

California Undercurrent in the ETNP

**Observational study of the California Undercurrent in the Eastern Tropical North Pacific.**

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## California Undercurrent in the ETNP

### Non technical summary

The California Undercurrent is a current that moves northward beneath the surface waters along the Western Coast of North America from the Eastern Tropical North Pacific. It is important to understand because it is the only current transporting warm, salty water to the Pacific Northwest region and beyond. Between 17 March 2012 and 27 March 2012 aboard a research vessel, 43 stations were occupied along the coast of Mexico between to determine the location of the undercurrent. Using the data from cruise, graphs were made depicting the water column and all its properties. The isopycnals (line of constant density) spread apart near the shelf break which was associated with the fastest current speed which was found to be between 100-300 meters and had an average density of  $26.6 \text{ kg/m}^3$ . The average speed of the undercurrent was between 0.05 and 0.1 m/s. The findings show evidence that the California Undercurrent is located as far south as Manzanillo, Mexico and enters and exits the Gulf of California.

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### Acknowledgments

I would like to thank the crew of the R/V *Thompson* and the professors that accompanied me and helped make my project a success on the TN278 cruise. I would also like to give thanks to the staff and professors at the School of Oceanography at the University of Washington for teaching me about oceanography and helping me achieve a higher education. I would like to give a special thanks to Charles Eriksen.

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### Abstract

The California Undercurrent is a subsurface current along the continental shelf break of the Western Coast of North America. It is important to understand because it is the only current transporting warmer, saltier water northward to the Northeast Pacific. The R/V *Thompson* occupied 43 along the coast of Mexico between the 17<sup>th</sup> and 27<sup>th</sup> of March 2012 to determine the location of the Undercurrent. Using the data from the CTD and the ADCP, graphs were made depicting the water column and all its properties. The spreading of the isopycnals for all stations was between 100-300 meters, which is the depth range for the fastest current, and had an average density of  $26.6 \text{ kg/m}^3$ . The average speed of the undercurrent was between 0.05 and 0.1 m/s. The findings show evidence that the California Undercurrent is identifiable as far south as Manzanillo, Mexico and it enters and exits the Gulf of California.

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The California Undercurrent is a subsurface current along the continental shelf break transporting water from the Eastern Tropical North Pacific to the Pacific Northwest and beyond (Hickey 1978, Pierce 2000). The undercurrent is relatively narrow, with its strongest current flow recorded being between 100-300 meters in depth (Gangopadhyay et al. 2011). The undercurrent moves warmer, saltier water northward that is high in nutrients but is low in oxygen concentration (Hickey, 1998), thus the study of its movement is important because it is the only source of water with these properties going poleward along the west coast of North America.

The existence of the California Undercurrent along the Baja Peninsula and beyond is not significantly well known due to lack of data (Durazo and Baumgartner 2002). Because it is not well known and it is moving its unique water properties poleward, it is important to study in order to gain a better understanding of biogeochemical cycling within the Eastern Tropic North Pacific (Castro et al. 2001). The Undercurrent is also important because it could have major effects on the ecosystem along its pathway because it transports the low oxygen but high temperature, salinity, and nutrient waters. It is currently unknown if the California Undercurrent affects any of the marine species regionally. Understanding the California Undercurrent and its pathway could lead to understanding if marine species within its pathway thrive on the characteristics of the Undercurrent. Because the undercurrent transports unique water properties along the shelf break, it also changes the chemistry of the water throughout its journey North (Castro et al. 2001). If the Undercurrent were to move at a slower speed, then the water further north would be warmed less, which could affect organisms in the region (Perez-Brunius et al. 2006).

The California Undercurrent has specific characteristics to include it being found to be between the depths of 0-1000 meters with the strongest current between 100-300 meters

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(Gangopadhyay et al. 2011). The location is approximated to be around 10-200 km offshore with a width of around 20-200 km (Gangopadhyay et al. 2011) usually around the shelf break (Wooster and Jones, 1970). It is also associated with having high 'spice'. For water of a given density, water that is high in temperature and salinity is considered to have higher spice. Many questions regarding the California Undercurrent are still unanswered: Does the Undercurrent enter and exit the Gulf of California? Does the Undercurrent traverse the coast of Mexico as it does the coast of the United States? Where does the Undercurrent originate? While previous studies have not addressed these questions they have answered others. A previous study of the California Undercurrent showed that a certain percentage of the Eastern Tropical North Pacific water gets transported northward (Thomson and Krassovski 2010). That study compared water properties at various locations from offshore Southern California and to offshore British Columbia. Results here complement that study to describe the percentage of the Pacific Equatorial Water that is within the California Undercurrent from Manzanillo, Mexico to San Diego, California. This paper presents the answers to the questions above by examining salinity, temperature, density, O<sub>2</sub>, and current profiles to determine undercurrent location.

## Methods

This study began off the coast of San Diego, California on March 17, 2012 aboard the R/V *Thompson* and continued through March 27, 2012 ending offshore Manzanillo, Mexico. Two main sampling tools were used throughout the cruise; the conductivity-temperature-depth (CTD) profiler, and the acoustic Doppler current profiler (ADCP). The cruise plan consisted of 43 CTD sampling stations (Fig 1.) CTD, sampling extended to just deeper than 1000 meters or a few meters above the sea floor, which was even shallower. CTDs recorded temperature, salinity,

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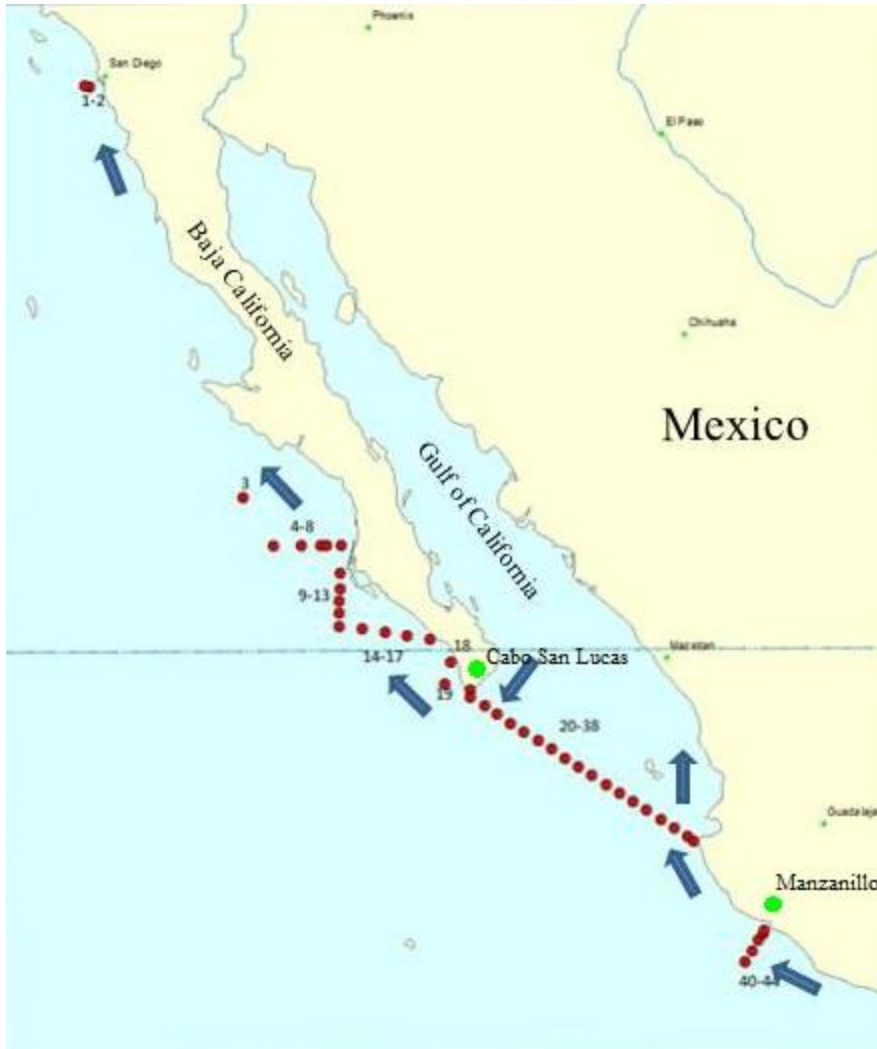


Fig. 1 A map of the Eastern Tropical North Pacific with the CTD station locations. The arrows indicate the direction the California Undercurrent is moving.

density, as well as dissolved oxygen through each profile. Water samples were collected at every other station between depths of 200 meters and 1000 meters for salinity and oxygen sensor calibration. The ADCP recorded current profiles from departure from San Diego continuously until arrival at Manzanillo, Mexico.

MATLAB scripts were used to analyze

CTD and ADCP records. Collections of stations comprising 6 transects were used to construct hydrographic and current sections from shallow water to offshore the continental shelf edge.

The 6 transects consisted of stations 4-8 (Soledad Basin), stations 8-13 (Magdalena Bay), stations 13-17 (Lusitania Bank), stations 20-24 (Cabo San Lucas), stations 34-38 (Cabo Corrientes), and stations 40-44 (Manzanillo) (Fig 2). Profiles of each transect from the CTD data were graphed to show the temperature, salinity, and density of the water. Another graph

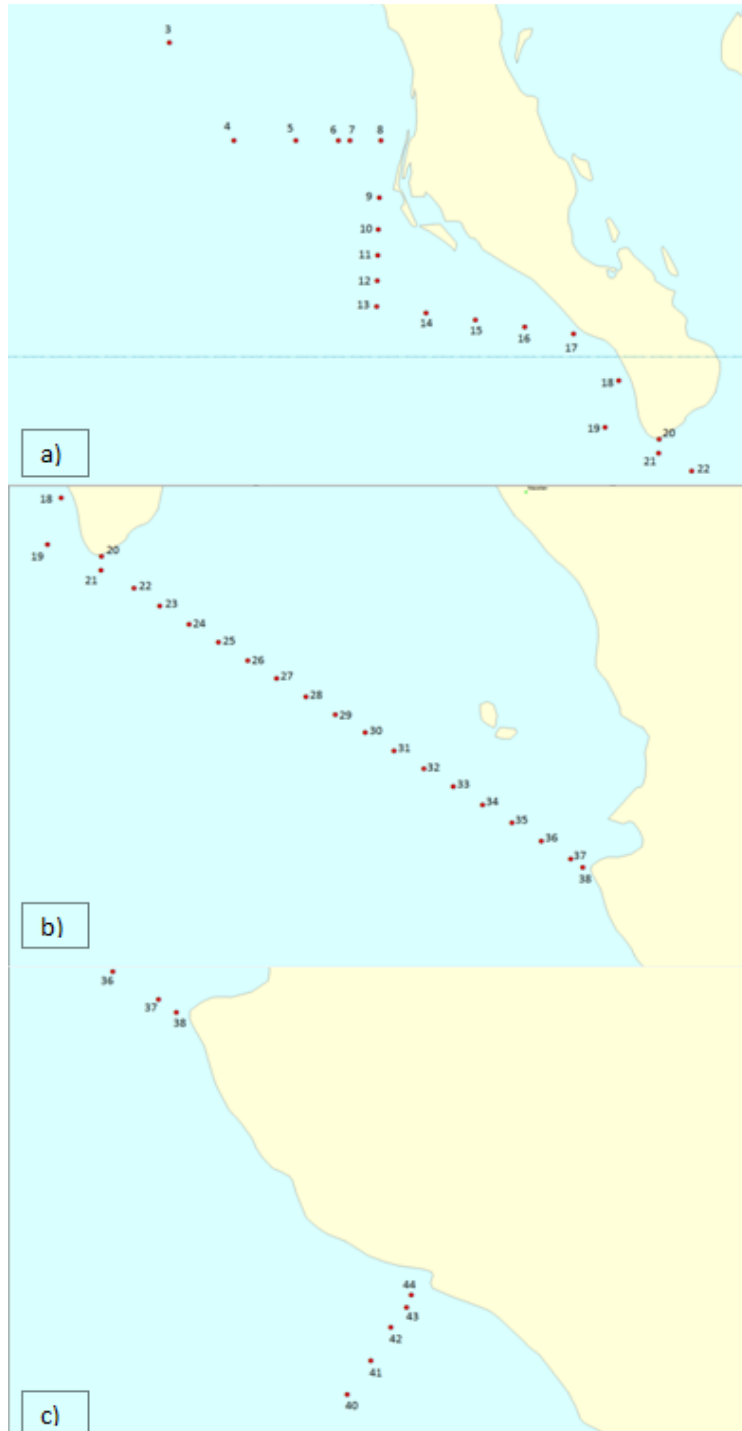


Fig. 2 Close up maps of the CTD transects used. Transects of 4-8 (Soledad Basin), 8-13 (Magdalena Bay), and 13-17 (Lusitania Bank) are shown in (a), the transects of 20-24 (Cabo San Lucas), and 34-38 (Cabo Corrientes) while showing the whole transect across the Gulf is shown in (b), and the transect of 40-44 (Manzanillo) is shown in (c).

was also created using the same program to show the spiciness of the water using a temperature-salinity plot. All the same information was then graphed again using a different program within MATLAB to show the water column as a section. The ADCP data was graphed using a program that plotted a color grid onto the section of each transect to show the speed and direction of the water within the water column. ADCP currents were filtered to suppress tidal fluctuations.

## Results

The principal hydrographic features of the region can be seen in plots of temperature, salinity, density, and the temperature-salinity (TS) relation. These are displayed in panels corresponding to each transect in figures 3-6. From the temperature

profiles (Fig 3) it is seen that surface water temperature increases as the stations get closer to the equator and all the stations show that the temperature decreases with depth. The salinity profiles (Fig 4) of the transects show that as the stations get closer to the equator the surface water salinity increases. The salinity profiles also show that the salinity of the water decreases within the first 100 meters of depth and then increase significantly before reaching its peak. Once it reaches its peak it decreases slightly and changes little below. As the stations get closer to Manzanillo the surface decrease amount and the significant increase to the peak become less severe. The density profiles (Fig 5) of the transects show that as the stations get closer to the equator the surface water density decreases and all the stations show that the density increases with depth. The TS plots (Fig 6) of the transects show that the spice of the water gets higher as the stations get closer to the equator. The graphs show that there is a spice peak at a density approximately  $26.6 \text{ kg/m}^3$  throughout the entire cruise. Graphs for the temperature, salinity, density, and  $\text{O}_2$  concentrations were also made using one station that best represented each transect (Fig 7) to better see the differences in the water properties going from the starting location to the end location. The oxygen profile (Fig 7a) shows that as the stations get closer to the equator the oxygen minimum zone increases in depth. The temperature and salinity profiles show a surface increase and the density profile shows a decrease as the stations get closer with equator.

Three section profiles were also made from the transects. Two were made from the CTD data while one was made from both the CTD and the ADCP. The section profiles (Fig 8) showing the density and spice show that there is a spreading of the isopycnals between  $26.5 \text{ kg/m}^3$  and  $26.6 \text{ kg/m}^3$  for nearly all of the sections. It also shows that a high amount of spice is between those spreading centers. In every section the spread is close to the coast at a depth

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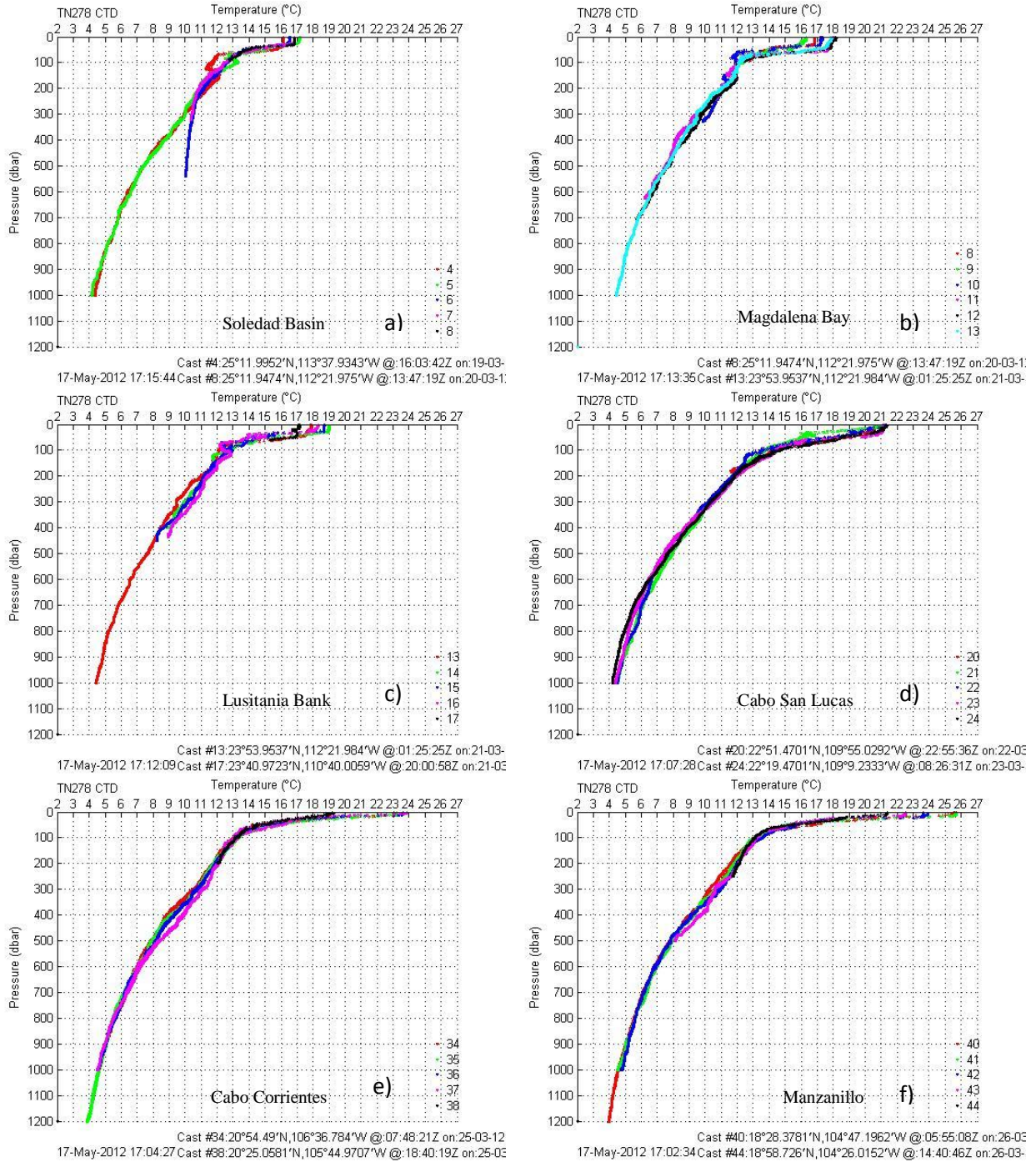


Fig. 3 Temperature profiles for the transects 4-8 (a), 8-13 (b), 13-17 (c), 20-24 (d), 34-39 (e), and 40-44 (f). Pressure is the vertical axis and Temperature is the horizontal axis.

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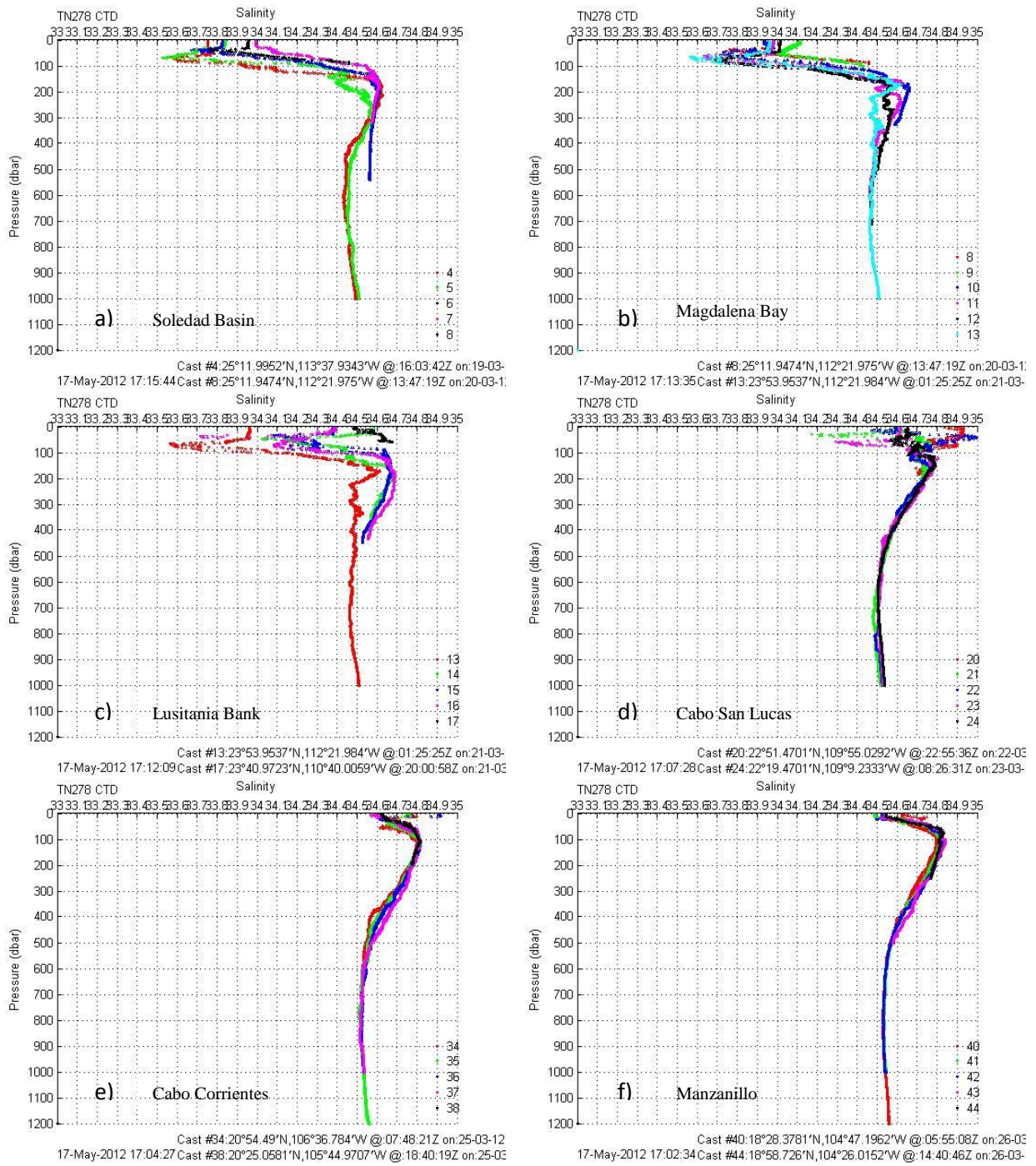


Fig. 4 Salinity profiles for the transects 4-8 (a), 8-13 (b), 13-17 (c), 20-24 (d), 34-39 (e), and 40-44 (f). Pressure is the vertical axis and salinity is the horizontal axis.

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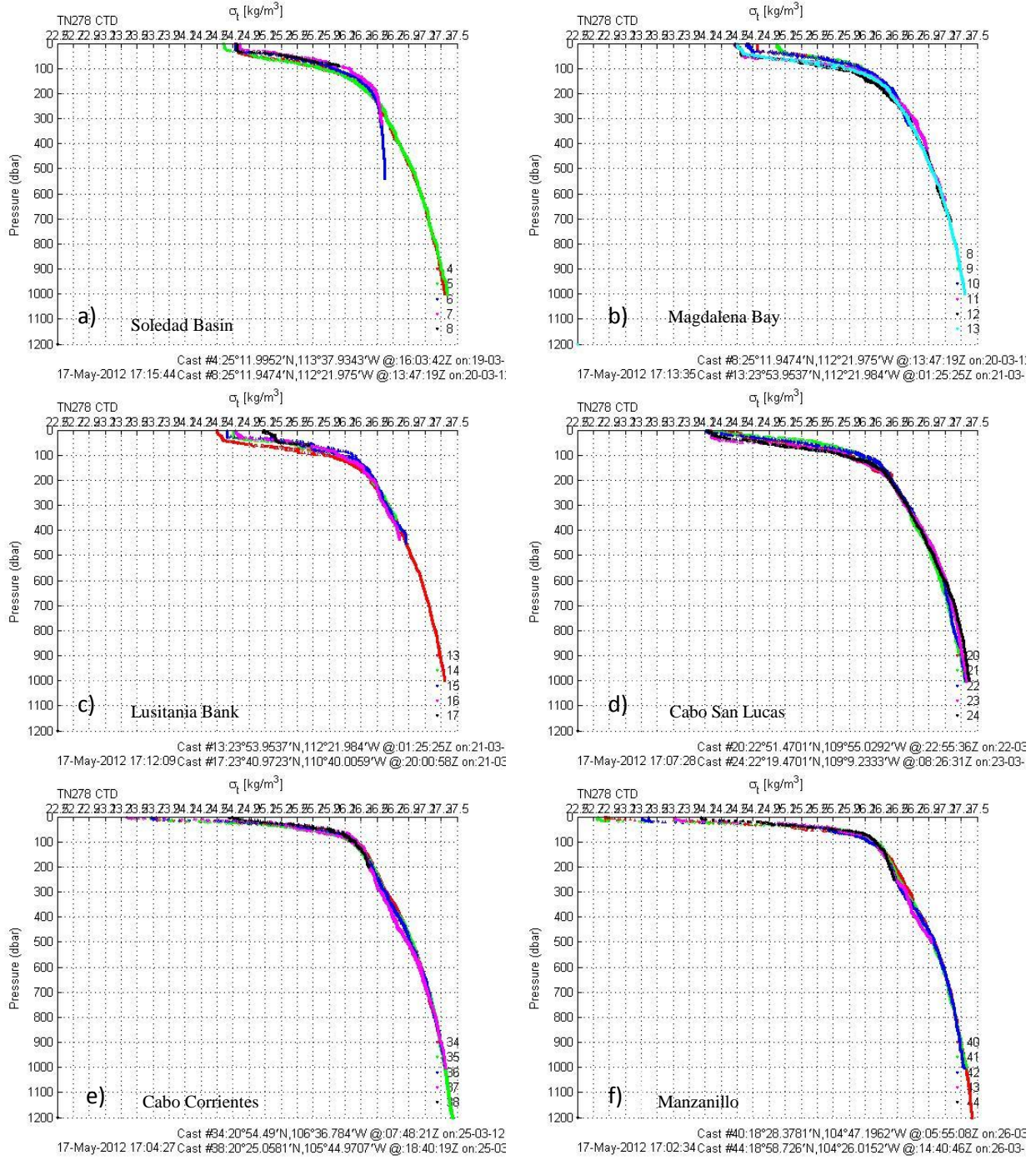


Fig. 5 Density profiles for the transects 4-8 (a), 8-13 (b), 13-17 (c), 20-24 (d), 34-39 (e), and 40-44 (f). Pressure is the vertical axis density is the horizontal axis.

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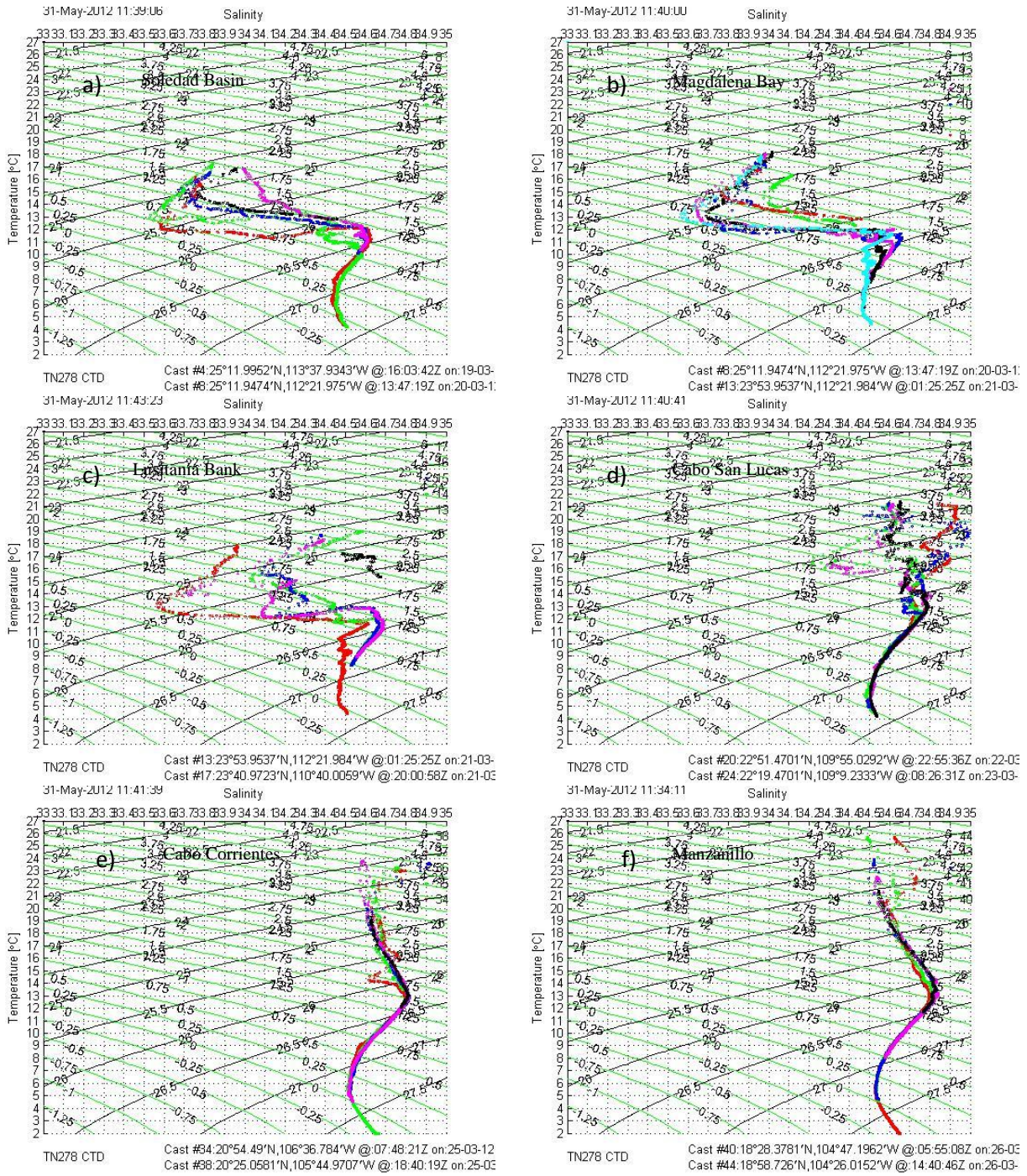


Fig. 6 Temperature-Salinity profiles for the transects 4-8 (a), 8-13 (b), 13-17 (c), 20-24 (d), 34-39 (e), and 40-44 (f). Temperature is the vertical axis and salinity is the horizontal axis. The black lines are density and the green lines are sigma-t levels.

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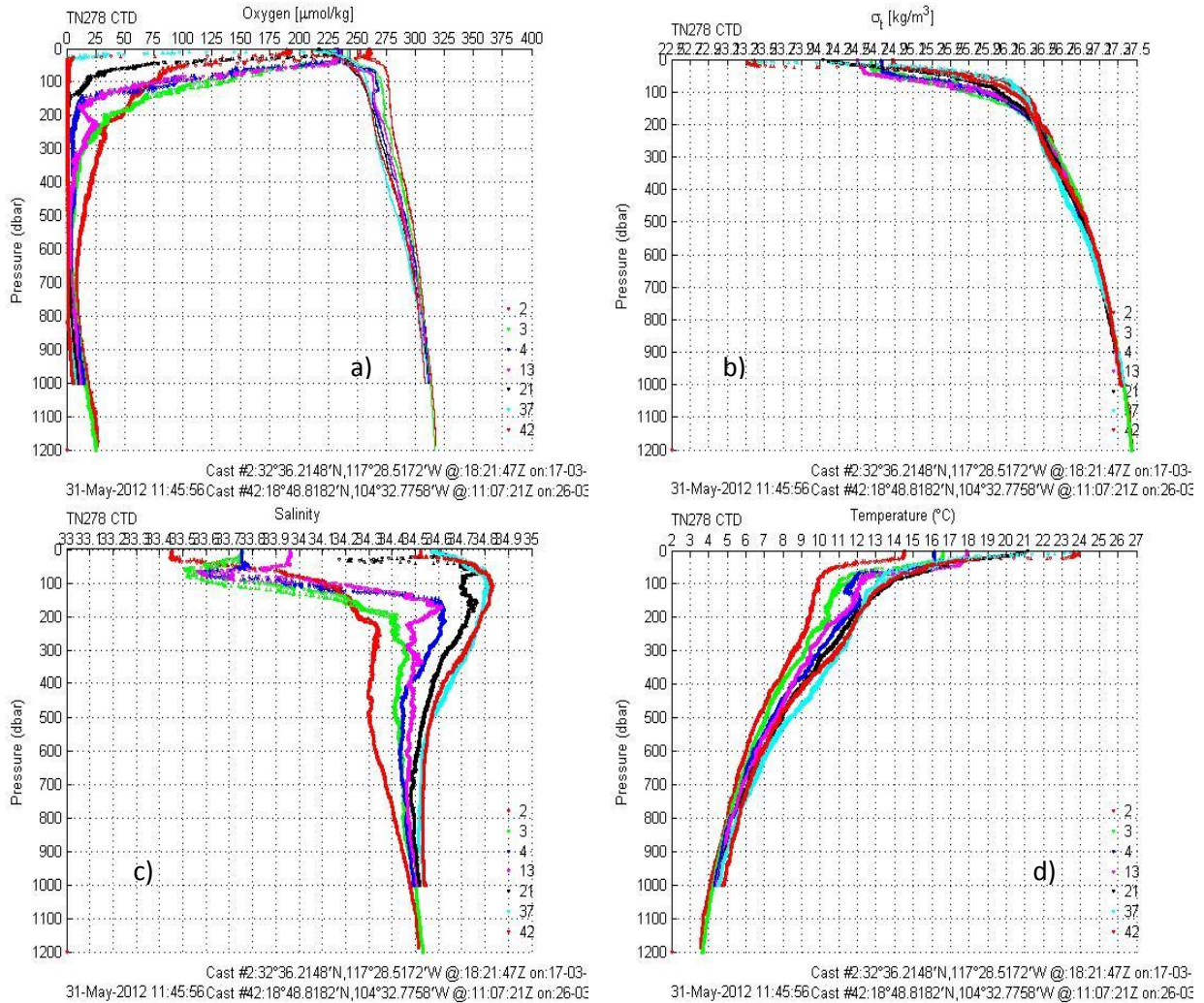


Fig. 7. One Station that best represented the water column for each transect from San Diego to Manzanillo plotted together to show the oxygen (a), density (b), salinity (c), and temperature (d) changes throughout the entire length of the study.

between 100-300 meters. The section profiles (Fig 9) showing the temperature, salinity, and  $\text{O}_2$  concentrations show that there is a spread in temperature and salinity that correlates with the spread of the density isopycnals. The section profiles (Fig 10) showing the velocity of the current throughout the section shows that the highest velocity in the northward flow is within 100-300 meters and close to the spreading of the isopycnals. The spreading of the isopycnals will also

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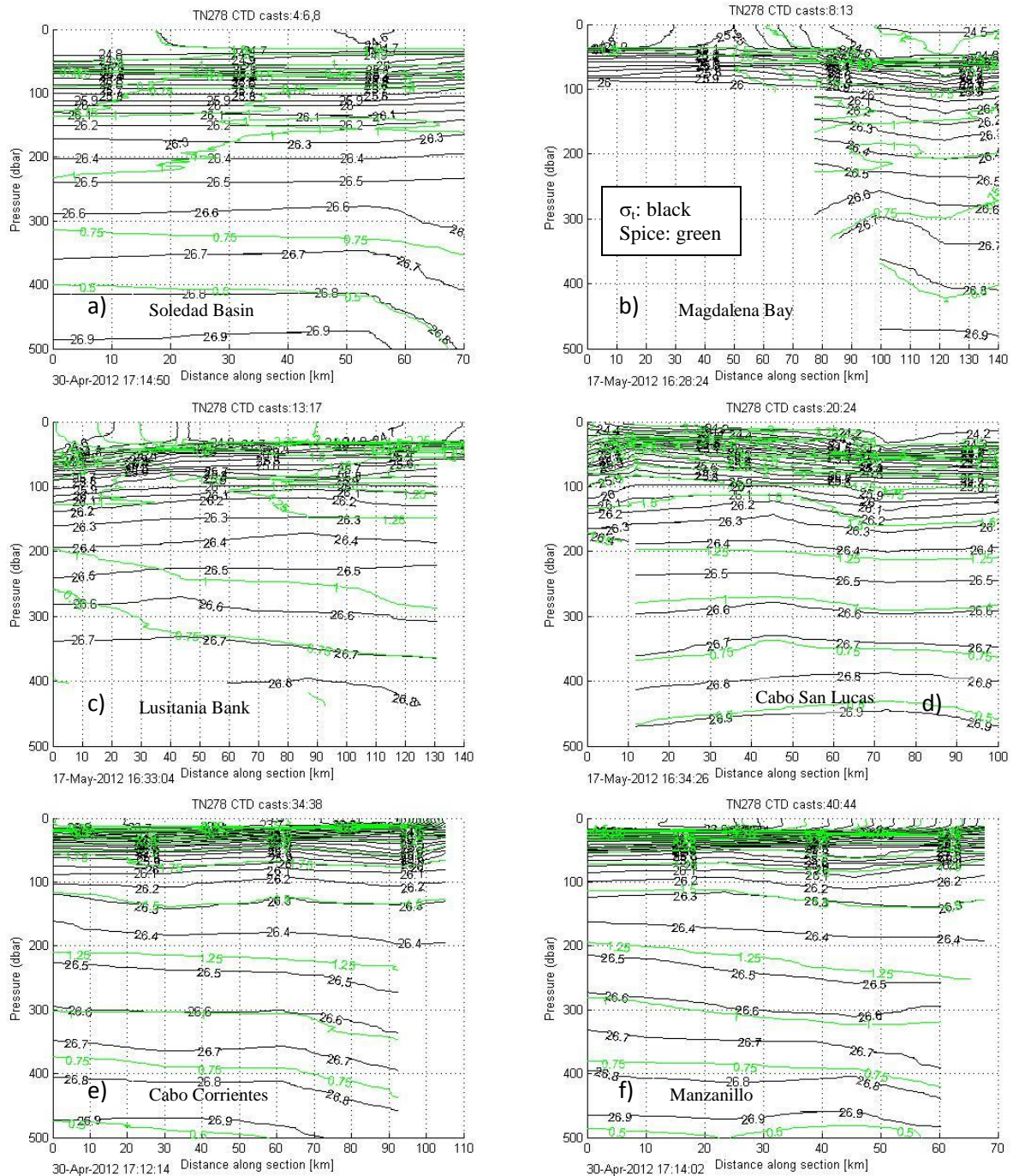


Fig. 8. Section of the water taken from a transect containing multiple CTD stations from stations 4-8 (a), stations 8-13 (b), stations 13-17 (c), stations 20-24 (d), stations 34-38 (e), and stations 40-44 (f) showing density (black) and spice (green). Stations 8-13 (b) and stations 20-24 (d) have the slope on the left of the image while the other stations have the slope on the right. Pressure is the vertical axis and distance is the horizontal axis.

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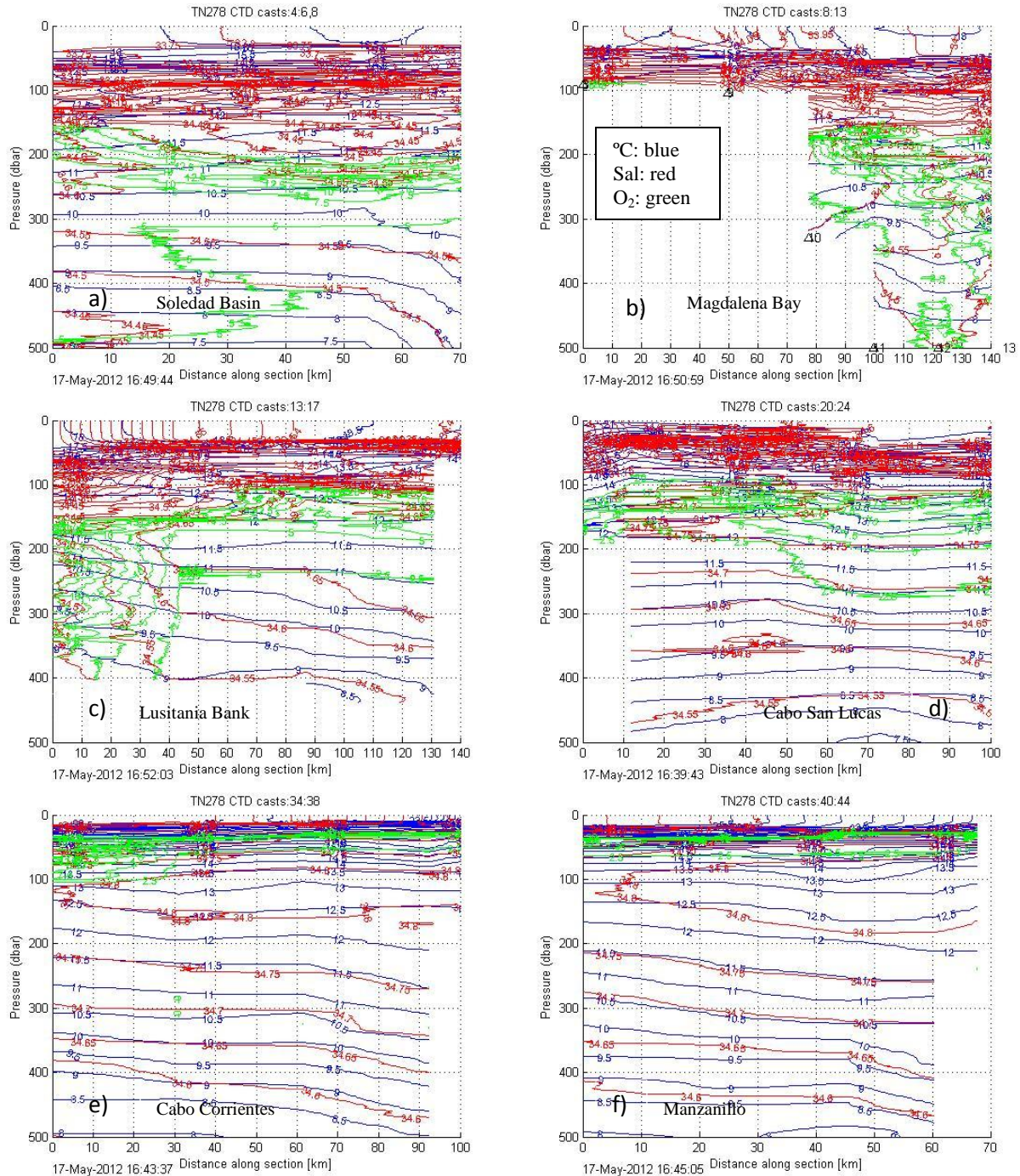


Fig. 9 Section of the water taken from a transect containing multiple CTD stations from stations 4-8 (a), stations 8-13 (b), stations 13-17 (c), stations 20-24 (d), stations 34-38 (e), and stations 40-44 (f) showing temperature (blue), salinity (red), and O<sub>2</sub> concentration (green). Stations 8-13 (b) and stations 20-24 (d) have the slope on the left of the image while the other stations have the slope on the right. Pressure is the vertical axis and distance is the horizontal axis.

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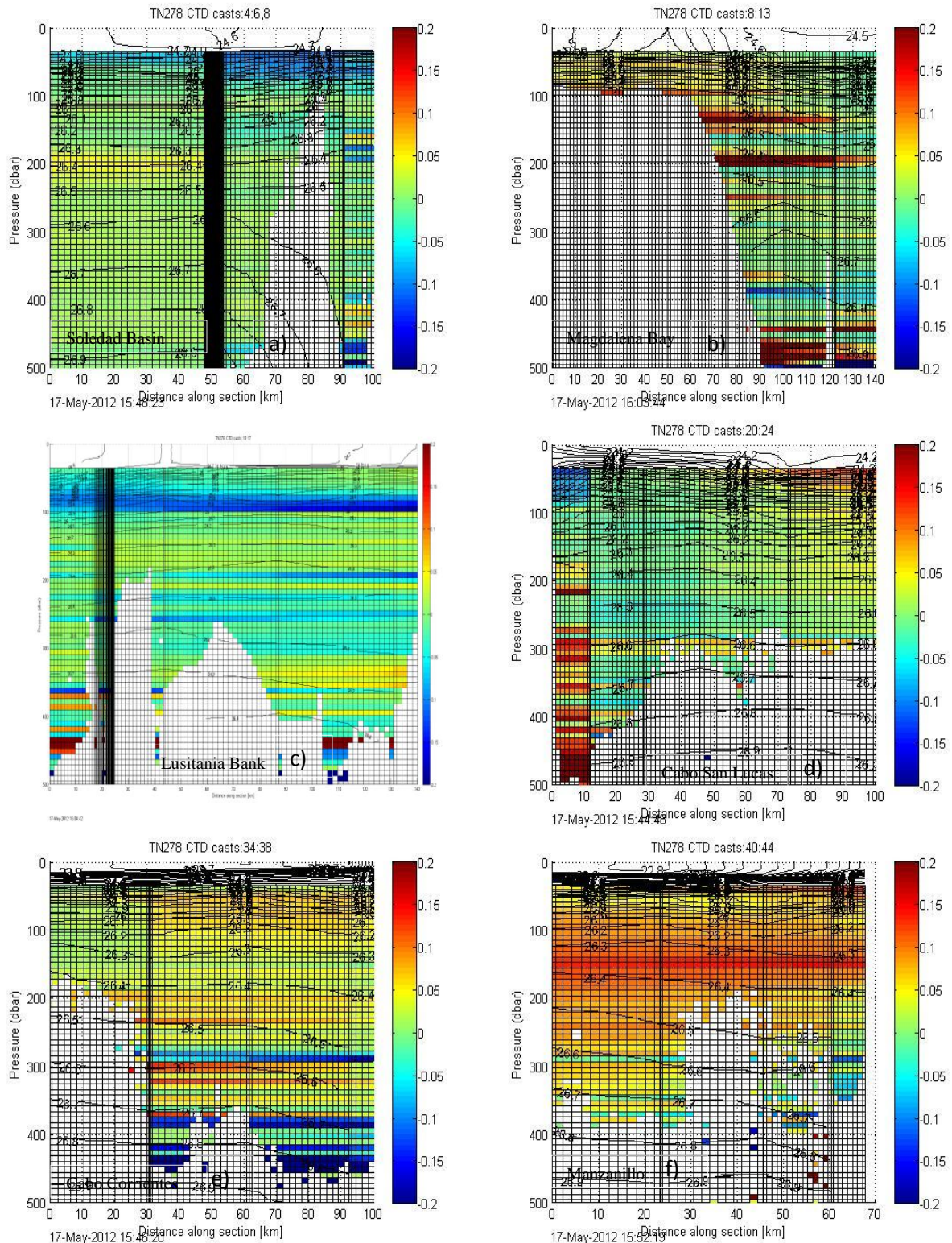


Fig 10. Current profiles for the transects 4-8 (a), 8-13 (b), 13-17 (c), 20-24 (d), 34-39 (e), and 40-44 (f). Pressure is the vertical axis and distance is the horizontal axis.

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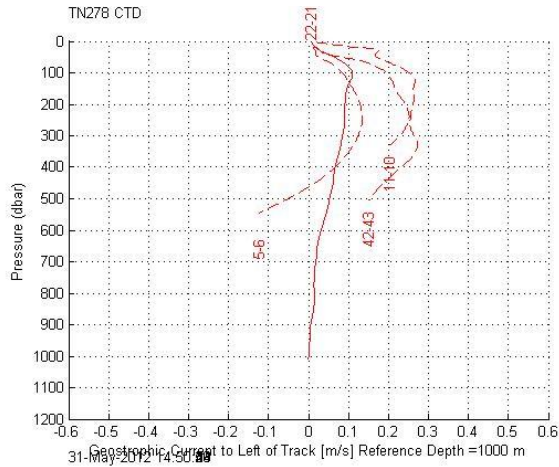


Fig. 11 The geostrophic shear between stations 5-6, 10-11, 21-22, 42-43. Pressure is the vertical axis and geostrophic current velocity is the horizontal axis.

imply a geostrophic shear (Fig 11) that is connected to a poleward flow. The maximum poleward flow at any given depth is where the isopycnal changes sign which would be at the spreading center. The shear shows that the maximum poleward flow is between 100-400 meters.

## Discussion

The California Undercurrent has been associated with having higher temperatures, salinity, and spice while having low oxygen. The temperature, salinity, and density plots for all the stations show the same characteristics of the California Undercurrent however the oxygen concentrations throughout the area observed were too low to use as significant data. Although it would have been advantageous to use the oxygen data to help pinpoint the Undercurrent (Collins et al.) there is an oxygen minimum zone (OMZ) in the researched area and being so close to the origin area and within the OMZ it caused difficulty with this research but it could be used more northward.

One of the major evidences of the California Undercurrent is the spreading of the isopycnals near the shelf break. When observing the sections (Fig 8) it is visible that each section has a spreading area and it is within the 100-300 meter range that is associated with the undercurrent. It can be confirmed that it is the undercurrent by observing the sections (Fig 9) to

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see that the salinity and temperature profiles are also spreading showing that at a given depth it will be warmer or saltier near the shelf break rather than farther away. The spice of the all the sections is also the highest in these areas too. From the ADCP data (Fig 10) the current flowing through the spreading of the isopycnals can be seen with the highest level of velocity in the

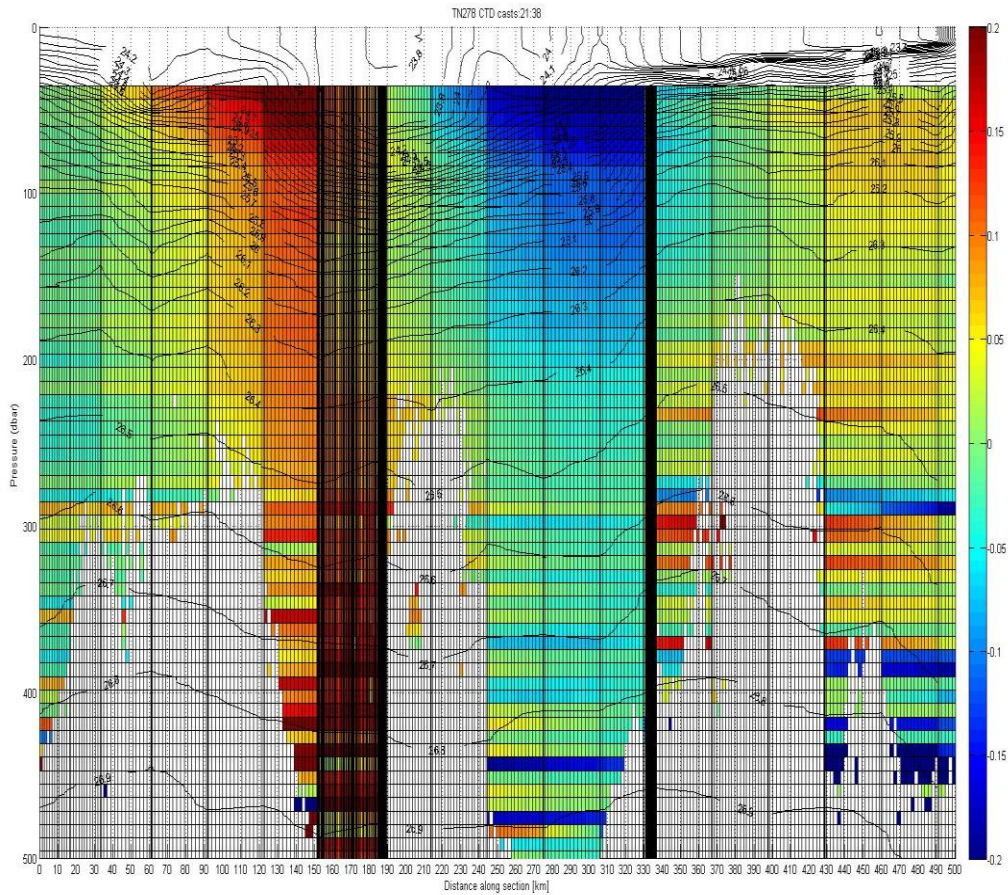


Fig. 12. Section of the water taken from the CTD and ADCP data from a transect containing stations from stations 21-38 showing density (black) and the velocity of the water in the colored grid. The image is of off the tip of Baja (left) to the coast of Mexico (right). Pressure is the vertical axis and distance is the horizontal axis.

northward flow. Because stations 40-44 (Fig 8f, 9f, and 10f) are also showing these observations it can be accepted that the California Undercurrent extends from at least Manzanillo, Mexico. Between stations 4-8 (Fig 10a) the spreading of the isopycnals is the greatest with the average northward flow for all the figures to be between 0.05 and 0.1 m/s. Station 21-38 (Fig 12) shows

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the whole length of the mouth of the Gulf of California. From the left part of the graph it is visible that the water is moving southward out of the Gulf of California around the tip of Baja while from the right it is visible that the water is moving northward into the Gulf of California. The middle of that transect is possibly showing an eddy that appeared while researching the area. The properties observed from the data compare to that of what has been documented of the properties of the Undercurrent (Gangopadhyay et al. 2011, Hickey 1978) which provides the evidence that the Undercurrents flow (Fig 1) was observed as far south as Manzanillo and entering and exiting the Gulf of Mexico.

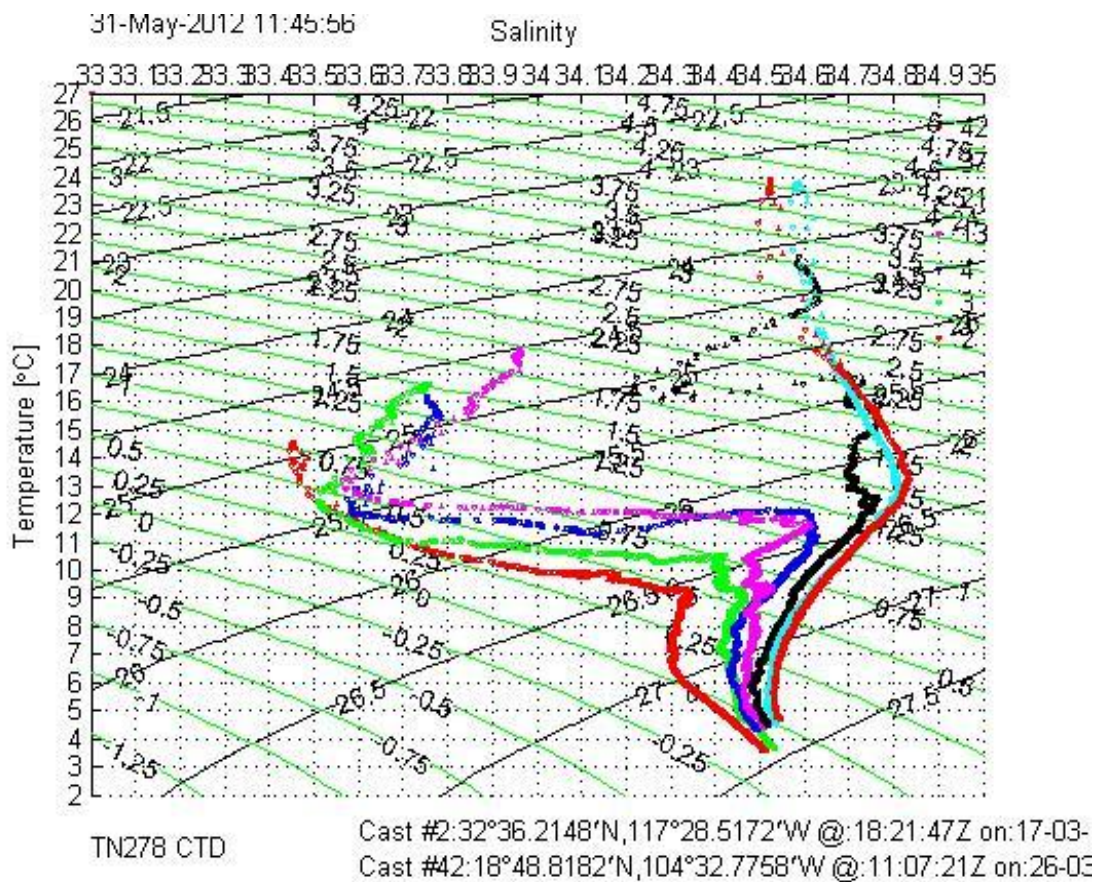


Fig. 13. Temperature-Salinity profiles of one station that best represented the water column for each transect from San Diego to Manzanillo plotted together. Stations 2,3,4,13,21,37, and 42. Temperature is the vertical axis and salinity is the horizontal axis. The black lines are density and the green lines are spice levels.

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The previous study by Thomson and Krassovski examined the percentage amount of Equatorial Pacific water that was being transported North by the California Undercurrent. Although they researched the undercurrent they only went as far south as Newport in their data. Looking at the TS plot made by the stations that best represent each transect (Fig13), and comparing it to the figure created by Thomson and Krassovski (Fig14) it can be determined approximately what percentage of the California Undercurrent is Equatorial Pacific water. It appears that station 43 would be close to 90 percent of the Equatorial Pacific water while station

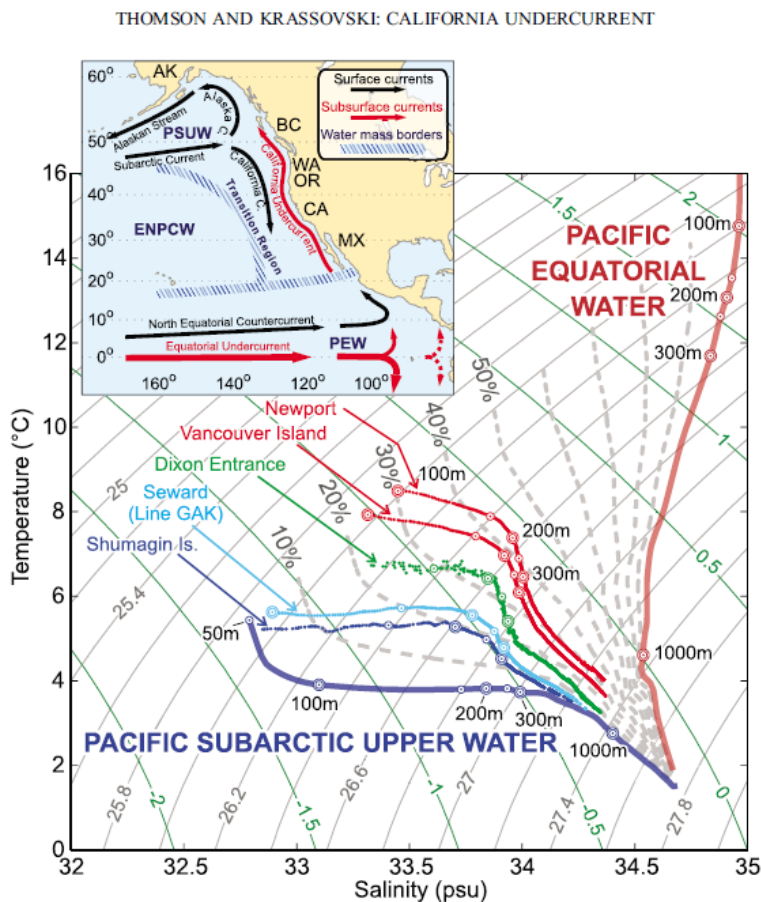


Fig. 14 Temperature-Salinity profile of stations Newport to Shumagin Island plotted together to see the percentage of the Pacific Equatorial water within the undercurrent. Temperature is the vertical axis and salinity is the horizontal axis. The black lines are density and the green lines are spice levels. (Thomson and Krassovski 2010)

2 was only about 40 percent.

This helps determine that the origin of the California Undercurrent is still further south than Manzanillo.

The findings in this paper help imply that the California Undercurrent is important and can be playing a major role on not only the physics but also the chemistry and biology of the waters it flows through. For future studies it would be beneficial to evenly space the stations and compact

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them closer together. Not all the sections are of the same distance apart and not enough stations were close to the coastal shelf break which could have had implications on the data. Adding more stations at closer intervals would make for a more accurate depiction of the California Undercurrent. Besides adding more stations, adding more transects would be beneficial to enhance the accuracy of the location of the undercurrent throughout the cruise. Adding transects within the Gulf of California and further South than Manzanillo would help to determine where the California Undercurrent truly begins and how far in the Gulf it is traveling. A year round research project would also help with understanding the dynamics of the undercurrent to observe if there are any seasonal variations.

## Conclusion

Between the dates of 17 March 2012 and 27 March 2012 the California Undercurrent was studied and it was concluded that the undercurrent:

- Was located as far south as Manzanillo and possibly further.
- Was traveling along the continental shelf break throughout the trip from Mexico to California.
- Was entering and exiting the Gulf of California.
- Has a high percentage of the Equatorial Pacific water at Manzanillo.
- Had the strongest current between 100-300 meters.
- Had an average velocity of 0.05-0.1 m/s.
- Had high spice at the average density of  $26.6 \text{ kg/m}^3$

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