; WAIS: West Antarctic Ice Sheet; EAIS: East Antarctic Ice Sheet; DML: Dronning Maud Land. Three red thick lines are the long transects, black lines are other multichannel seismic reflection data; yellow stars = ODP Leg 113 boreholes; orange circles = SHALDRIL boreholes. Purple circles are the locations of refraction seismic experiments of various expeditions, which were used in setting up the velocity model of the region.