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Gas hydrate within the Winona Basin, offshore western Canada

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ABSTRACT

In western Canada gas hydrates have been thought to exist primarily in the Cascadia accretionary prism off southern Vancouver Island, British Columbia (BC). We present evidence for the existence of gas hydrate in folds and ridges of the Winona Basin up to 40 km seaward from the foot of the continental slope off northern Vancouver Island. The occurrence of a bottom-simulating reflector (BSR) observed in a number of vintage seismic reflection profiles is strongly correlated to faulted, and folded sedimentary ridges and buried folds. The observed tectonic structures of the Winona Basin are within the rapidly evolving Juan de Fuca – Cascadia – Queen Charlotte triple junction off BC. Re-processing of multi-channel data imaged mildly to strongly deformed sediments; the BSR is confined to sediments with stronger deformation. Changes in the amplitude character of sediment-reflections above and below the depth of the base of gas hydrate stability zone were also used as an indicator for the presence of gas hydrate. Additionally, regional amplitude and frequency reduction below some strong BSR occurrences may indicate free gas accumulations. Gas hydrate formation in the Winona Basin appears strongly constrained to folds and ridges and thus correlated to deeper-routed fluid-advection regimes. Methane production from in situ microbial activities as a source of gas to form gas hydrates, as proposed to be a major contributor for gas hydrates within the accretionary prism to the south, appears to be insufficient to produce the widespread gas hydrate occurrences in the Winona Basin. Potential reasons for the lack of sufficient in situ gas production may be that sedimentation rates are 5–100 times higher than those in the accretionary prism so that available organic carbon moves too quickly through the gas hydrate stability field. The confinement of BSRs to ridges and folds within the Winona Basin results in an areal extent of gas hydrate occurrences that is a factor of five less than what is expected from regional gas hydrate stability field mapping using water-depth (pressure) as the only controlling factor only.

1. Introduction

Gas hydrates off southern Vancouver Island in the accretionary prism of the Cascadia subduction zone occur typically below water depths of ~600 m and have been studied intensively over the past 25 years. Geophysical studies conducted in the Winona Basin, and the Juan de Fuca – Cascadia – Queen Charlotte triple junction north of the accretionary prism focused on the tectonic features associated with the switch from subduction in the south to transform faulting in the north (Fig. 1). Until now, no studies were conducted in this northern region that focussed on gas hydrates and fluid flow.

Geographically, most investigations of gas hydrates at the northern Cascadia margin have focused on an area west of Barkley Sound, around the Integrated Ocean Drilling Program (IODP) Expedition 311 transect that extends from the deformation front landward across the accretionary prism (e.g. Riedel et al., 2006a,b). Seismic data collected across the margin of southern Vancouver Island have been used to map the bottom-simulating reflector (BSR), which indicates the base of gas hydrate stability (e.g. Hyndman and Davis, 1992). The interpreted regional extent of gas hydrates off Canada's west coast is mainly based on a few multi-channel seismic (MCS) lines collected in 1989 as part of the Ocean Drilling Program (ODP) Leg 146 pre-site surveys (Hyndman et al., 2001). Two deep drilling expeditions were conducted to investigate the gas hydrate occurrence on the Cascadia margin. ODP Leg 146 established three sites in 1992 (Westbrook et al., 1994): Site 888 in the deep abyssal plain, and Sites 889/890 about mid-slope over a strong BSR. In 2005, a more complete coring, and logging program was conducted as part of the IODP Expedition 311 (Riedel et al., 2006a). A transect of five drill/core sites was established spanning the accretionary prism from the occurrence of gas hydrate close to the deformation front to the eastward limit of gas hydrate occurrence in shallower waters.

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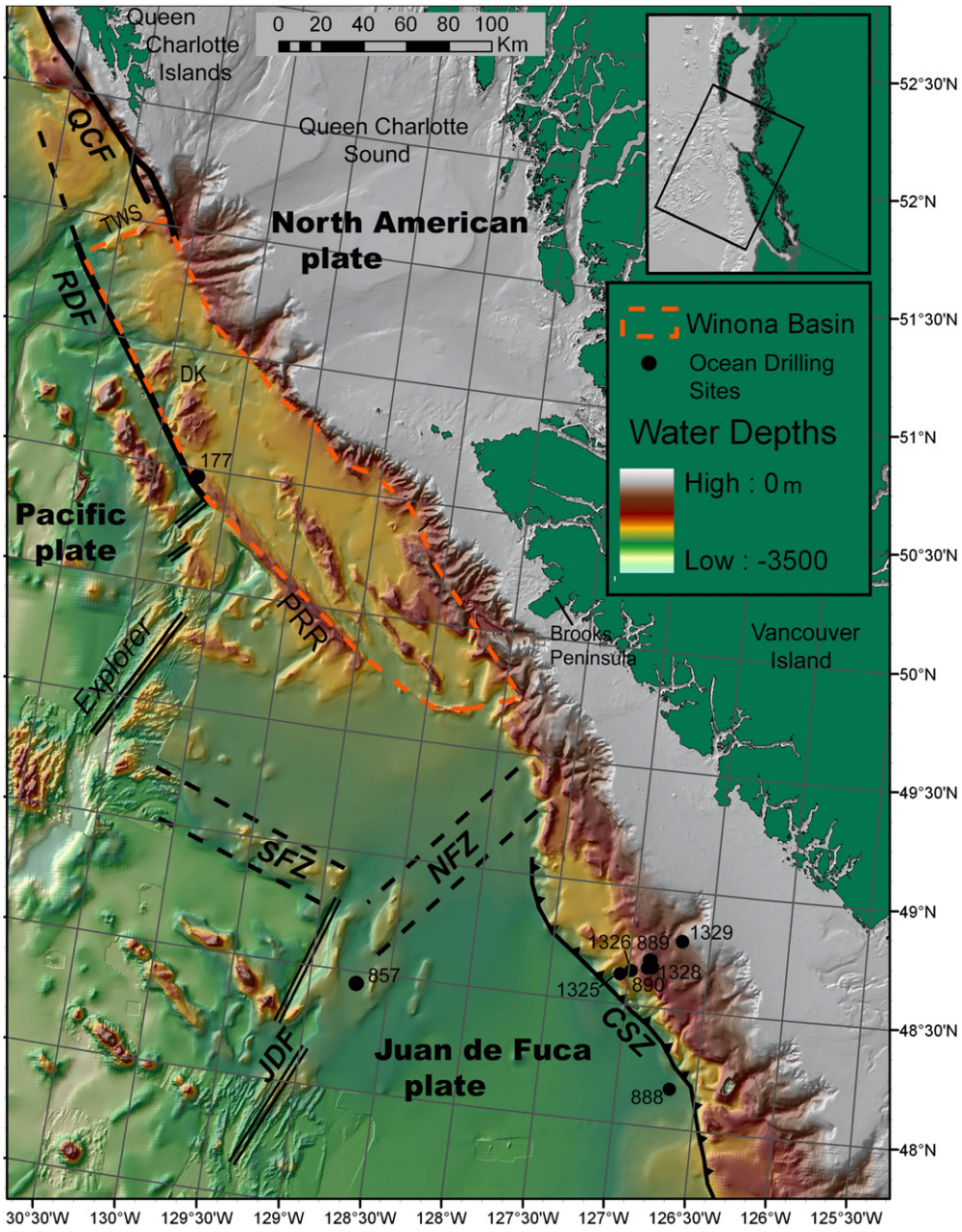

Figure 1. Regional map of Pacific – North America – Juan de Fuca triple junction. The Winona Basin extends south from the Tuzo Wilson Seamounts (TWS) ending just offshore Brooks Peninsula. This peninsula is thought to define the northernmost extent of a subducted plate under Vancouver Island and of present day subduction tectonics. South of the Nootka fault zone (NFZ) sediments have been pushed into an accretionary prism above the Cascadia subduction zone (CSZ). Regional faults from north to south include: Queen Charlotte fault (QCF), Revere-Dellwood fault (RDF), and Sovanco fault zone (SFZ). Spreading centers are the Explorer and Juan de Fuca (JDF) ridges. Volcanic edifices within the basin are the Dellwood Knolls (DK) which appear to have been faulted apart (Rohr and Furlong, 1995).

The surveys and studies conducted prior to IODP Expedition 311 and the evidence for the presence and content of gas hydrate are summarized in several review articles (e.g. Hyndman et al., 2001; Spence et al., 2000; Riedel et al., 2009). Extensive geophysical site-survey data exist along this transect of the Cascadia margin, including (a) conventional MCS reflection data (Hyndman et al., 1994; Hyndman, 1995) with associated analyses (Yuan et al., 1994, 1996, 1999), (b) high-resolution MCS, single-channel seismic (SCS), and pseudo 3-D seismic surveys (Riedel et al., 2002; Scherwath et al., 2006; Riedel, 2007; Fink and Spence, 1999), (c) ocean-bottom seismic (OBS) surveys (e.g. Hobro et al., 2005; López, 2008; Dash et al., 2009), and (d) deep-tow high-resolution MCS surveys (e.g. Gettrust et al., 1999; Chapman et al., 2002; He et al., 2009). Heat-flow studies (Davis and Hyndman, 1989; Davis et al., 1990; Ganguly et al., 2000; Riedel et al., 2006c, 2010; He et al., 2007) were used to calibrate the base of gas hydrate stability zone (GHSZ) together with the extensive data from ODP and IODP downhole temperature measurements (e.g. Riedel et al., 2010).

Theories of formation of gas hydrates on Canada's west coast based on these extensive studies mentioned above focussed on the role of fluid flow and accompanying gas migration either along faults of the accretionary prism or pervasively from prism sediment thickening and overall deformation (e.g. Hyndman and Davis, 1992). New data from IODP Expedition 311 showed in contrast that the average concentrations of gas hydrate seen along the drilling transect can almost entirely be formed through in situ microbial methane production (e.g. Malinverno, 2010) without the need for advection of gas from below. Across most of the accretionary prism a BSR is