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Seafloor fluid seeps on Kimki Ridge, offshore southern California: Links to active strike-slip faulting

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ABSTRACT

The Kimki Ridge fluid seeps are located in western Catalina Basin about 60 km southwest of the southern California mainland and at a water depth of approximately 1100 m. Multichannel seismic reflection profiles collected by the U.S. Geological Survey (USGS) in 2014 show acoustic transparency within the Kimki Ridge, suggesting the possibility of fluid seeps and possible sub-seafloor fluid pathways. Subsequent multibeam bathymetric and backscatter intensity data collected during a cooperative University of Washington/USGS cruise in early 2016 show subtle seafloor buildups with high acoustic backscatter (reflectivity) in three places along Kimki Ridge, supporting the existence of fluid seepage. A Remotely Operated Vehicle (ROV) dive, conducted as part of the *Nautilus* Exploration Program, took place in August 2016 to confirm the presence of these previously unknown seeps and document their characteristics as well as those of any associated biological communities. Two of the three seeps were explored by ROV, and showed abundant evidence of fluid seepage, including characteristic algal mats, chemosynthetic clams, and authigenic carbonate formation. The seeps are comprised of carbonate buildups 1–3 m thick and 300–500 m across. Within these areas, we interpret broad crater-like depressions 30–50 m across and 1–2 m deep to be individual seep vents. The seep areas appear to be broad zones of diffuse seepage that support chemosynthetic biologic communities; however, active venting was not observed. Geochemical analyses of rock samples collected from the seeps indicate microbially driven anaerobic oxidation of methane at or near the sediment water interface. Seismic-reflection profiles show chimney-like fluid pathways along the limbs and in the axis of the fold forming Kimki Ridge, and evidence of methane in shallow sediments can be traced into the adjacent Catalina Basin. A system of closely spaced faults located at the axis of the Kimki Ridge anticline may serve as pathways to allow fluid flow to the seafloor. Our data are consistent with other studies that suggest that transpression is an important component in the formation and localization of fluid seeps in a strike-slip setting, implying that seep formation may be a common occurrence at fault stepovers or transpressional bends in strike-slip systems.

1. Introduction

Methanogenic fluid seeps in basins along active margins are increasingly recognized as important nutrient sources for chemosynthetic ecosystems (Judd and Hovland, 2007; Grupe et al., 2015), especially in isolated offshore basins such as those of the California Inner Continental Borderland (ICB) (Fig. 1). Until recently, seafloor fluid seeps were rarely observed in the California ICB (e.g., San Clemente Basin (Lonsdale, 1979; Torres et al., 2002) and Santa Monica Basin (Hein et al., 2006; Paull et al., 2008)). Newly discovered seeps offshore Palos Verdes and Point Dume, near Redondo Knoll (Levin et al., 2015), in San Diego Trough (Maloney et al., 2015), and now Kimki Ridge, however, show that seafloor fluid seeps are not unusual occurrences in the ICB and may even typify certain geologic environments (Maloney et al., 2015).

The possibility of seafloor fluid flow in Catalina Basin along the western ICB (Fig. 1) was first suggested by Ford and Normark (1980), who noted anomalous sub-bottom reflections along the informally named "Kimki Ridge" during seismic reflection studies of active faulting along the northern part of the San Clemente fault. Kimki Ridge is located in the northwestern Catalina Basin along the San Clemente fault system (Fig. 1). Catalina Basin is a part of the larger offshore California ICB, extending offshore as far as ~ 100 km between the California cities of Ventura and San Diego. Catalina Basin is located along the western

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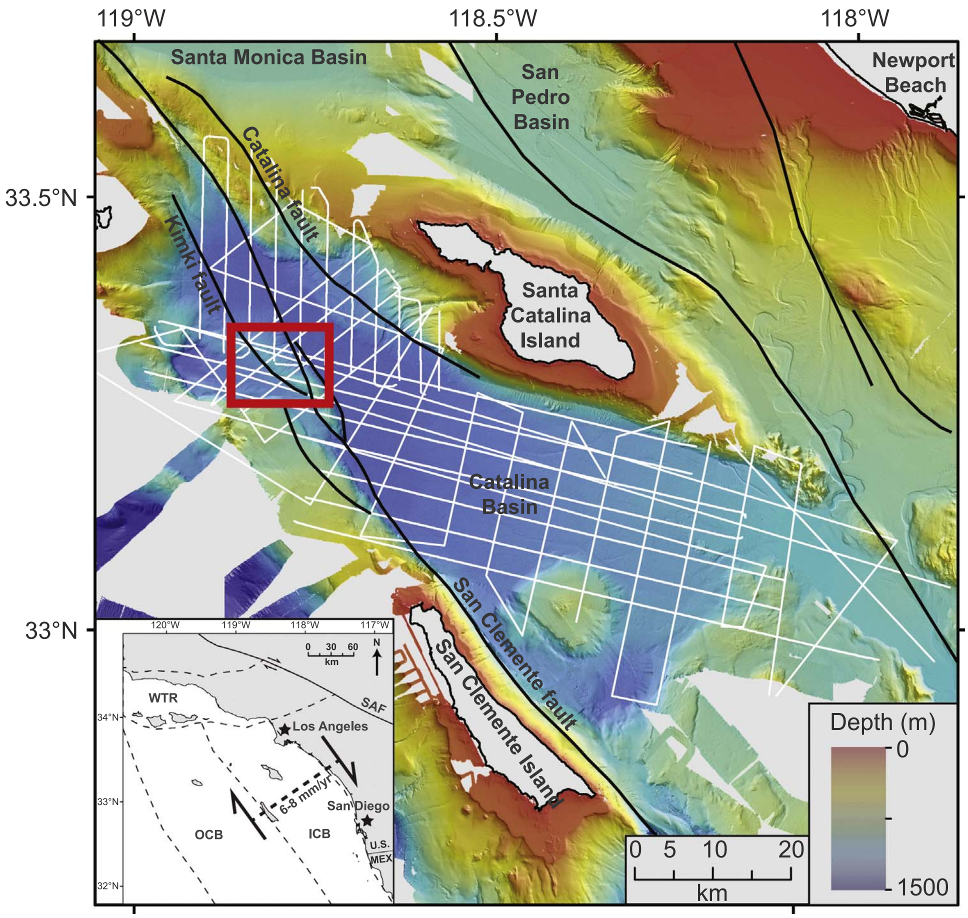

Fig. 1. Shaded-relief bathymetry of Catalina Basin and surrounding area, offshore southern California, color showing depth. Faults shown in black, white lines are seismic reflection profiles. Location of the Kimki Ridge study area (Fig. 2) shown by red box. Inset shows southern California tectonic setting, including slip vectors showing relative motion across the Inner Continental Borderland (black arrows). ICB = Inner Continental Borderland; OCB = Outer Continental Borderland; WTR = Western Transverse Ranges; SAF = San Andreas fault. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

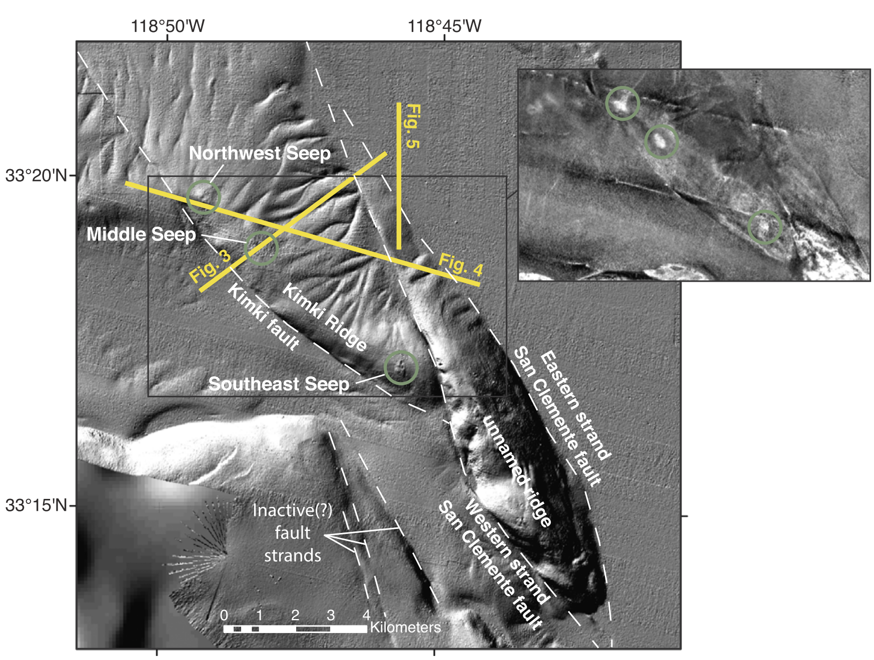

Fig. 2. Shaded relief bathymetry of the western part of Catalina Basin showing the location of fluid seeps along Kimki Ridge (green circles) and seismic reflection profiles (yellow). Faults shown as dashed white lines. Inset shows acoustic backscatter, brighter shades are higher intensities. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

edge of the central ICB, with Catalina Island to the northeast, San Clemente Island to the southwest, and Santa Barbara Island to the northwest. The ICB region was originally formed due to extension in the wake of the clockwise rotation of the Western Transverse Ranges, now located to the north of the ICB (Crouch and Suppe, 1993; Nicholson et al., 1994; Bohannon and Geist, 1998; ten Brink et al., 2000). Today, the ICB sits along the Pacific/North America plate boundary within a broad shear zone associated with the San Andreas right-lateral strike-slip system. Tectonically, the ICB region is structurally complex, and has undergone transtension, transpression, and strike-slip – sometimes simultaneously – since the Miocene (Bohannon et al., 2004; Legg et al., 2007; Fisher et al., 2009a, 2009b).

The San Clemente and Catalina fault zones (and islands of the same names) define Catalina Basin's topography and modern tectonic