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OPEN-FILE REPORT O-89-07

STUDIES OF HYDROTHERMAL EFFLUENTS ON THE GORDA RIDGE

by

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Final Report for Contract No. 63-630-8602

Submitted to:

Oregon Department of Geology and Mineral Industries

and the

Gorda Ridge Technical Task Force

Released March 1989

NOTICE

This report is based on results of a research program directed by the joint federal-state Gorda Ridge Technical Task Force, managed by the Oregon Department of Geology and Mineral Industries, and funded by the Minerals Management Service, U.S. Department of the Interior, through Cooperative Agreement. Opinions expressed are those of the author and do not constitute endorsement by the sponsoring agencies or the Task Force.

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CONTENTS

ILLUSTRATIONS

INTRODUCTION

This research was carried out as part of the overall study of hydrothermal processes on the Gorda Ridge supported the U.S. Minerals Management Service through the State of Oregon Department of Geology and Mineral Industries. This specific contract supported research designed to sample, trace the origin of, and evaluate the magnitude of active hydrothermal effluents on the Gorda Ridge identified by our program in 1985 (Collier et al., 1986, Baker et al, 1987). A major goal of this work was to provide the best possible estimate of the location of active venting in order to prepare targets for submersible dives to be carried out later in the summer (1986) using the U.S. Navy's DSV *Sea Cliff*. The primary activities of this project were:

1) Final data processing for navigation and CTD data sets collected during WECOMA cruise W8508AA was completed with integration of other available data sets to develop survey sites and dive targets for the NOAA and submersible cruises.

2) Participate in a cruise on the NOAA Ship Discoverer to site "GR14" in June, 1986. During this cruise, R. Collier assisted in the direction of the hydrographic sampling program and carried out shipboard manganese determinations with the assistance of S. Holbrook.

3) Develop sampling equipment and strategies for use on the DSV Sea Cliff during the hydrothermal dive program in August. Equipment included a Neal Brown CTD mounted on the submersible's sail and the water samplers to be deployed on the submersible's forward equipment basket.

Beyond these specific activities, R. Collier served as the OSU representative on the Task Force-appointed Dive Planning Committee. In this capacity, he contributed to numerous technical and scientific planning activities in Oregon and San Diego and assisted in overall organizational operations at OSU. During this program he was also certified as "equipment operator" on board the DSV *Sea Cliff*.

BACKGROUND

Hydrothermal circulation has a profound effect on the chemistry of seawater which can be seen on scales ranging from the global oceans (Clarke et al., 1969; Edmond et al., 1979) to the individual orifices of the dramatic "black smoker" high-temperature vents (Spiess et al., 1980). The input of heat and chemicals to the seafloor may have long-range effects on marine sediments (Dymond et al, 1973; Lyle et al., 1987), on marine biological communities (Grassle, 1986; Cowen et al., 1986) and on the abyssal circulation near the major ridge axes (Stommel, 1982). These hydrothermal "fingerprints" are also powerful prospecting tools for the location of active seafloor vents. This report discusses the application of these tools towards the demonstration of active venting on the Northern Gorda Ridge.

The Gorda Ridge is the only spreading center in the Pacific exhibiting slow spreading physiography, with an axial valley approximately 700 meters deep. The tectonics and regional geology of the ridge are discussed by Riddihough (1980), Clague et al. (1984), and Malahoff (1984). While the southern ridge segment, the sediment-filled Escanaba Trough, has been the focus of studies on sediment-hosted sulfide mineralization, the northern ridge has been surveyed primarily for active venting analogous to that recently found on the Mid-Atlantic Ridge (Rona et al, 1986). Previous to the Task Force supported surveys discussed below, the only evidence of hydrothermal activity on the northern ridge segment came from samples of altered basalt and hydrothermal precipitates dredged by the U.S. Geological Survey (Clague et al., 1984).

The ridge lies beneath the main body of the California Current (Hickey, 1986) and the southward-flowing surface waters in the region are largely subarctic in character. A plume of low-salinity water from the Columbia River occasionally extends this far offshore. Very little is known about the abyssal circulation in this region and current meter measurements are essentially non-existent. The northern ridge axis is an extremely deep canyon with relatively limited isopycnal exchange routes open to the north and south. Within this environment, currents are most probably tidally dominated with exhibit strong topographic control.

Most of the data discussed in this report were collected during three field expeditions in 1985 and 1986 (see Figure 1). The first expedition, an 18-day cruise on the National Oceanic and Atmospheric Administration (NOAA) ship *Surveyor* during May 1985, was part of the NOAA VENTS program and was designed to determine if hydrothermal venting was presently occurring anywhere along the central ridge axis. This program resulted in the first clear evidence of active venting in at least two locations on the northern-most segment of the Gorda Ridge (Baker et al, 1987). These locations were centered on the east wall of the axial valley at the "narrowgate" section (station #GR14) and near the ridge's intersection with the Blanco Fracture Zone (station #GR15).

A second follow-up cruise was organized by the Gorda Ridge Technical Task Force on the R/V *Wecoma* (cruise W8508AA) for 7 days in August, 1985. During this expedition, the hydrothermal plumes at GR14 and GR15 were relocated and extensively sampled (Collier et al, 1986). The precise location of the vents producing the plumes was not determined. Later in 1986, dredge samples were recovered at GR14 from the U.S.G.S. Ship *S.P. Lee* which carried hydrothermally altered alumina-rich clays and boehmite (Howard and Fisk, 1988).

RESULTS

Final Processing of Data from W8508AA. The Task Force-supported cruise W8508AA took place in August, 1985 as a follow-up to the NOAA cruise on the ship *Surveyor* which originally demonstrated the active venting (Baker et al, 1987). Distinct temperature anomalies (≈ 30 millideg. C) and suspended particle "plumes" were found at both locations during the two separate expeditions in 1985. These plumes had stabilized at depths between 2450 m. and 2900 m. and were separated from the bottom by at least 200 meters. Detailed sections through the plume at GR14 demonstrated dimensions of at least 2 km (east-west) and 2-4 km (north-south), centered over the east wall of the axial valley. The plumes at GR14 and GR15 were not physically connected along the ridge axis. Chemical anomalies in the plumes included high concentrations of dissolved manganese, helium-3, radon-222, and iron-rich hydrothermal precipitates. The composition and hydrography of the plumes suggest that they originated from high-temperature vents.

The CTD's collected during W8508AA were towed in a vertical zig-zag fashion ("tow-yo") through the plumes. The CTD was repeatedly raised and lowered above the bottom while towing the instrument at a speed of 1 knot. The spatial extent of the plume at GR14 can be seen by comparing the intersecting vertical sections of temperature anomaly developed from CTD2 and CTD11 (locations in Figure 1). The plume, when sampled by CTD2 along an east-west survey line, was located high in the east wall and had two maxima centered at 2400 and 2600 meters depth (Figure 2a). When the site was reoccupied 5 days later with CTD11 (Figure 2b), the plume was basically in the same geographic location but was nearly 100 meters shallower in depth. The overall dimension of the plume was estimated to be 2 km wide (east-west) and 2-4 km long (north-south). The plume at GR15 was not well-sampled on the *Wecoma* cruise although chemical anomalies were as large for this northern plume as they were for GR14 during the earlier *Surveyor* cruise. Cross-axis CTD sections (Figure 1) demonstrated that the two hydrothermal plumes were

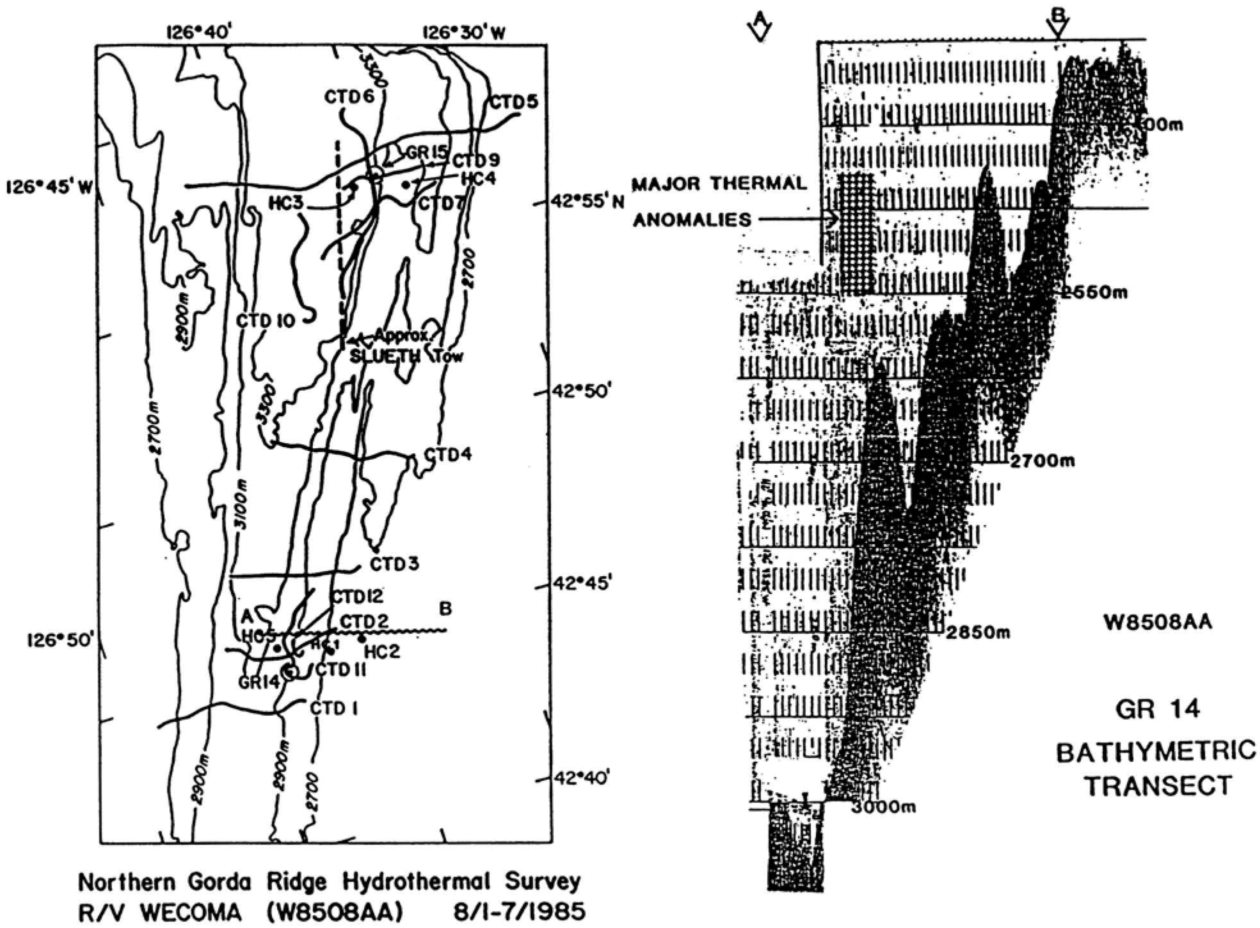

FIGURE 1. Bathymetric map (left) reproduced from seabeam data including stations occupied on the N. Gorda Ridge during 1985 and 1986 (Baker et al., 1987; Collier et al., 1986). Solid lines are the tracks of "tow-yo'd" CTD casts. Data from CTD 11, starting near station GR14, is shown later in section (looking east) in Fig. 4. A 12 kHz bathymetric record (right) was run from the axis moving east. The track of this record is represented on the map by the line A~~B. The approximate location of the major thermal anomalies shown in Figure 2 is noted on the record.

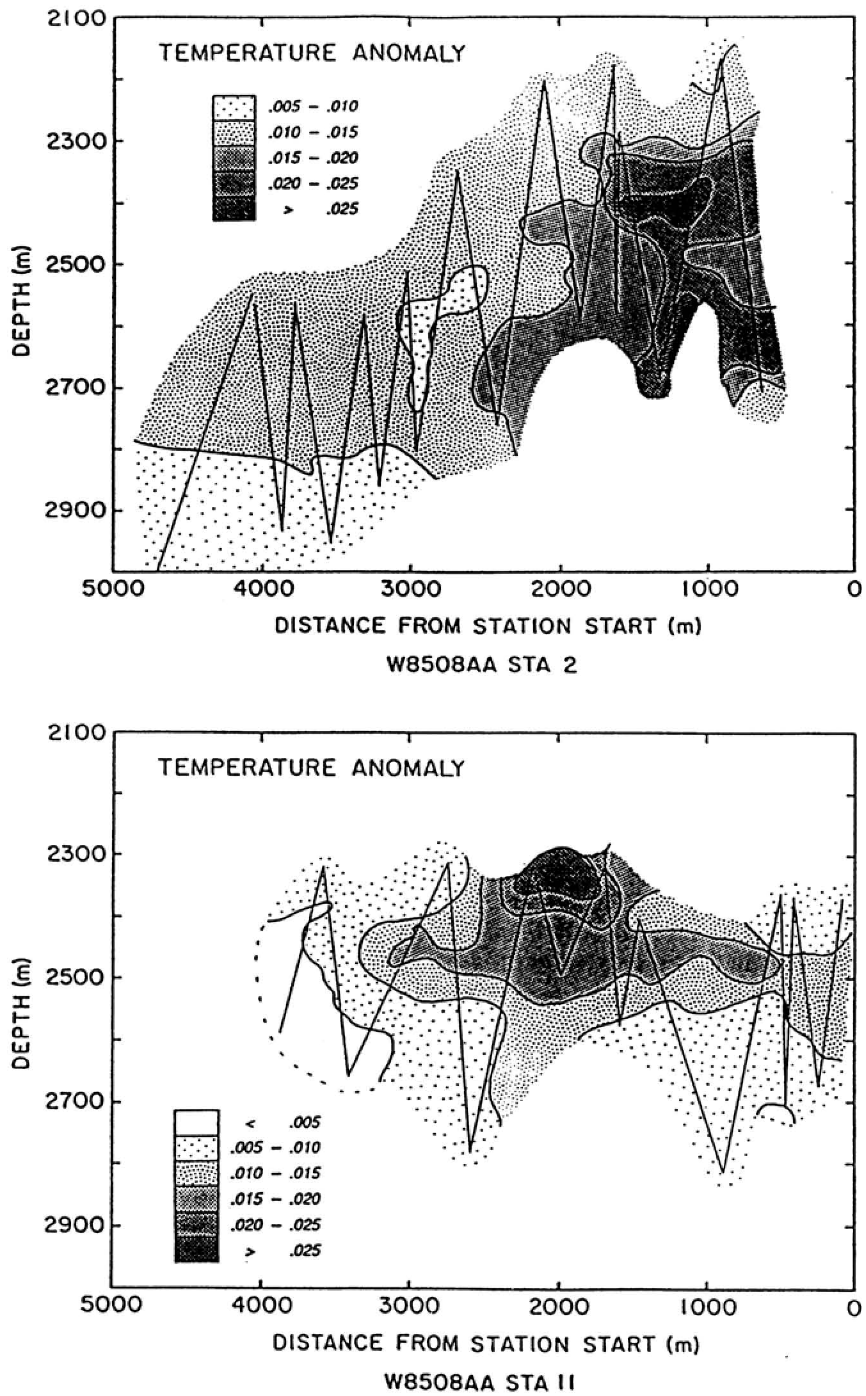

Figure 2. Contour plots of temperature anomaly detected during CTD tow-yo's (W8508AA). (4a) is the section made by CTD2 - the view is looking towards the north (up the valley). (4b) is the section made by CTD11 - the view is looking toward the west. The sections are roughly normal to each other (see Figure 1) and were collected approximately 4 days apart. The path of the CTD instrument is shown by thin zig-zag lines.

not connected on isopycnals along the east wall of the valley. Based on this observation, there must be at least two separate sources of venting along the northern ridge segment.

The plume carried a particle load that was clearly detectable with the transmissometer. Concentrations of suspended particles in the plume, which are chemical precipitates formed when the hydrothermal effluent mixes with cold, alkaline seawater (Von Damm and Bischoff, 1987), correlate well with the measured temperature anomaly (Figure 3) demonstrating the utility of combining these tracers. The intensity of the light absorption relative to temperature in the GR14 plume is somewhat lower than that in plumes encountered on the southern Juan de Fuca and Endeavour Ridges. This may be the result of differences in the chemistry and temperature of the primary vent fluids at the different sites.

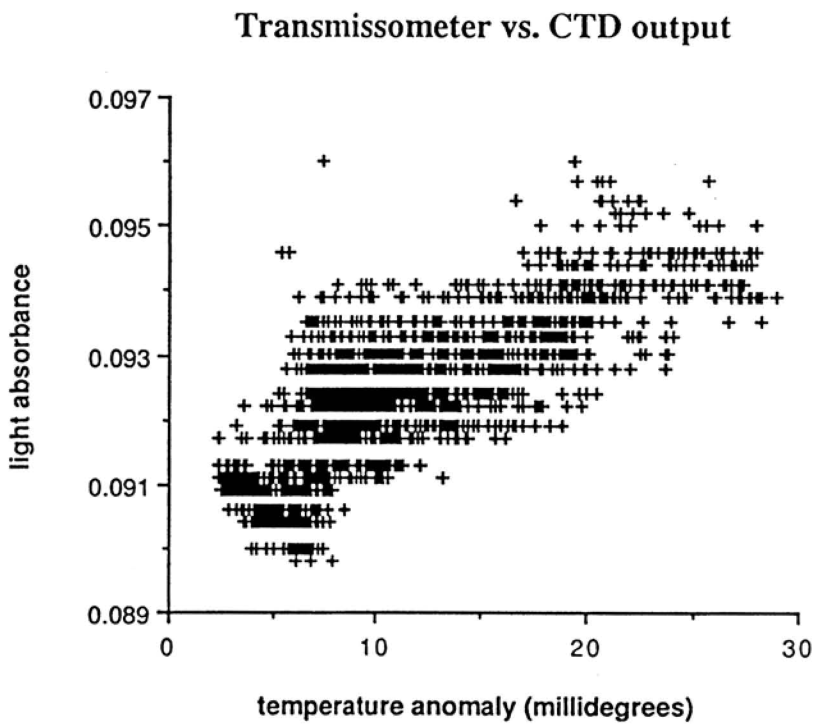

Figure 3. Correlation of transmissometer (light absorbance) and temperature anomaly data from CTD11. High particle concentrations (high light absorbance, low transmission) correspond with high temperature anomalies. These data, along with the elevation of the plume above, suggest that high temperature venting is occurring.

NOAA Ship Discoverer Cruise (June 17-26, 1986). In an attempt to precisely locate active venting sites on the Gorda Ridge at the GR14 site, we participated in the NOAA VENTS program cruise (RP-15-DI-86 Leg1) lead by NOAA scientists E. Baker and P. Rona. Our major task on this cruise was the shipboard determination of Mn as a hydrothermal tracer. The largest source of dissolved manganese to the oceans is hydrothermal circulation. Analysis of its dispersal in hydrothermal plumes has been an integral part of the discovery of almost every marine hydrothermal area studied to date. This metal is highly enriched in hydrothermal vents (~10^5 times ambient concentrations) and its intermediate residence time in seawater makes it a powerful "prospecting tool". Coupling its distribution with a set of other hydrothermal tracers (e.g. temperature, ^{222}Rn, Fe and suspended hydrothermal precipitates) has provided a great deal of basic information on the location, nature and scale of active venting. Application of these tools lead to the discovery of active venting at two sites along the northern Gorda Ridge in 1985 (Collier et al., 1986, Baker et al., 1987).

Due to a failure in the CTD winch, the hydrographic program of this cruise was limited to one CTD cast, one SLEUTH (towable CTD) tow and one hydrocast without the CTD (Figure 4). The SLEUTH tow essentially surrounded the hydrothermal sites identified in 1985 and the CTD and hydrocast were positioned as close to previous maxima as possible. Numerous small temperature and particle anomalies were detected but these were weak and poorly correlated. With these limited samples, we were unable to identify any thermal, suspended particle or chemical anomalies associated with active venting.

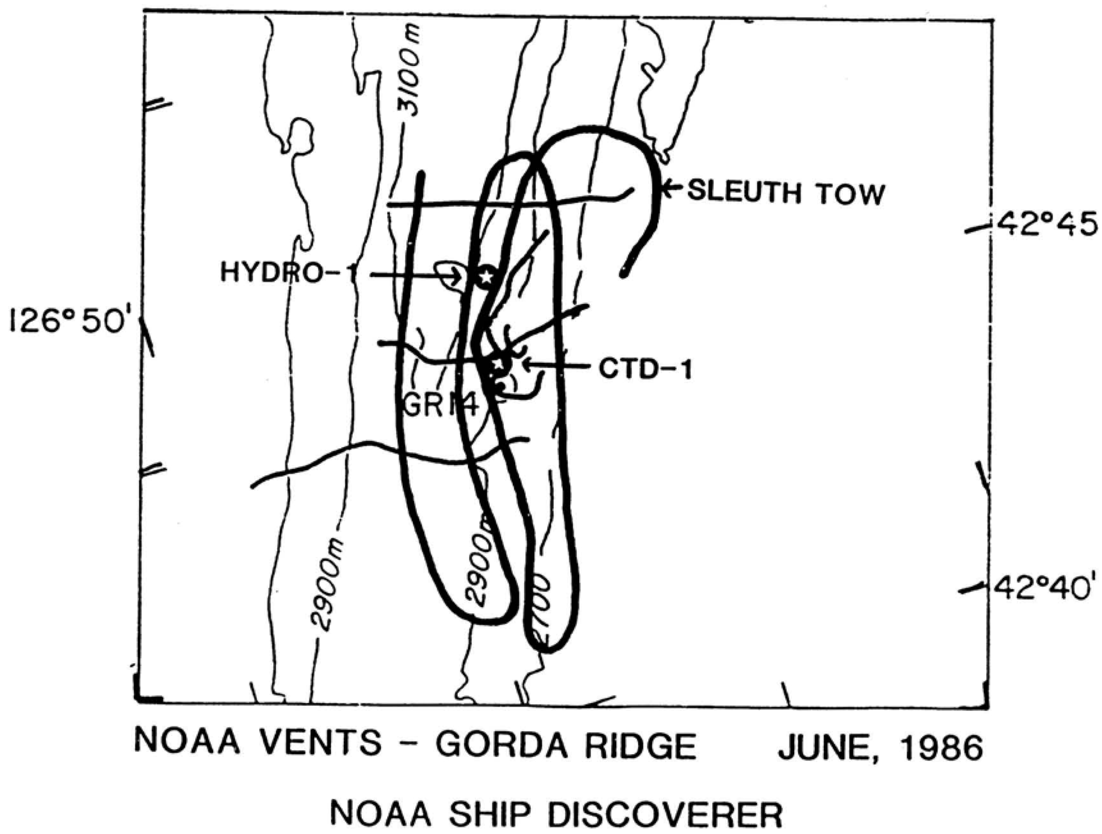

Figure 4. Sample map from the NOAA VENTS - GORDA RIDGE cruise on the NOAA Ship *Discoverer,* June 1986 to site GR14. Solid line represents the track of the towed CTD "SLEUTH" and the starred points represent the approximate locations of hydrocasts.

Manganese concentrations were determined at sea in a special laboratory van using trace metal atomic absorption methods developed for this program (Collier et al., 1986). The original Gorda Ridge survey (Baker et al, 1987) used manganese data to uniquely identify active venting regions from other parts of the water column within the axial valley of the entire Gorda Ridge. In Figure 5, eight vertical profiles of dissolved manganese are shown from the *Surveyor* cruise (Collier et al., 1986). The four stations in Figure 5a show background concentrations expected for this environment, with a normal increase towards the seafloor resulting from benthic remobilization of Mn. Stations GR14 and GR15 (Figure 5b) each clearly demonstrates the presence of a hydrothermal plume. Another smaller anomalous signal is present at GR3 within the Escanaba Trough.

In 1986, the manganese concentrations in the two vertical profiles at GR14 were at background levels (Table 1, Figure 6). This is consistent with the failure to detect a thermal anomaly during this expedition. It has been shown in our experience that even a relatively large plume may not be detected by sampling just "upstream" of it. Because the precise location of the vent source and configuration of the bottom currents are unknown, the two single profiles in 1986 cannot constrain the scale of venting present at that time. However, coupled with the data from the SLEUTH tow, we conclude that the volume of venting in 1986 was relatively small if we missed it with the sample coverage shown in Figure 4 .

<u>Sampling Equipment Development.</u> In order to collect critical CTD data to assist the submersible *Sea Cliff* in its eventual search for the vents, we contracted with the Scripps Physical and Chemical Oceanographic Data Facility (PACODOF) to provide a Neil Brown CTD, 1 meter path-length transmissometer and custom deck set for mounting on the submersible. We fashioned a harness for the instrument behind the main sail and completed through-hull wiring to connect the instrument to its onboard computer and power supply. A set of software programs were developed to give the diving scientist a real-time indication of ambient thermal and particle anomalies such as those shown in Figures 2 and 3.

Pre-dive activities included efforts to choose dive dates, personnel, modifications to SEA CLIFF, additional equipment , support vessel requirements, maintain liaison with the Navy, choose general dive targets, schedule training checkouts for SEA CLIFF "equipment operator" ratings, and preparation of sample collection and archiving materials. Surface vessel sampling programs (dredging, coring and fish trapping) were also prepared.

The field program included the USGS's R/V LEE as well as the DSV SEA CLIFF and the Navy-contracted submersible support vessel M/V TRANSQUEST. Both surface ships operated out of Eureka, CA for the duration of the project. The scientists from OSU participated in experiments from all these research platforms.

Due to high winds at the study sites, most of the dive dates within the original window were scrubbed. Only Lyle and Carey were finally able to make dives, and these were limited in extent. Eventually, a total of eight dives were made in the Escanaba region and no dives were made at the Northern Gorda sites (GR14, 15). Extensive sulfide mineralization was discovered and sampled at two sites in the Escanaba. No evidence of active venting was documented.

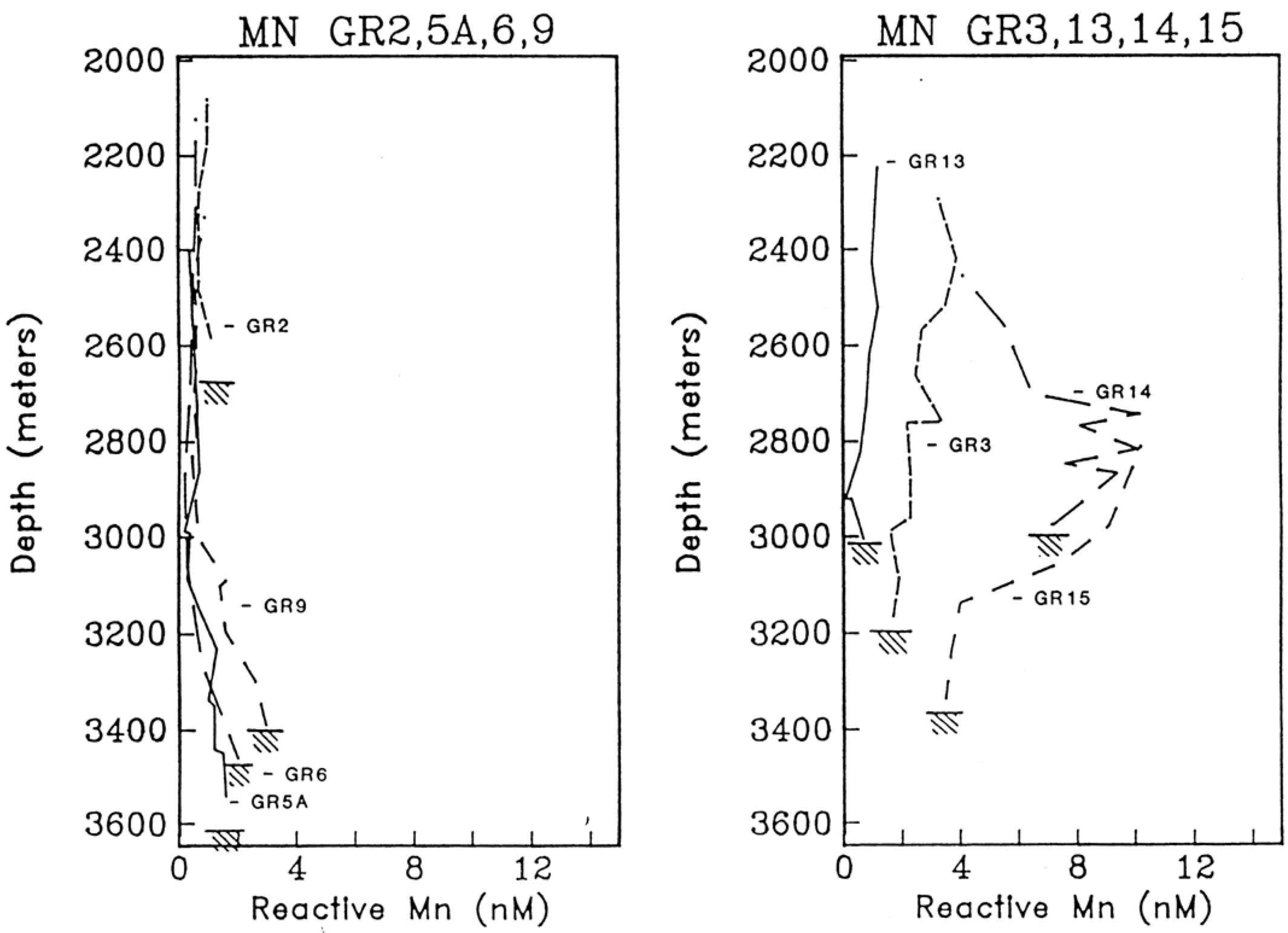

Figure 5. Vertical profiles of total reactive manganese (TRMn) from Gorda Ridge (Baker et al., 1987; Collier et al, 1986). (6a) overlays of 4 "background" stations and (6b) overlays of GR14, GR15 hydrothermal stations. GR3 shows possible hydrothermal influence.

TABLE 1. Manganese data from NOAA Ship *Discoverer* cruise, June, 1986.

CTD 1 (6/22/86) 42°46.2'N 126°43.4'W	
Sample depth(m)	Manganese (nM/liter)
2100	1.5
2200	0.9
2245	1.0
2302	1.1
2339	0.8
2376	1.0
2375	0.6*
2398	1.0
2447	0.7*
2448	1.3
2506	1.0
2503	0.6*

Hydrocast 1 (6/24/86) 42°46.0'N 126°42.8'W	
Sample depth(m)	Manganese (nM/liter)
2373	1.1
2473	1.1
2523	1.2
2623	0.8
2673	1.1
2723	1.3
2773	1.5
2863	1.1
2913	1.2
2963	0.9

* These samples were collected with "GoFlo"-type water samplers (as opposed to standard Niskin samplers with plastic-coated springs). In each case, the GoFlo sample was 0.3-0.4 nM lower than the Niskin sample at the same depth. This may indicate a slight amount of contamination from the Niskin bottles, although it does not appear to affect the general form of the profile or the clear lack of hydrothermal signal in these samples.

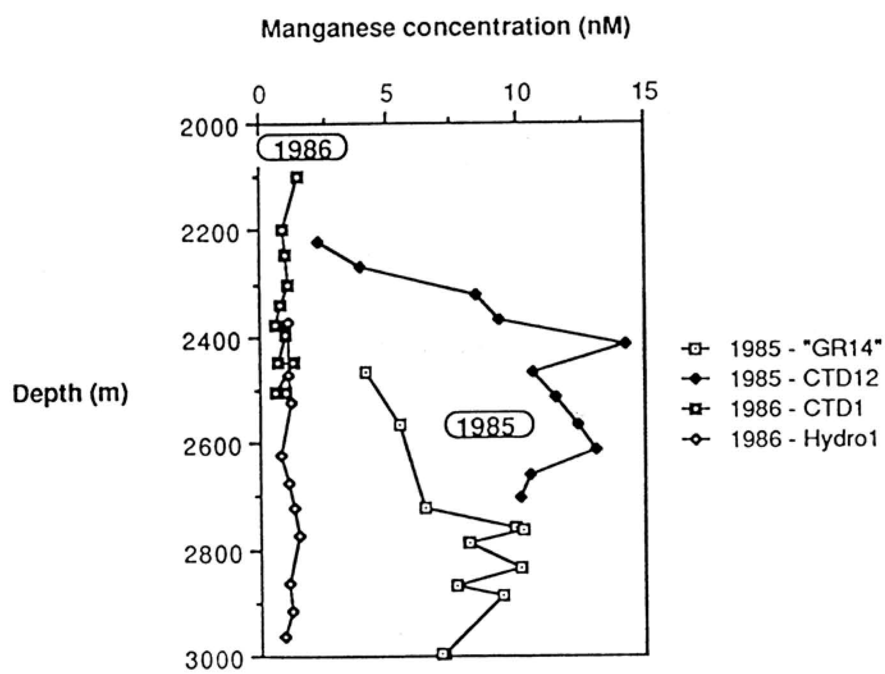

Figure 6. Vertical profiles of TRMn at station GR14. The 1985 data show that active venting was sampled; the 1986 data show no evidence of a hydrothermal component above background (see Figure 6).

DISCUSSION

The results of these three field expeditions clearly demonstrate the presence of active hydrothermal venting on northern Gorda Ridge. This is occurring in at least two locations, known as GR14 and GR15 (Figure 1), but may also occur elsewhere along the ridge (e.g. GR3, 4, 5). The physical and chemical "fingerprints" present in these plumes are directly analogous to those detected in the water column above all other mid-ocean ridge vent systems. Furthermore, the elevation and chemistry of the plumes observed in 1985 suggest that these were "high-temperature" vents (>100°C).

A final synthesis of the locations of the Gorda Ridge sampling stations is presented in Figure 7. The provisional base map used for this figure is a NOAA multibeam survey derived from Malahoff, 1985 and modified by Rona and Clague (in press). The navigation methods for each sample sited were often different (for instance, samples from W8508AA were navigated from the surface vessel only using a combination of satnav and loran-C) such that the accuracy of the positions may be in error by as much as a minute in longitude and several tenths of a minute in latitude. However, we expect the precision is much better than this and note that the bathymetric control on the samples collected fit very well with the map presented.

A remarkable feature of the surveys at GR14 was the apparent disappearance of the plume between the 1985 and 1986 surveys. This could be related to temporal variation in venting, or it could demonstrate that the areal extent of the plume was quite limited in 1986. It is not surprising to find variations in intensity of venting because hydrothermal vents are short-lived geophysical events. However, the relative constancy of most of the other systems sampled over similar or longer time scales (Galapagos, 21°N, Juan de Fuca) would make this observation unique. Currently, the heat and chemical output of the hydrothermal system at GR14 appears to be small in comparison to systems like the Endeavour Ridge (Kadko et al, 1986).

Although the hydrothermal anomalies sampled at GR15 were as strong as any measured at GR14, our coverage of the site is extremely poor. GR15 lies on the edge of a large, relatively flat bench which is extremely under-sampled. Although the specific area has been the focus of many small seismic events recorded on coastal networks (Bibee, personal comm.), it is not known at present if or how these seismic signals are related to hydrothermal activity.

In 1988, active venting at Escanaba was discovered by J. Edmond using the DSV *Alvin*. In September, 1988, active venting was discovered on the GR14 site by P. Rona and others using the DSV *Sea Cliff*. (see Rona and Clague, in press). The high temperature vents were located near the position of down-cast 4 on CTD#2 from W8508AA (see Figure 7).

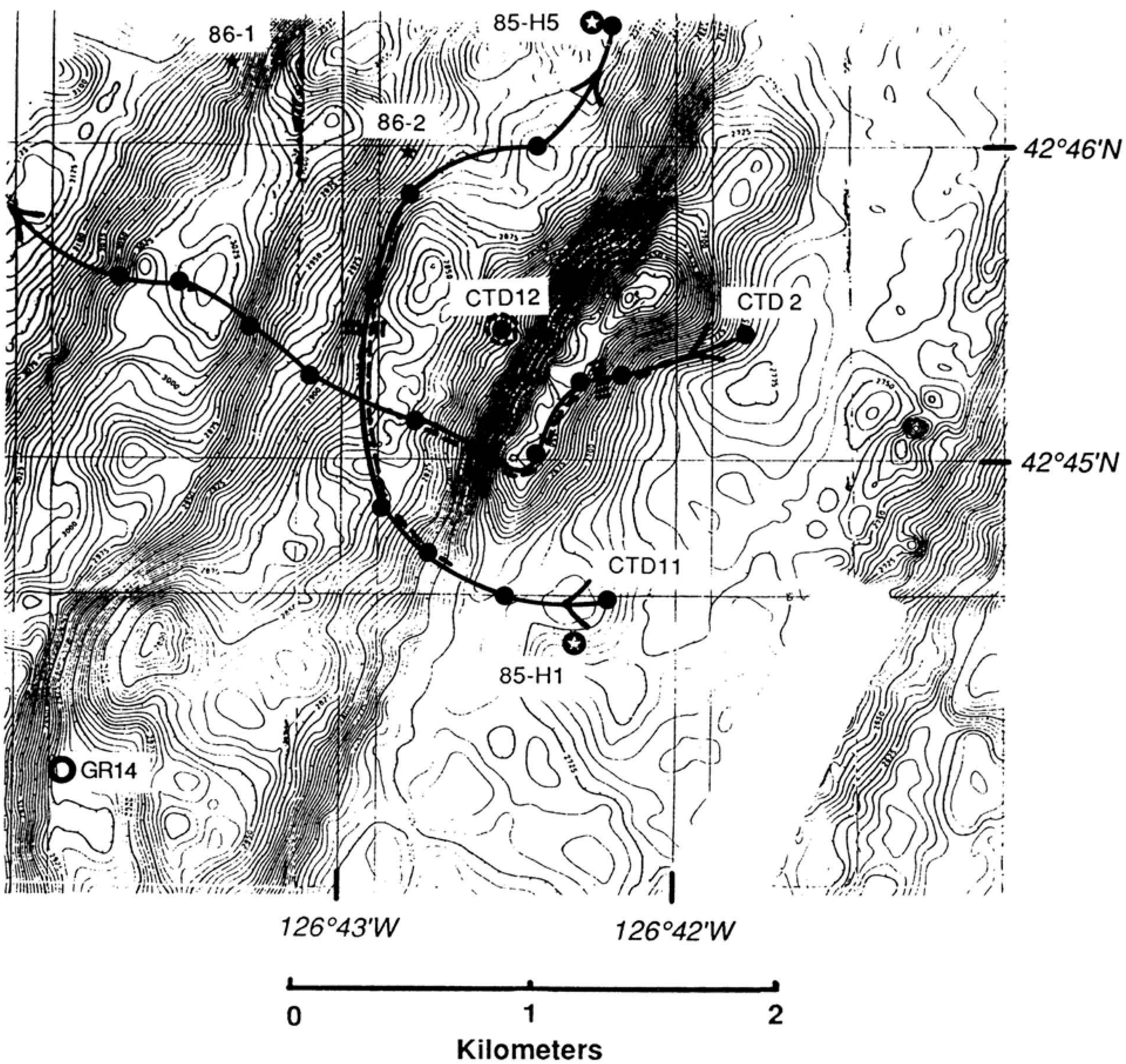

Figure 7. Hydrocasts and CTD stations occupied in the vicinity of site GR14, Northern Gorda Ridge. The provisional base map used for this figure is a NOAA multibeam survey derived from Malahoff, 1985 and modified by Rona and Clague (in press). Station key: (**O**) site GR14 occupied by NOAA Ship *Surveyor*, May 1985 [Baker et al, 1987]; (●) towed CTD's and (✪) hydrocasts ocupied by R/V *Wecoma*, August 1985 [Collier et al, 1986]; (★) CTD-hydrocasts occupied by NOAA Ship Discoverer during June 1986 [see Figure 5]. The dots (●) along the towed CTD tracks represent the approximate location of the bottom of each down cast shown as a zig-zag in Figure 2. The dashed sections of the tows demonstrated significant thermal anomalies and the point with a group of dashes was the location of the maximum anomaly seen during the tow.

Note that the navigation methods for each sample positioned were often different (for instance, samples from W8508AA were navigated from the surface vessel only using a combination of satnav and loran-C) such that the accuracy of the positions may be in error by up to a minute in longitude and several tenths of a minute in latitude. However, the precision is much better than this and we note that the bathymetric control on the samples collected during the casts fit very well with the map as presented.

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