Interferometric Sidescan Bathymetry, Sediment and Foraminiferal Analyses; a New Look at Tomales Bay, California

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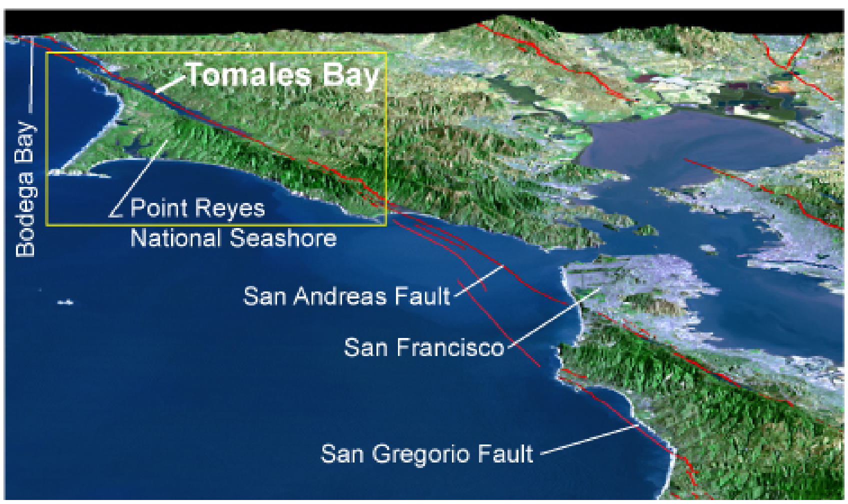

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Cover illustration: Perspective view of Tomales Bay and nearby San Francisco Bay area (http://www.sfbayquakes.org/northview.html).

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Chapter 1. Interferometric Sidescan Bathymetry, Sediment and Foraminiferal Analyses: A New Look at Tomales Bay

By

Roberto J. Anima, John L. Chin, David Finlayson, Mary McGann, Florence L. Wong

Introduction

The United States Geological Survey (USGS) in collaboration with Point Reyes National Sea Shore (PRNS), and the Tomales Bay Watershed Council [http://www.tomalesbaywatershed.org/] has completed a detailed bathymetric survey, and sediment and foraminiferal analyses of the floor of Tomales Bay, California (Figure 1-1). The study goals are to document the submarine morphology, sediment distribution, sedimentary features, and distribution of foraminifera to provide a framework for future studies. The USGS collected swath bathymetric data with a SEA SWATHplus interferometric sidescan sonar system (http://www.jrm-software.co.uk/swathplus.aspx?nav=products, 2004, 2005) and an echo sounder system (2006). The data were processed into continuous mosaic images that show detail of the bay floor with 0.2-m vertical and 4-m horizontal resolution. Acoustic backscatter data from the 2004 and 2005 surveys were processed into 2-m resolution grids. In addition, 27 sediment samples were collected from various parts of the bay for grain size analyses and a comprehensive study of the distribution of foraminifera in Tomales Bay. The foraminiferal analysis determined that the invasive foraminifera *Trochammina hadai* from Japan was present in Tomales Bay.

The project was conducted in response to a request from the National Park Service and the Tomales Bay Watershed Council to look at the environmental impacts of human activities in the surrounding watersheds that ultimately flow into the bay. The mapping, sediment, and foraminiferal data establish a baseline survey for future comparisons of possible geologic and anthropogenic changes that might occur due to changes in land use in the surrounding watershed. These data may also aid in determining the possible pathways of pollutants entering the bay from the surrounding watersheds.

Geologic Setting

Tomales Bay, which is approximately 20 km long, 2 km wide, with an average depth of 6 m, is the fault-line valley of the San Andreas Fault (Clark and Brabb, 1997) (Figure 1-2). The San Andreas Fault marks the transform tectonic boundary between the Pacific and North American lithospheric plates. Inverness Ridge borders the bay along the southwest, which consists of Upper Cretaceous granitic and older metamorphic rocks of the Salinian block (Clark, and Brabb, 1997). Along the north-east side of Tomales Bay are greywacke, shale, conglomerate, chert, serpentinite, and limestone of the Jurassic and Cretaceous Franciscan Complex. The mouth of Tomales Bay consists of modern beach and dune sands. The east shore of the bay is underlain by alluvial and estuarine clay, silt, sand, and gravel of the Pleistocene Millerton Formation. Tomales Bay receives sediment input from Lagunitas Creek to the south, tributaries draining Inverness Ridge to the west, the Walker Creek watershed, and tributaries draining into the east side of the bay.

Data Collection and Processing

Approximately 17 km^2 of Tomales Bay were mapped between November 2004 and August 2006 using a SEA SWATHplus interferometric sidescan sonar system (bathymetry and backscatter; USGS field activities F-1-04-TB, F-2-05-TB) and a single beam echo sounder (bathymetry, B-1-06-TB; Figure 1-3). The sonar was deployed from the *R/V Frontier*, a 25-ft (7.6 m) USGS research vessel that was specially outfitted for mapping.

Navigation for the research vessel and all data were collected using Differential Global Positioning System (DGPS). Processing parameters for the data set are reported in Chapter 2 of this report. Perspective views of the data were generated using Surfer software (http://www.goldensoftware.com/products/surfer/surfer.shtml; Figure 1-4). An oversized map sheet of bathymetry at a scale of 1:24,000 accompanies this report.

Sediment samples were collected in August 2005 (F-1-05-TB) using a small Van Veen grab sampler (10 x 5 mm) across the channel and main bay using the sampling scheme of McCormick and others (1994) (Figure 1-2). Grain size analysis data are summarized in Table 1-1 and provided in the Appendix as a Microsoft Excel workbook. Separate worksheets in the workbook present the standard Folk, Ward, and Inman (1957) sediment parameters, and sample distribution by 0.25-phi intervals.

Bathymetry

Tomales Bay can be divided into three distinct areas, the mouth, central bay, and south bay (Areas A, B and C, respectively, Figure 1-5). The mouth of the bay covers the area from north of Avalis Beach and Lawsens Landing south to Pelican Point and Blakes Landing. This area consists of the main tidal channel with large sand waves formed by ebb and flood tidal currents, and smaller, narrow tidal runoff channels. The central bay extends from Blakes Landing and Pelican Point to Marconi on the east and Hearts Desire Beach on the west. The south bay extends from Marconi and Hearts Desire Beach to an area south of Millerton Point along the east to the town of Inverness on the west. This area is relatively flat and shallow with water depths decreasing rapidly toward the Lagunitas Creek delta.

No bay floor features that relate to the San Andreas Fault were observed on the collected imagery.

Area A (Figures 1-4A, 1-4B, 1-5): The mouth of the bay, contains sand waves and subaqueous dunes. These sand waves and dunes are produced by tidal flow in the narrow confines of the northern portion of the bay. The morphology of the subaqueous dunes, with steep lee slopes, suggests a predominant flood orientation and dominance of flood tides over ebb tides. These sand waves are found along every channel surveyed in this part of the north bay. The deepest portions of this area are located near the mouth at Avalis Beach (17-18 m), the area across the channel from Toms Point (14-15.9 m), southeast of White Gulch (19 m), northwest of Preston Point (16-17.9 M), and southeast of Pelican Point (16-17.9 m) (Map Sheet 1).

Area B (Figure 1-5): The central bay is a relatively flat area with an average depth of 6 m, scattered rock outcrops in the northern part of the area (south of Pelican Point), and deep (as much as 14 m) depressions adjacent to promontories along both the west and east sides of the bay. From north to south along the west side of the bay the depressions are found off of Pelican Point, the point south of Tomales Beach, north of Marshall Beach, and the point south of Lairds Landing. Depressions are also found along the east side of the bay (from north to south) near Cypress Grove, Reynolds, and

Marconi (Figure 1-4C; Map Sheet 1).

Area C (Figure 1-5): The southeastern portion of the bay consists of a relatively flat area with what appears to be the leading edge of the Lagunitas Creek delta along the eastern side. Only slight variations in water depth are visible in the shaded relief map (Figure 1-4D; Map Sheet 1). Along the western side of the bay nine small depressions lie offshore of small rocky outcrops.

Sediment

Sediment found in Tomales Bay tend to decrease in grain size from the mouth in the north toward the south, becoming progressively finer grained approaching the south bay (Figure 1-6). Coarse to medium sand is found at the mouth of the bay in contrast to fine- to very fine-grained sand just south of Pelican Point on the west side of the bay. Along the east side of the bay from near the Walker Creek delta to Blakes Landing the sediment becomes much finer, from fine sand to coarse silt. Fine to very fine sand is found along the margins of the estuary near the mouths of streams that drain the watersheds to along the east and west sides of the bay. In the central and south areas, south of Pelican Point, the sediment size ranges from medium to very fine silt. We did not sample the sediment south of Shallow Beach (most of Area C) due to shallow depths.

Foraminifera

Results of the foraminifera analysis are reported in Chapter 3 and summarized here. The Q-mode cluster analysis of the presence/absence data from 27 sites collected in 2005 grouped the census data into two clusters and two outliers (Figure 1-7). The clusters separated the sites approximately north and south of Walker Creek, forming the North Bay and Middle Bay assemblages, respectively (Figure 1-7).

The North Bay assemblage consists of seven samples from Sand Point to Walker Creek characterized by the presence of *Elphidium crispum, Glabratella* sp., *Nonionella basispinata, Cibicides* sp., *Tricholyalus ornatissima, Elphidiella hannai,* and *Buccella frigida,* as well as a few other rare species. The two outliers (F1-05-TB-2 and F1-05-TB-5) are coarse sand samples that are also located north of Walker Creek (Figure 1-7). The first contains rare *Tricholyalus ornatissima,* whereas the second has rare *Rotorbinella* sp. and *Buccella frigida*. According to Lankford and Phleger

(1973) and McGann (2007), most of the species of the North Bay assemblage are characteristic of fully marine, nearshore environments.

The Middle Bay assemblage is represented by 17 samples south of Walker Creek and one to the north at Toms Point (Figure 1-7). These sites are characterized by an estuarine foraminiferal fauna. The invasive species *Trochammina hadai* has been recovered in all of these samples except at site F1-05-TB-15. Of those samples that have been qualitatively evaluated, foraminiferal abundance is high, as is faunal diversity (17-21 species/sample). Common species include *Ammonia beccarii, Elphidium excavatum, Elphidiella hannai, Buccella frigida, Buliminella elegantissima, Fursenkoina pontoni, Hopkinsina pacifica, Bolivina* spp., and *Fissurina* spp., among others.

Acknowledgments

The Coastal and Marine Geology program of the U.S. Geological Survey (USGS) provided funding for this research. We wish to thank Ben Becker (PRNS) for allowing us to use the facilities at Point Reyes National Seashore for staging our surveying operation. We want to thank Mike Boyle, and Larry Kooker, USGS electronic technicians, who set up and operated the mapping system; Andy Stevenson (USGS) who was stationed onshore to do the initial data processing; and Gerry O'Brien and Gregory Gable (USGS), who served as our boat operators. This manuscript benefited from reviews by Curt Storlazzi and Jamie Conrad.

References:

Clark, J.C., and Brabb, E.E., 1997, Geology of the Point Reyes National Seashore and Vicinity, Marine County, California: A Digital Database: U.S. Geological Survey Open-File Report 97-456 [http://pubs.usgs.gov/of/1997/of97-456/]

Folk, R.L., and Ward, W.C., 1957, Brazos River bar, a study in the significance of grain-size parameters: Journal of Sedimentary Petrology, v. 27, p. 3-27.

U.S. Geological Survey field activity data

F-1-04-TB http://walrus.wr.usgs.gov/infobank/f/f104tb/html/f-1-04-tb.meta.html

F-1-05-TB http://walrus.wr.usgs.gov/infobank/f/f105tb/html/f-1-05-tb.meta.html

F-2-05-TB http://walrus.wr.usgs.gov/infobank/f/f205tb/html/f-2-05-tb.meta.html

B-1-06-TB http://walrus.wr.usgs.gov/infobank/b/b106tb/html/b-1-06-tb.meta.html

Table 1-1. Summary grain size properties for grab samples collected in 2005 from Tomales Bay, California. See Table 1-2 for complete analyses.

Sample #	% Gravel	% Sand	% Silt	% Clay	% Mud	Mean Phi	Mean mm	Std. Dev.	Variance
TB-1	5.98	94.02	0.00	0.00	0.00	0.25	0.84	0.58	0.34
TB-2	0.00	100.00	0.00	0.00	0.00	1.30	0.41	0.23	0.05
TB-3	2.19	97.81	0.00	0.00	0.00	1.27	0.41	0.68	0.46
TB-4	0.00	100.00	0.00	0.00	0.00	1.85	0.28	0.56	0.31
TB-5	13.39	84.28	1.70	0.62	2.33	1.31	0.40	1.66	2.76
TB-6	0.00	99.30	0.70	0.00	0.70	1.58	0.33	0.62	0.38
TB-7	0.00	94.04	4.39	1.57	5.96	2.62	0.16	1.17	1.38
TB-8	0.00	93.49	4.83	1.69	6.51	2.47	0.18	1.25	1.56
TB-9	0.00	94.36	3.63	2.01	5.64	2.34	0.20	1.33	1.77
TB-10	0.00	78.81	15.72	5.47	21.19	3.31	0.10	1.94	3.78
TB-11	0.00	70.79	22.48	6.72	29.21	4.02	0.06	1.81	3.29
TB-12	0.00	1.15	75.35	23.50	98.85	6.58	0.01	1.82	3.30
TB-13	0.00	10.73	69.65	19.61	89.27	6.04	0.02	1.98	3.93
TB-14	0.00	94.61	3.33	2.06	5.39	3.01	0.12	1.15	1.33
TB-15	2.37	88.57	6.85	2.21	9.06	2.06	0.24	1.81	3.28
TB-16	0.00	8.92	61.20	29.88	91.08	6.69	0.01	2.21	4.90
TB-17	0.00	23.31	52.26	24.42	76.69	5.98	0.02	2.54	6.47
TB-18	0.00	1.19	66.41	32.40	98.81	7.04	0.01	1.88	3.53
TB-19	0.00	0.44	60.76	38.80	99.56	7.46	0.01	1.73	3.00
TB-20	0.00	93.82	3.68	2.51	6.18	2.75	0.15	1.42	2.02
TB-21	0.00	0.00	56.20	43.80	100.00	7.76	0.00	1.60	2.57
TB-22	0.00	0.00	54.10	45.90	100.00	7.86	0.00	1.55	2.40
TB-23	26.21	46.50	13.53	13.76	27.28	2.22	0.21	4.00	16.04
TB-24	0.00	1.73	51.37	46.90	98.27	7.77	0.00	1.71	2.93
TB-25	0.00	0.00	49.70	50.30	100.00	8.04	0.00	1.49	2.23
TB-26	0.00	0.03	54.47	45.50	99.97	7.83	0.00	1.58	2.49
TB-27	15.80	76.64	5.11	2.44	7.55	1.06	0.48	2.17	4.69

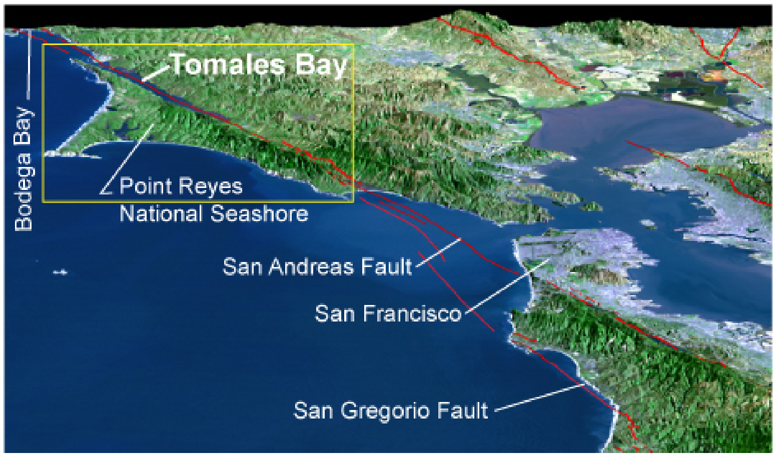


Figure 1-1. Perspective view of Tomales Bay and nearby San Francisco Bay area, California.

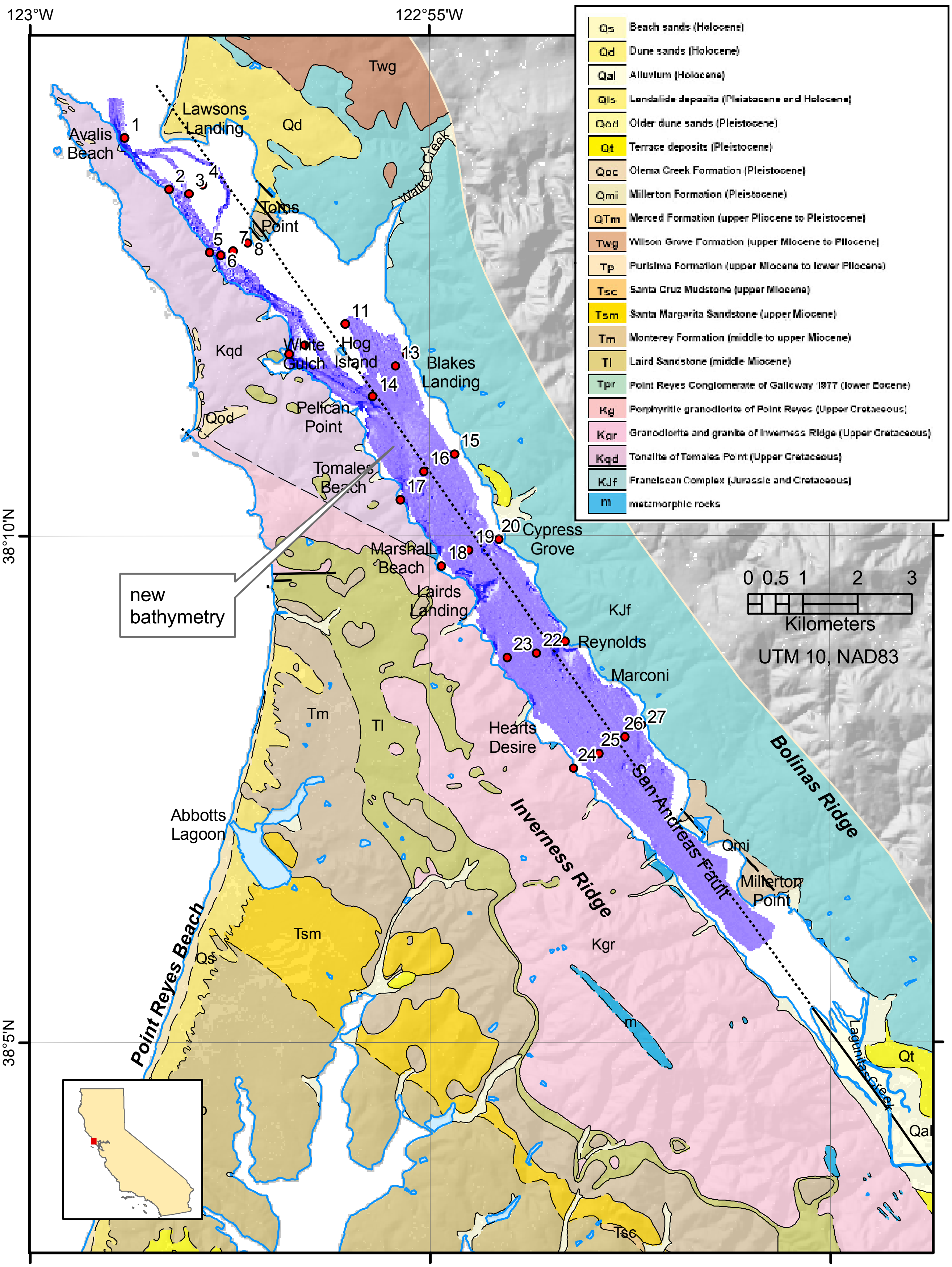


Figure 1-2. Geologic setting of multibeam bathymetry and sediment samples collected in Tomales Bay area (after Clark and Brabb, 1997).

Figure 1-3. Interferometric sidescan sonar data collection equipment.

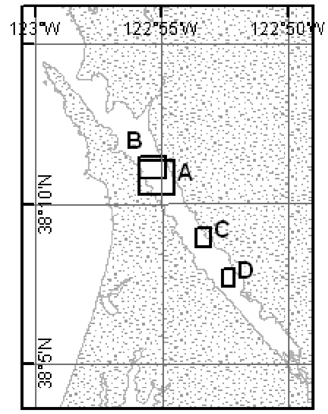
A. Navigation screen in the electronics "sugar shack."

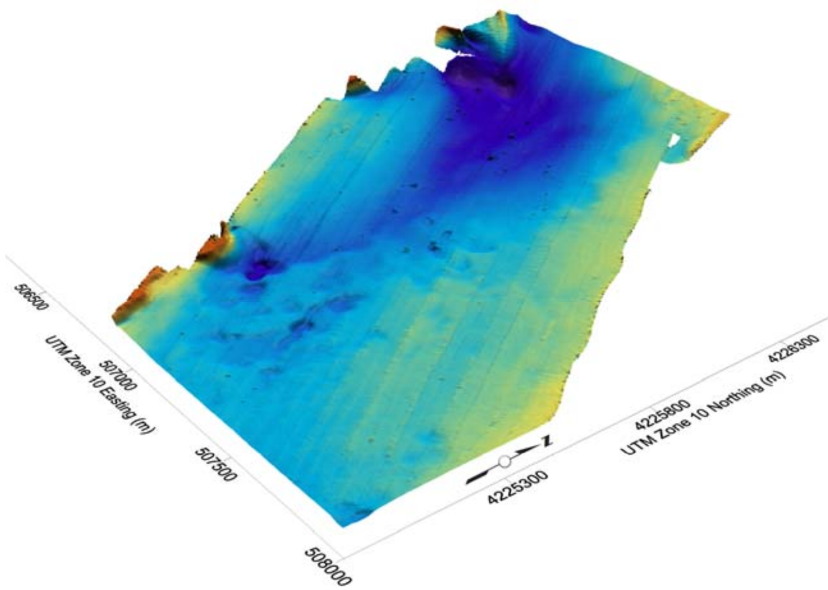
C. SEA SWATHplus computer (blue case) integrates the incoming soundings with GPS fixes, and ship pitch, roll, and yaw from the motion sensor (magenta box), to produce the final data set.

B. Dual monitors for incoming swath-bathymetry data. Left screen shows swath coverage, signal strength, and reflectance (backscatter). Right screen shows control dialog boxes.

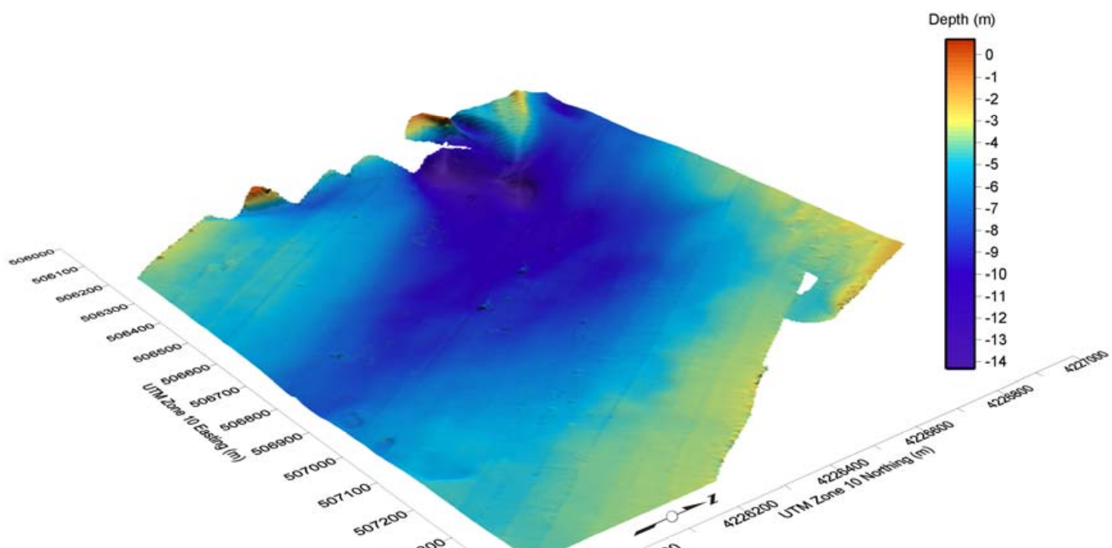
D. Side mounted transducer visible just below the water line (circled in blue). Depth of the transducer is adjustable with a block and tackle arrangement.

Figure 1-4. Perspective views of interferometric sidescan sonar bathymetric data, Tomales Bay, California. Perspective images generated with Surfer software (described in text).



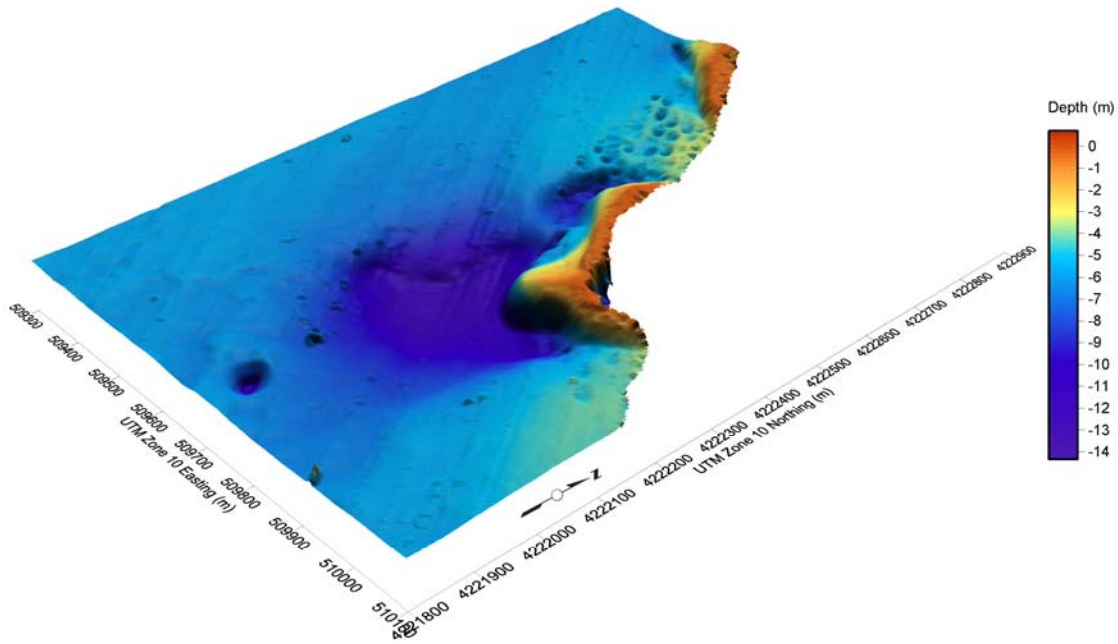


A. View of the west side of Tomales Bay from Tomales Beach (top) southward (see index map for location). The depression in the middle of the image is 12 m deep. Average surrounding water depth is 5 m. See B. for depth legend.

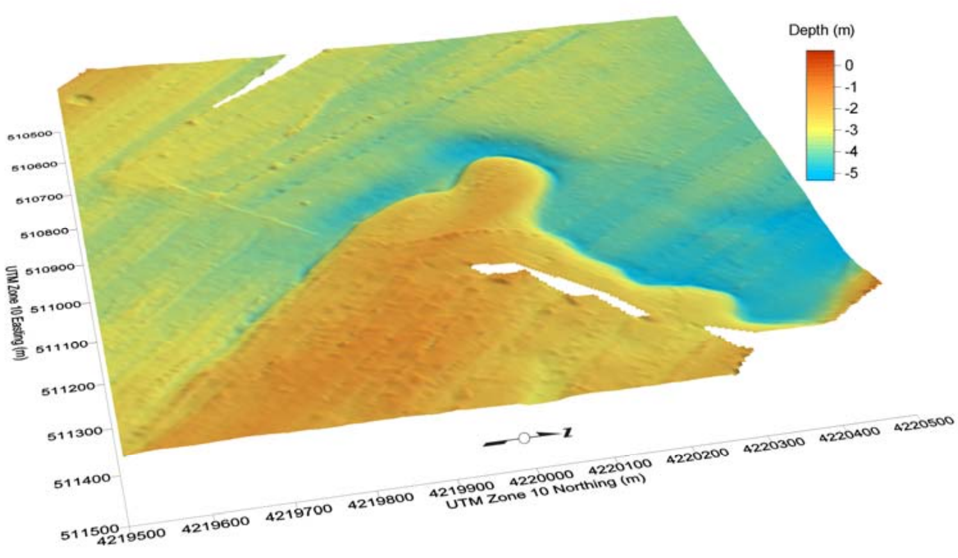


B. Close-up of the northern extent of the area shown in A. Adjacent to Pelican Point, sand waves extend into the double depression (purple near top of image). The depression on the east is 17.4 m deep, the one to the west is 18.0 m deep. The sand waves lie between 5 m and 16 m water depth. Average depth is 8 m.

Figure 1-4. (continued)



C. View over the point near Reynolds toward the mouth of the bay. The depression (light to dark blue) adjacent to the point is 14.3m deep. Average surrounding water depth is 4.7 m.



D. View from the edge of the Lagunitas Creek delta at the southern end of Tomales Bay. The average depth of the delta is 3.4 m and the average depth at the margin of the delta is 6.0 m. The average depth in the area is 5 m.

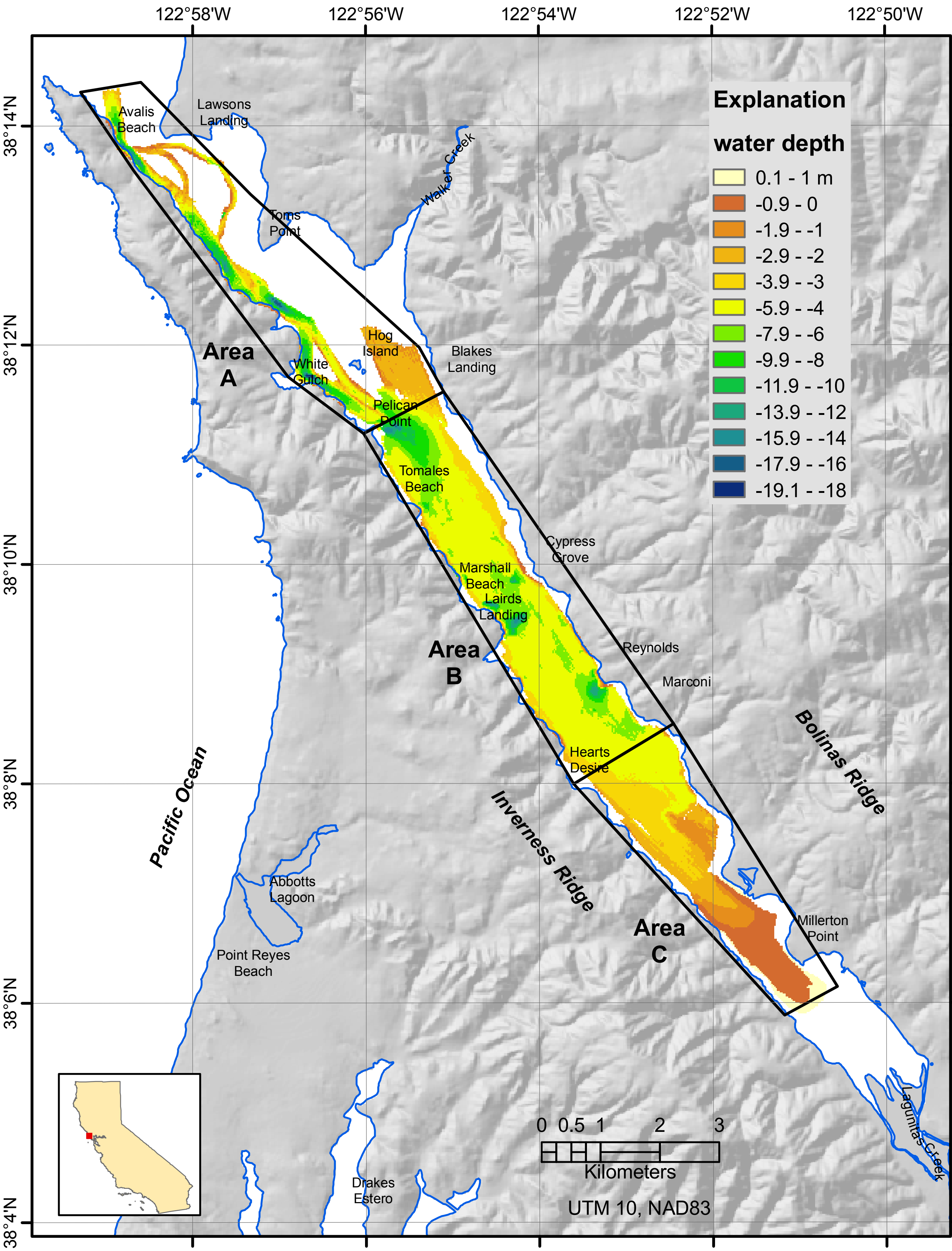


Figure 1-5. Mouth (A), central (B), and south (C) areas of Tomales Bay, California, including new bathymetry described in this report.

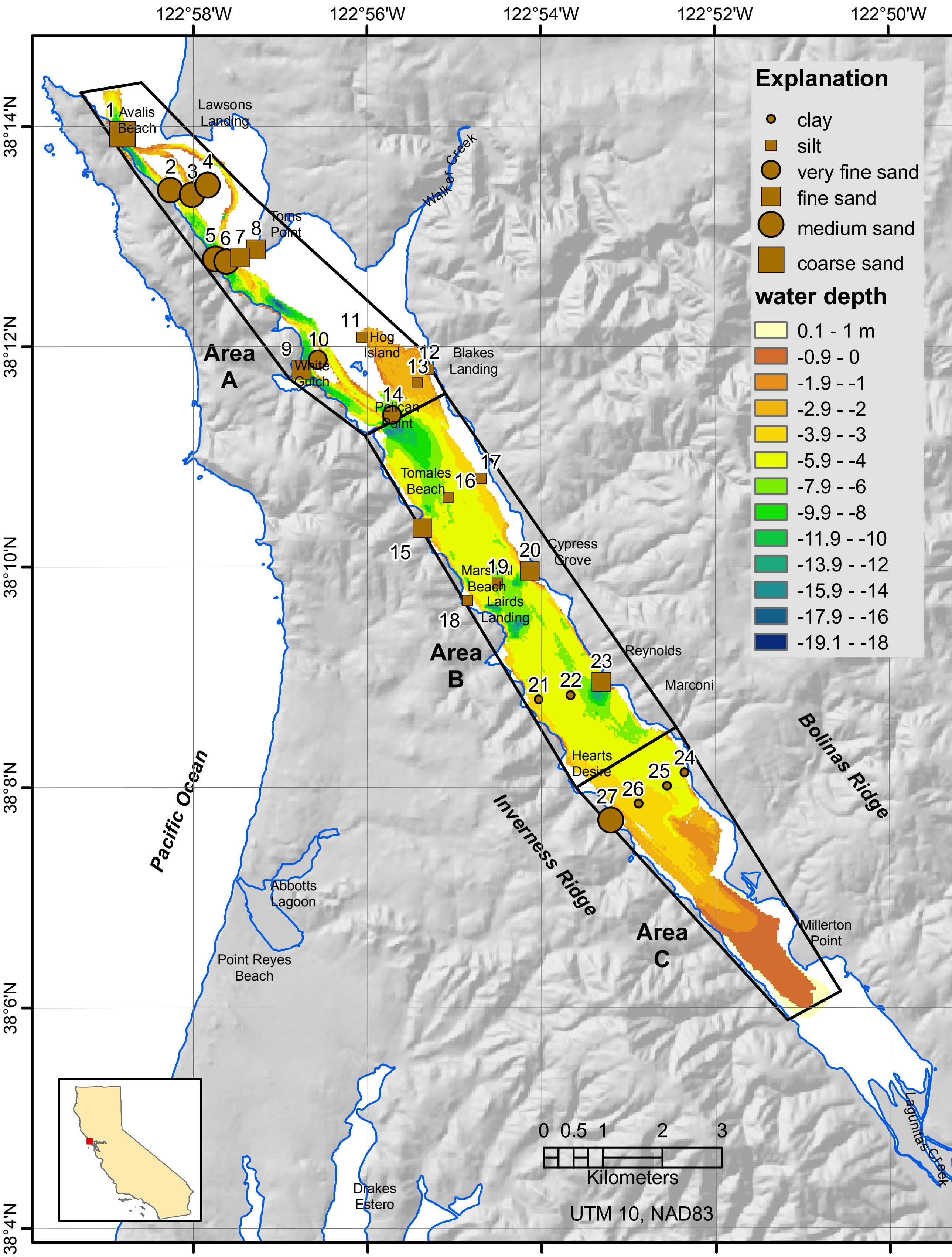


Figure 1-6. Grain size and locations of sediment samples from Tomales Bay, California.

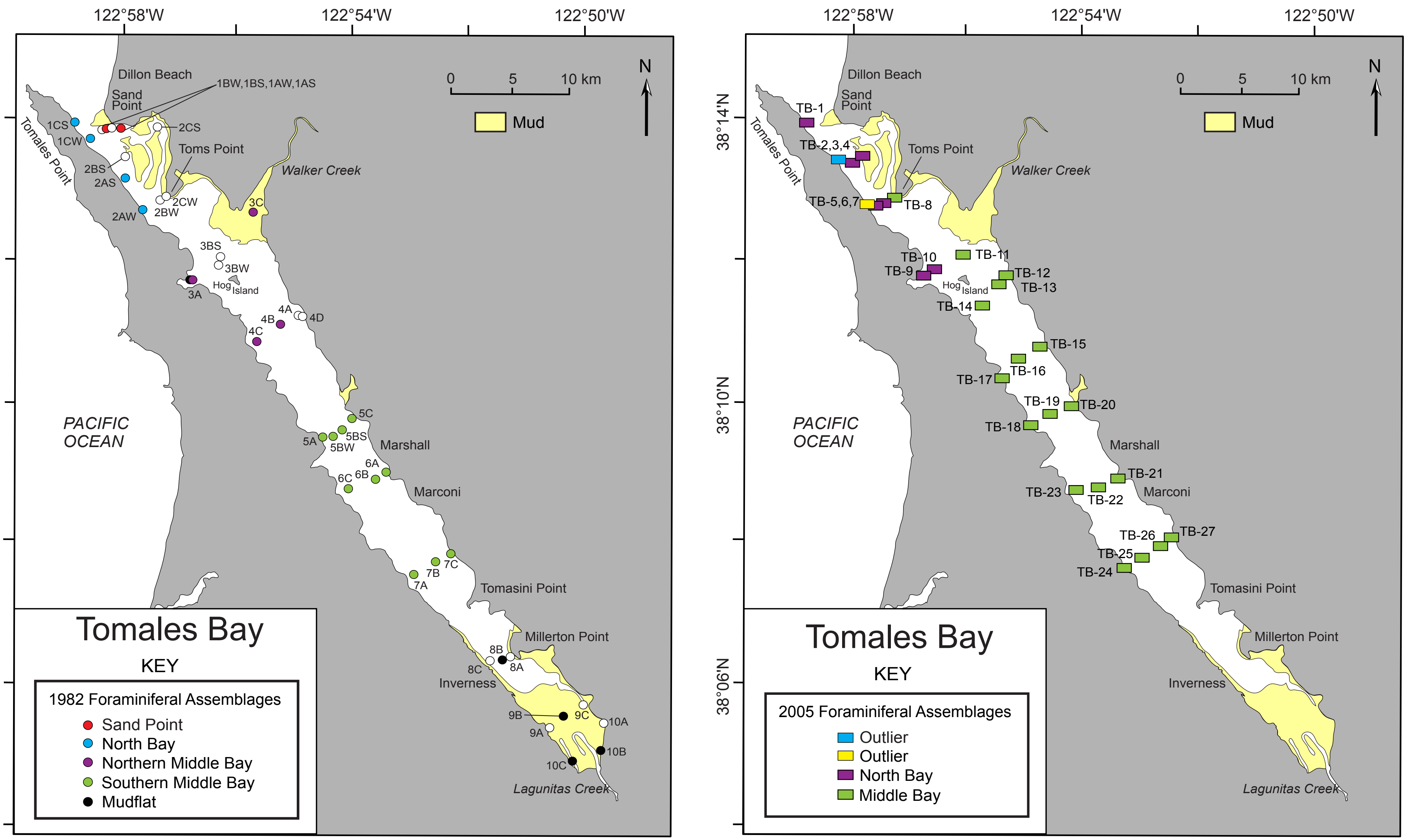


Figure 1-7. Comparison of 1982 and 2005 foraminiferal assemblages in Tomales Bay, California.

Chapter 2. Sonar Processing Procedures

by David P. Finlayson

The Tomales Bay bathymetry Digital Elevation Model (DEM) is composed of data from three bathymetric surveys collected between November 2004 and August 2006 (see Table 1). During the 2004 and 2005 surveys, the northern and central bay surveys (F-1-04-TB and F-2-05-TB, respectively) were conducted using an interferometric sidescan system, which collected both bathymetry and backscatter data. In 2006, the shoal tidelands in the southern portion of the bay were surveyed (B-1-06-TB) using a single-beam echo sounder for bathymetry only. The final bathymetry data set described in this report is a composite of these three surveys. The acoustic backscatter data were processed for the northern and central surveys.

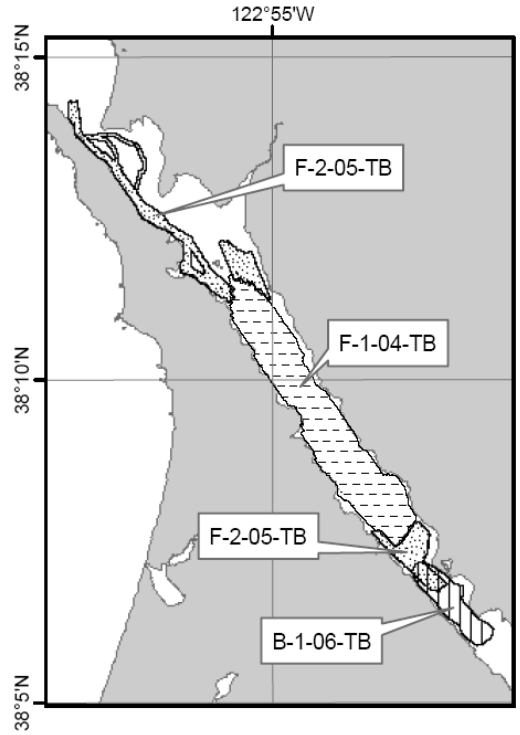


Table 1: List of surveys

USGS CMG ID	Date	Chief Scientist	Sonar
F-1-04-TB	November 2004	John Chin	SEA SWATHplus Interferometric Sidescan
F-2-05-TB	November 2005	Roberto Anima	SEA SWATHplus Interferometric Sidescan
B-1-06-TB	August 2006	John Chin	ESE50 Echo Sounder with AshKin GPS kinematic corrections

Swath Bathymetry

Swath bathymetry for the northern and central portions of Tomales Bay (cruise F-1-04-TB and F-2-05-TB) were collected using a pole-mounted, SEA Inc., 234 kHz, SWATHplus interferometric sidescan sonar system (see Glossary). Attitude compensation and vessel positioning were provided by a CodaOctopus F180 attitude and positioning system. Sound velocity profile measurements were collected with an Applied Micro Systems, SvPlus 3472.

The horizontal datum of the surveys was established by differential GPS using the WGS84 ellipsoid. The vertical datum of the surveys was based on Mean Lower Low

Water (MLLW) predictions for Marshall, Tomales Bay, using the software Tides and Currents by Nobeltec.

Raw bathymetry and amplitude data were collected using the Swath Processor software provided with the SEA SWATHplus sonar system and gridded at 1 m resolution using the accompanying Grid Processor software package. These raster data were then exported to Fledermaus, edited and smoothed in that package and finally exported to ESRI ASCII Grid format using USGS in-house software.

The uncertainty in bathymetric measurements collected by the SWATHplus is a complex function of the GPS navigation, short and long period motion compensation, the sonar propagation model and the intrinsic resolution of the system. An estimate of the uncertainty can be obtained by comparing soundings from independent, overlapping track lines. Assuming that differences between overlapping soundings are normally distributed, twice the standard deviation of differences represents the 95% confidence level in the bathymetry. For survey F-1-04-TB, the mean and standard deviation of overlapped soundings was -0.10 m and 0.76 m, respectively. For survey F-2-05-TB, the mean and standard deviation was 0.01 m and 0.48 m, respectively. Therefore, a conservative estimate of the bathymetric uncertainty in the data is about 1.52 m overall (2 times 0.76 m). However, a comparison of grid elevations having overlapping coverage between the 2004 and 2005 surveys revealed a 1.44 m vertical offset (median of all overlapping cells). This error may be due to a misconfiguration of the F180 unit, but the exact cause of the error is unknown. In the final DEM, a static offset of +1.44 m was added to the 2004 data to minimize the vertical offset between the 2004 and 2005 data. This static error combined with the statistical uncertainty in the soundings suggests that the total propagated error in the survey is likely to be greater than 1.50 m.

Single-Beam Bathymetry

Single-beam echo sounder data were collected over the shallow tidelands of southern Tomales Bay during August 2006 (cruise B-1-06-TB). A pole-mounted ESE50 Echo sounder with a co-located Real-time kinematic (RTK) GPS receiver system provided real-time vertical and horizontal positioning of the sonar transducer during operations. These data were reduced to positional soundings on the sea floor using HYPACK (version 6.2) with a 30-second averaging period (to remove heave), gridded into a 10-m resolution DEM using Surfer version 8.0, and exported to ESRI ASCII Grid format using USGS in-house software.

The horizontal and vertical datum of the survey was established by the RTK GPS system as WGS84 and NAVD88, respectively. The error ellipse on the location of the GPS receivers is typically < 5 cm and this propagates through to the sea floor with RMS errors on sea bed elevation of < 10 cm.

4 m Composite Bathymetry

Each of the three surveys was resampled to a 4 m cell spacing using the Spline Smooth tool of Surfer 8. The swath bathymetry was converted from MLLW to NAVD88 vertical datum using VDatum (NOAA Office of the Coast Survey and National Geodetic Survey), and then the three surveys were blended together in ESRI ArcGIS using the MOSAIC TO NEW RASTER tool with the blend option. The final data set was trimmed to the convex hull of the survey data area.

Acoustic Imagery

The SWATHplus interferometric sidescan stores backscatter amplitude with each bathymetric sounding. These amplitude data can be plotted to produce an acoustic image of the sea floor. Cell values in the image represent the relative strength of the acoustic signal returned (backscattered) to the transducer off of the sea bed. A cell value equal to 1.0 is an average strength return, cell values above 1.0 are relatively stronger than average; values less than 1 are below average strength returns.

The first step in the procedure applies an empirical gain function to the raw soundings to counteract systematic artifacts observed in the amplitude values that are associated with variable slant-ranges and grazing angles. The procedure normalizes the raw amplitude values with the mean amplitude of all soundings in the survey collected at similar ranges and depths from the transducer. Second, the normalized amplitude values are gridded using the Generic Mapping Tools (GMT). Third, the amplitude grid is converted to ESRI ASCII grid format, loaded into ArcGIS and the surveys from the two years (F-1-04-TB and F-2-05-TB) are mosaicked together.

Glossary

Applied Micro Systems, SvPlus 3472 sound velocity collector
    http://www.appliedmicrosystems.com/
CodaOctopus F180 attitude and positioning system
    http://www.codaoctopus.com/motion/f180/techspec.asp
DEM digital elevation model
ESE50 echo sounder
ESRI geographic information systems software
    http://webhelp.esri.com/arcgisdesktop/9.2/
Generic Mapping Tools (GMT) http://gmt.soest.hawaii.edu/
HYPACK 6.2 survey software http://www.hypack.com/default.aspx
Nobeltec Tides and Currents software http://www.nobeltec.com/products/prod_tides.asp
SEA SWATHplus interferometric sonar system http://www.jrm-software.co.uk/swathplus.aspx?nav=products
Surfer 8.0 surface gridding software
    http://www.goldensoftware.com/products/surfer/surfer.shtml
VDatum vertical datum software http://nauticalcharts.noaa.gov/csdl/vdatum.htm

Chapter 3. 2005 Tomales Bay Foraminiferal Study

by Mary McGann

1. Introduction

The first comprehensive study of the distribution of foraminifera in Tomales Bay was undertaken in 1982 by McCormick et al. (1994). Fifty-two species were identified from 30 sites collected along ten transects in both the winter and summer, with two replicates from each site (Figure 3-1). All of the species recovered are common today either nearshore, in shallow embayments, or in estuaries along the Pacific Coast of North America (Ingle, 1980; Jennings and Nelson, 1992; McCormick and others, 1994; McGann, 2007; Murray, 1991; Phleger, 1967; Scott and others, 1976).

In 1995, the common estuarine Japanese foraminifera *Trochammina hadai* Uchio was first identified as an invasive along the western coast of the United States when it was discovered in sediment of San Francisco Bay (McGann and Sloan, 1996, 1999). A re-examination of archived sediment samples and past literature suggests that the species actually had been introduced between 1981 and 1983 (McGann et al., 2000). Since that time, *T. hadai* has become a dominant foraminifer in San Francisco Bay, constituting up to 93% of the foraminiferal fauna. This pattern of expansion shows how quickly an invasive microorganism may proliferate in its new environment. *Trochammina hadai* has now been found in 14 ports and estuaries from San Diego Bay to Prince William Sound, including Tomales Bay (McGann et al., 2000; McGann, unpublished data).

The goal of this study is to determine how widespread the present occurrence of the invasive Japanese microorganism is in Tomales Bay and to provide a preliminary assessment of the distribution of foraminifera in the bay in 2005 compared to the baseline study undertaken in 1982. A future publication will generate a detailed 2005 spatial distribution pattern of foraminifera in the bay and address how the ecosystem has been altered due to this recent marine bioinvasion.

2. Methods

In August 2005, 27 sediment samples were collected in Tomales Bay in the general vicinity of those sites sampled in the 1982 baseline study (Figure 3-1). The uppermost two centimeters of sediment were obtained by a grab sampler and analyzed for foraminifera. These sediment samples were wet-sieved through nested 63 µm, 150 µm and 1.0 mm screens to remove the clays (<63 µm) while minimizing damage to the finer screens. The >63 µm-size fractions were recombined and a mixture of isopropyl alcohol and rose Bengal stain was added to each sample in order to identify foraminifers that were living or recently alive at the time of collection (Bernhard, 1988, 2000). After soaking for a day, the stained sediment samples were again wet-sieved through the three screens to segregate the size fractions. The remaining sediment was transferred to filter paper and air-dried.

Foraminifers were extracted from the >63 µm fraction of the dried sediment. Samples were split with the aid of a microsplitter into an aliquot containing at least 300 benthic foraminifers and all specimens were picked and identified. If the sample contained <300 foraminifers, all that were present were picked. If necessary, samples that contained few foraminifers were subjected to heavy liquid separation by sodium polytungstate in order to concentrate the foraminifers before picking. The foraminiferal slides and residues of this study are on file at the U.S. Geological Survey, Menlo Park, California.

Relative foraminiferal species abundances for the census data collected in 1982 (McCormick et al., 1994) were computed using a sum of benthic foraminifers in those samples with >100 foraminifers. Once converted to frequency data, a Q-mode cluster analysis described the relationship between the benthic foraminiferal assemblages. The cluster analysis grouped the samples according to their degree of similarity. Clustering was based on a square root transformation of the data, a Bray-Curtis similarity coefficient, and amalgamated by a group averaged linkage strategy (Clarke and Gorley, 2006). Primer v. 6, a statistical software package created by Primer-E, Ltd., was used for this analysis (Clarke and Gorley, 2006).

Presence/absence data for the census data collected in 2005 in Tomales Bay were also subjected to a Q-mode cluster analysis using Primer v. 6. A Sørenson similarity coefficient was used, which is the equivalent of the Bray-Curtis but calculated on presence/absence data (Clarke and Gorley, 2006) and the data were amalgamated by a group-averaged linkage strategy.

3. Results

A minimum of 33 species of benthic foraminifers were identified in the samples collected in Tomales Bay in 2005 (Table 3-1), including both arenaceous and calcareous taxa. Of these species, the most common are *Ammonia beccarii* (Linné), *Buccella frigida* (Cushman) [*Buccella tenerrima* (Bandy) of McCormick et al., 1994], *Elphidiella hannai* (Cushman and Grant), *Elphidium crispum* (Linné), *Elphidium excavatum* (Terquem) [*Cribroelphidium excavatum* (Terquem) of McCormick et al., 1994], *Glabratella* sp., *Trochammina hadai*, and *Trichohyalus ornatissima* (Cushman) [*Glabratella ornatissima* (Cushman) of McCormick et al., 1994] (Table 3-2). In 2005, the invasive foraminiferal species *T. hadai* was present throughout much of the bay, occurring at 17 of 27 sites. Other biologic constituents recovered include diatoms, ostracods, amphipods, thecamoebians, and questionable spores.

4. Discussion

Presence of *Trochammina hadai*

The invasive species *T. hadai* was not found in Tomales Bay in the 1982 baseline study but is spatially widespread in 2005 (Figure 3-1). The species was not recovered in the turbulent waters near the opening of the bay at Sand Point and Tomales Point, but it is present in the lower energy region from Toms Point to southwest of Marconi, similar to its occurrence in many ports and bays along the western United States (McGann et al., 2000). Although samples were not obtained south of Tomasini Point in 2005, the invasive species could also be present on the mudflats from Millerton Point to Lagunitas Creek, as it lives in these environments in many other estuaries (McGann et al., 2000; McGann, unpublished data).

Trochammina hadai accounts for up to 15% of the foraminiferal assemblage in the Tomales Bay samples in 2005. Although the species' abundance is not nearly as high as in nearby San Francisco Bay (McGann et al., 2000), it still constitutes a significant portion of the assemblage.

Trochammina hadai was probably transported from Japan to western North America in ballast sediment, in anchor mud, or in sediment associated with oysters imported for mariculture (McGann et al., 2000). At this time it is not known precisely when the species was introduced into Tomales Bay, but it most likely occurred after 1982.

1982 Baseline Foraminiferal Study

The Q-mode cluster analysis of the census data of the foraminiferal distributions in Tomales Bay in 1982 generated by McCormick et al. (1994) grouped into five clusters (Figure 3-2). It identified these assemblages: Sand Point, North Bay, Northern Middle Bay, Southern Middle Bay, and Mudflat (Figure 3-3; Table 3-3).

Only two summer samples (1A2S and 1B2S) grouped to form the Sand Point assemblage. The fauna of this assemblage is characteristic of turbulent water (McCormick et al., 1994) with its dominance (77-86%) by *Trichohyalus (Glabratella) ornatissima* and presence of fully marine nearshore species *Elphidium crispum* and *Cassidulina limbata*.

Eight samples (both winter and summer of sites 2A and 1C) combined to form the North Bay assemblage. This represents a more diverse assemblage, with 34 species present in contrast to only seven in the Sand Point assemblage. The dominant species include *Buccella frigida* (*Buccella tenerrima* of McCormick et al., 1994), *Elphidium (Cribroelphidium) lene*, and *Rotorbinella campanulata*, with abundant *Buliminella elegantissima*, *Cibicides lobatulus*, and *Elphidium (Cribroelphidium) excavatum*, and occasionally abundant *Elphidiella hannai* and *Rosalina globularis* (*Rosalina* *columbiensis* of McCormick et al., 1994). These species are characteristic of fully marine, nearshore environments (Lankford and Phleger, 1973; McGann, 2007).

The Northern Middle Bay assemblage is a compilation of 10 samples (sites 3A, 3C, 4B and 4C) from the winter and summer of 1982. The dominant species in this assemblage are *Elphidiella hannai, Buliminella elegantissima, Buccella frigida,* and *Elphidium excavatum*. Other common species include *Elphidium lene* and *Hopkinsina pacifica*. This assemblage is a combination of nearshore and estuarine species, and therefore represents a transitional fauna between the turbulent waters to the north and the quieter conditions to the south.

The Southern Middle Bay assemblage is represented by the highest number of samples (25) in the study of McCormick et al. (1994) grouped by the cluster analysis. The northern subgroup of the assemblage (14 winter and summer samples from sites 5A, 5B, 5C, and 6B) is characterized by abundant *Elphidiella hannai, Buccella frigida,* and *Elphidium excavatum* as in the Northern Middle Bay assemblage, but has more abundant *Hopkinsina pacifica,* as well as *Bulimina denudata, Ammonia beccarii,* and *Bolivina* spp., few *Buliminella elegantissima*, and only very rare *Elphidium lene*. The southern subgroup of the assemblage (11 winter and summer samples from sites 6A, 6C, 7A, 7B, and 7C) is more characteristic of a lower energy, estuarine environment with dominant *Hopkinsina pacifica* and *Ammonia beccarii,* as well as common *Fursenkoina pontoni, Bulimina denudata* and *Buliminella elegantissima*, and lesser amounts of *Elphidium excavatum* and *Bolivina* spp. The Southern Middle Bay assemblage is typical of subtidal estuarine environments, similar to modern faunas in San Francisco Bay estuary (San Pablo, Richardson, Central, and South bays; Arnal and others, 1980; Locke, 1971; Means, 1965; Quinterno, 1968; Slater, 1965). Foraminifera are abundant and the fauna is diverse (42 species recovered), with both arenaceous and calcareous taxa represented.

Nine samples were grouped into the Mudflat assemblage (winter and summer samples of sites 3A, 8B, 9B, and 10B). The foraminiferal assemblage is dominated by two species: *Elphidium excavatum* and *Ammonia beccarii*. Surprisingly, two samples from site 3A (i.e., 3A1-S and 3A2-S) located north of Hog Island clustered with the mudflat samples at the southern portion of Tomales Bay; the clustering pattern being attributed to the overwhelming abundance (54-93%) of *Elphidium excavatum* in those samples. Thirteen other calcareous taxa are also present but occur only rarely, and arenaceous taxa are represented by nine species [*Ammobaculites catenulatus, Ammofrondicularia (Reophax?)* sp., *Haplophragmoides columbiensis, Miliammina fusca, Reophax communis, Reophax* sp., *Texularia agglutinans, Trochammina inflata*, and *Trochammina pacifica*]. Similar assemblages have been reported from the mudflat, marsh, and brackish waters regions in Suisun, Richardson, and San Pablo bays in the San Francisco Bay estuary (Connor 1975; Locke, 1971; Means, 1965; Slater, 1965), and Bodega Bay harbor (McGann, unpublished data). Foraminiferal faunas of these stressful environments, with wide ranging water temperatures and salinity, as well as high organic input, typically are characterized by high foraminiferal standing crops and low faunal diversity (Murray, 1973; Phleger, 1970). Particularly notable also is the abundance of *Ammofrondicularia (Reophax?)* sp. in sample 3A2-S, in which the species constitutes 44% of the foraminiferal assemblage.

Commonly, calcareous taxa are either present in rare abundances or are absent in marginal environments due to unfavorable physical and chemical conditions within the sediment. The low pH of mudflat and marsh soils commonly results in the dissolution of their tests and dominance by arenaceous taxa (Jennings and Nelson, 1992; Parker and Athern, 1959; Phleger, 1967; Scott and Medioli, 1980; Scott and Leckie, 1990). One would expect that to be the case in the samples from the mudflats at the extreme southern end of the bay (sites 9 and 10). However, the foraminiferal assemblages at these sites in Tomales Bay in 1982 were still dominated by calcareous taxa.

The five clusters identified here differ somewhat from those presented by McCormick et al. (1994) (Table 3-3). The difference is most likely due to the fact that their Q-mode cluster analysis was performed on the frequency abundances of only the 14 major species recovered whereas the present study utilized the abundance of 56 species (only *Bolivina* spp., *Quinqueloculina* spp., and unknowns were eliminated) from the samples containing more than 100 foraminifera total. McCormick et al. (1994) identified three major groups (turbulent zone, midbay, and bay ends), as well as a south bay subgroup. The turbulent zone stations were from 1CS to 3A and included the species *Rotorbinella campanulata, Trichohylaus (Glabratella) ornatissima,* and *Elphidium (Cribrononion) lene*. This group is roughly equivalent to the Sand Point and North Bay assemblages identified in the present study (Figure 3-3). Six estuarine species make up the midbay group occurring between stations 4B and 8B: *Quinqueloculina bellatula, Hopkinsina pacifica, Fursenkoina pontoni, Bulimina denudata, Bolivina (Brizalina) acuminata,* and *Bolivina (Brizalina) vaughani*. The estuarine species *Elphidiella hannai, Buccella tenerrima*, and *Buliminella elegantissima* comprise the bay ends group, and *Elphidium (Cribroelphidium) excavatum* and *Ammonia beccarii* were considered widespread species, occurring in nearly every sample. When combined, the midbay group, bay ends group, and widespread species of McCormick et al. (1994) are equivalent to the Middle Bay (Northern and Southern combined) assemblages in this study. Lastly, the south bay subgroup (samples 8A to 10C) is the equivalent of the mudflat assemblage of this study.

2005 Foraminiferal Study

The Q-mode cluster analysis of the presence/absence data from 27 sites collected in 2005 grouped the census data into two clusters and two outliers (Figure 3-4). The clusters separated the sites approximately north and south of Walker Creek, forming the North Bay and Middle Bay assemblages, respectively (Figure 3-5).

The North Bay assemblage grouped seven samples from Sand Point to Walker Creek which are characterized by the presence of *Elphidium crispum, Glabratella* sp., *Nonionella basispinata, Cibicides* sp., *Tricholyalus ornatissima, Elphidiella hannai*, and *Buccella frigida*, as well as a few other rare species. The two outliers (TB-2 and TB-5) are coarse sand samples that are also located north of Walker Creek (Figure 3-5). The first contains rare *Tricholyalus ornatissima,* whereas the second has rare *Rotorbinella* sp. and *Buccella frigida*. According to Lankford and Phleger (1973) and McGann (2007), most of the species of the North Bay assemblage are characteristic of fully marine, nearshore environments.

The Middle Bay assemblage is represented by 17 samples south of Walker Creek and one to the north at Toms Point (Figure 3-5). These sites are characterized by an estuarine foraminiferal fauna. The invasive species *Trochammina hadai* has been recovered in all of these samples except at site TB-15. Of those samples that have been qualitatively evaluated, foraminiferal abundance is high, as is faunal diversity (17-21 species/sample). Common species include *Ammonia beccarii, Elphidium excavatum, Elphidiella hannai, Buccella frigida, Buliminella elegantissima, Fursenkoina pontoni, Hopkinsina pacifica, Bolivina* spp., and *Fissurina* spp., among others.

The next phase of this study is to quantitatively analyze the 2005 foraminiferal samples. In the process, more assemblages may be identified and others better defined, making the comparison to the 1982 baseline data more meaningful.

5. References

Arnal, R. E., Quinterno, P. J., Conomos, T. J., and Gram, R., 1980, Trends in the distribution of recent foraminifera in San Francisco Bay, *in* Sliter, W. V., ed., Studies in Marine Micropaleontology and Paleoecology. A Memorial Volume to Orville L. Bandy: Cushman Foundation for Foraminiferal Research Special Publication 19, p. 17-39.

Bernhard, J. M., 1988, Postmortem vital staining in benthic foraminifera: duration and importance in population and distributional studies: Journal of Foraminiferal Research, v. 18, p. 143-146.

Bernhard, J. M., 2000, Distinguishing live from dead foraminifera; methods review and proper applications: Micropaleontology, v. 46, suppl. 1, p. 38-46.

Clarke, K. R., and Gorley, R. N., 2006, PRIMER v. 6, user manual/tutorial: Plymouth, UK, Prime-E Ltd., 190 p.

Connor, C. L., 1975, Holocene sedimentation history of Richardson Bay, California: M.S. thesis, Stanford University, Stanford, California, 112 pp.

Jennings, A. E., and Nelson, A. R., 1992, Foraminiferal assemblage zones in Oregon tidal marshes - relation to marsh floral zones and sea level: Journal of Foraminiferal Research, v. 22, p. 13-29.

Lankford, R. R., and Phleger, F. B, 1973, Foraminifera from the nearshore turbulent zone, western North America. Journal of Foraminiferal Research, v. 3, p. 101-132.

Ingle, J. C., Jr., 1980, Cenozoic paleobathymetry and depositional history of selected sequences within the southern California continental borderland. Cushman Foundation for Foraminiferal Research, Special Publication no. 19, p. 161-195.

Locke, J. L., 1971, Sedimentation and foraminiferal aspects of the recent sediments of San Pablo Bay: M.S. thesis, San Jose State College, San Jose, California, 100 pp.

McCormick, J. M., Severin, K. P., and Lipps, J. H., 1994, Summer and winter distribution of foraminifera in Tomales Bay, northern California: Cushman Foundation for Foraminiferal Research Special Publication 32, p. 69-101.

McGann, M., 2007, Foraminiferida, *in* Carlton, James T., ed., The Light and Smith Manual (4th ed.): Intertidal invertebrates from central California to Oregon: University of California Press, p. 46-69.

McGann, M., and Sloan, D., 1996, Recent introduction of the foraminifer *Trochammina hadai* Uchio into San Francisco Bay, California, USA: Marine Micropaleontology, v. 28, no. 1, p. 1-3.

McGann, M., and Sloan, D., 1999, Benthic foraminifers in the regional monitoring program's San Francisco estuary samples, *in* 1997 Annual report for the regional monitoring program for trace substances in the San Francisco estuary. Richmond, California, San Francisco Estuary Institute, p. 249-258.

McGann, M., Sloan, D., and Cohen, A. N., 2000, Invasion by a Japanese marine microorganism in western North America: Hydrobiologia, v. 421, p. 25-30.

Means, K. D., 1965, Sediments and foraminifera of Richardson Bay, California. M.A. thesis. University of Southern California, Los Angeles, California, 80 pp.

Murray, J. W. ,1991, Ecology and paleoecology of benthic foraminifera: Essex, Longman Scientific and Technical, 397 p.

Parker, F. L., and Athearn, W. D., 1969, Ecology of marsh foraminifera in Poponesset By, Massachusetts: Journal of Paleontology, v. 33, p. 333-343.

Phleger, F. B, 1967, Marsh foraminiferal patterns, Pacific Coast of North America: Ann. Institute Biolologie Universita National Auton. Mexico 38, Series Cienco Del Mar y Limnolologie, v. 1, p. 11-38.

Phleger, F. B, 1970, Foraminiferal populations and marine marsh processes: Limnology and Oceanography, v. 15, no. 4, p. 522-534.

Quinterno, P. J., 1968, Distribution of recent foraminifera in central and south San Francisco Bay: M.S. thesis, San Jose State College, San Jose, California, 83 pp.

Scott, D. B., and Medioli, F. S., 1980, Living vs. total foraminiferal populations – their relative usefulness in paleoecology: Journal of Paleontology, v. 54, p. 814-831.

Scott, D. B., Mudie, P. J., and Bradshaw, J. S., 1976, Benthonic foraminifera of three southern Californian lagoons: ecology and recent stratigraphy: Journal of Foraminiferal Research, v. 6, p. 59-75.

Scott, D. K., and Leckie, R. M., 1990, Marsh foraminifera of Prince Edward Island – their recent distribution and application for former sea level studies: Maritime Sediments and Maritime Geology, v. 17, p. 98-129.

Slater, R. A., 1965, Sedimentary environments in Suisun Bay, California: M.A. thesis, University of Southern California, Los Angeles, California, 104 pp.

Table 3-1. Benthic foraminifera identified in the 2005 Tomales Bay samples.

Ammonia beccarii (Linné)
Bolivina pacifica Cushman and McCulloch
Bolivina spissa Cushman
Bolivina subexcavata Cushman and Wickenden
Bolivina vaughani Natland
Buccella frigida (Cushman)
Bulimina denudata Cushman and Parker
Buliminella elegantissima (d'Orbigny)
Cibicides sp.
Elphidiella hannai (Cushman and Grant)
Elphidium crispum (Linné)
Elphidium excavatum (Terquem)
    Elphidium excavatum var. *selseyensis* (Heron-Allen and Earland)
    Elphidium excavatum var. *clavatum* Cushman
Fissurina cucurbitasema Loeblich and Tappan
Fissurina lucida (Williamson)
Fissurina spp.
Florilus labradoricus (Dawson)
Fursenkoina pontoni (Cushman)
Glabratella sp.
Hopkinsina pacifica Cushman
Miliolinella oblonga (Montagu)
Nonionella basispinata (Cushman and Moyer)
Nonionella stella Cushman and Moyer
Quinqueloculina sp.
Reophax nana Rhumbler
Rotorbinella sp.
Spiroplectammina biformis (Parker and Jones)
Suggrunda eckisi Natland
Textularia earlandi Phleger
Trichohyalus ornatissima (Cushman)
Trochammina charlottensis Cushman
Trochammina inflata (Montagu)
Trochammina kelletae Thalmann
Trochammina hadai Uchio
Trochammina vesicularis Göes

Table 3-2. Qualitative distribution of benthic foraminifera and other biological constituents in the 2005 Tomales Bay samples.

	Sample Number																										
Species	F1-05-TB-1	F1-05-TB-2	F1-05-TB-3	F1-05-TB-4	F1-05-TB-5	F1-05-TB-6	F1-05-TB-7	F1-05-TB-8	F1-05-TB-9	F1-05-TB-10	F1-05-TB-11	F1-05-TB-12	F1-05-TB-13	F1-05-TB-14	F1-05-TB-15	F1-05-TB-16	F1-05-TB-17	F1-05-TB-18	F1-05-TB-19	F1-05-TB-20	F1-05-TB-21	F1-05-TB-22	F1-05-TB-23	F1-05-TB-24	F1-05-TB-25	F1-05-TB-26	F1-05-TB-27
Ammonia beccarii											X	X		X	X			X	X	X	X	X			X		X
Bolivina pacifica																X											
Bolivina spissa																X											
Bolivina subexcavata?																X											
Bolivina vaughani																									X		
Buccella frigida	X				X				X		X			X		X			X		X	X			X		
Bulimina denudata																X									X		
Buliminella elegantissima																X									X		
Cibicides sp.									X																		
Elphidiella hannai	X		X	X		X	X		X	X		X	X	X		X	X	X	X		X		X	X	X		
Elphidium crispum			X			X																					
Elphidium excavatum								X	X		X		X	X	X	X								X	X		X
Fissurina cucurbitsema																X											
Fissurina lucida																									X		
Fissurina spp.																X											
Florilus labradoricus																X											
Fursenkoina pontoni																X									X		
Glabratella sp.	X		X	X		X			X																		
Haplophragmoides sp.?									X																		
Haynesina sp.?															X												X
Hopkinsina pacifica																									X		
Miliolinella elongata																									X		
Nonionella basispinata									X							X									X		
Nonionella stella																X											
Quinqueloculina sp.																							X				
Reophax nana																X									X		
Rotorbinella sp.					X																						
Spiroplectammina biformis																									X		
Suggrunda eckisi																X											
Textularia earlandi																X									X		
Trichohyalus sp.		X	X	X																							
Trochammina charlottensis																X											
Trochammina inflata																				X							
Trochammina kelletae																X									X		
Trochammina hadai								X			X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Trochammina vesicularis																X											
Other Constituents																											
Amphipods																X											
Diatoms										X	X					X									X		
Ostracods										X						X							X		X		
Spores?																									X		
Thecamoebians																X									X		

Table 3-3. Tomales Bay foraminiferal assemblages, representative species, and ecological interpretation determined in the studies of McCormick et al. (1994) and this study. Dominant species highlighted in yellow. Taxonomic synonomies in the two studies (McCormick et al., 1994, in parentheses): *Bolivina (=Brizalina) acuminata, Bolivina (=Brizalina) vaughani, Buccella frigida (=B. tenerrima), Elphidium (=Cribroelphidium) excavatum, Elphidium (=Cribrononion) lene, Rosalina globularis (=R. columbiensis)* and *Trichohylaus (=Glabratella) ornatissima.* Number of sites with occurrences of *Trochammina hadai* in the 2005 study in brackets.

McCormick et al. (1994)		
1982 Cluster Analysis Assemblages	Representative Species	Ecological Interpretation
Turbulent Zone	*Elphidium lene* *Rotorbinella campanulata* *Trichohylaus ornatissima*	Nearshore (fully marine)
Midbay	*Ammonia beccarii* *Bolivina acuminata* *Bolivina vaughani* *Bulimina denudata* *Elphidium excavatum* *Fursenkoina pontoni* *Hopkinsina pacifica* *Quinqueloculina bellatula*	Estuarine
Bay Ends	*Ammonia beccarii* *Buccella frigida* *Buliminella elegantissima* *Elphidiella hannai* *Elphidium excavatum*	Estuarine
Southbay subgroup	*Ammonia beccarii* *Elphidium excavatum* *Haplophragmoides columbiensis* *Miliammina fusca* *Reophax communis* *Reophax sp.* *Trochammina inflata*	Estuarine

This study		
McCormick et al. (1994) 1982 Assemblages	Representative Species	Ecological Interpretation
Sand Point	*Cassidulina limbata* *Elphidium crispum* ***Trichohylaus ornatissima***	Nearshore (fully marine)
North Bay	***Buccella frigida*** *Buliminella elegantissima* *Cibicides lobatulus* *Elphidiella hannai* *Elphidium excavatum* ***Elphidium lene*** *Rosalina globularis* ***Rotorbinella campanulata***	Nearshore (fully marine)
Northern Middle Bay	***Buccella frigida*** ***Buliminella elegantissima*** ***Elphidiella hannai*** ***Elphidium excavatum*** *Elphidium lene* *Hopkinsina pacifica*	Transitional and estuarine)
Southern Middle Bay	Northern subgroup: *Ammonia beccarii* *Bolivina* spp. ***Buccella frigida*** *Bulimina denudata* *Buliminella elegantissima* ***Elphidiella hannai*** ***Elphidium excavatum*** *Elphidium lene* *Hopkinsina pacifica* Southern subgroup: ***Ammonia beccarii*** *Bolivina* spp. *Bulimina denudata* *Buliminella elegantissima* *Elphidium excavatum* *Fursenkoina pontoni* ***Hopkinsina pacifica***	Subtidal estuarine
Mudflat	*Ammobaculites catenulatus* *Ammofrondicularia (Reophax?)* sp ***Ammonia beccarii*** ***Elphidium excavatum*** *Haplophragmoides columbiensis* *Miliammina fusca* *Reophax communis* *Reophax sp.* *Textularia agglutinans* *Trochammina inflata* *Trochammina pacifica*	Estuarine

This study		
2005 Assemblages	Representative Species	Ecological Interpretation
Outlier 1	*Trichohylaus ornatissima*	Nearshore (fully marine)
Outlier 2	*Buccella frigida* *Rotorbinella* sp.	Nearshore (fully marine)
North Bay	*Buccella frigida* *Cibicides* sp. *Elphidiella hannai* *Elphidium crispum* *Glabratella* sp. *Nonionella basispinata* *Trichohylaus ornatissima* *Trochammina hadai* [1]	Nearshore (fully marine)
Middle Bay	*Ammonia beccarii* *Buccella frigida* *Buliminella elegantissima* *Bolivina* spp. *Elphidiella hannai* *Elphidium excavatum* *Fissurina* spp. *Fursenkoina pontoni* *Hopkinsina pacifica* [16]	Subtidal estuarine

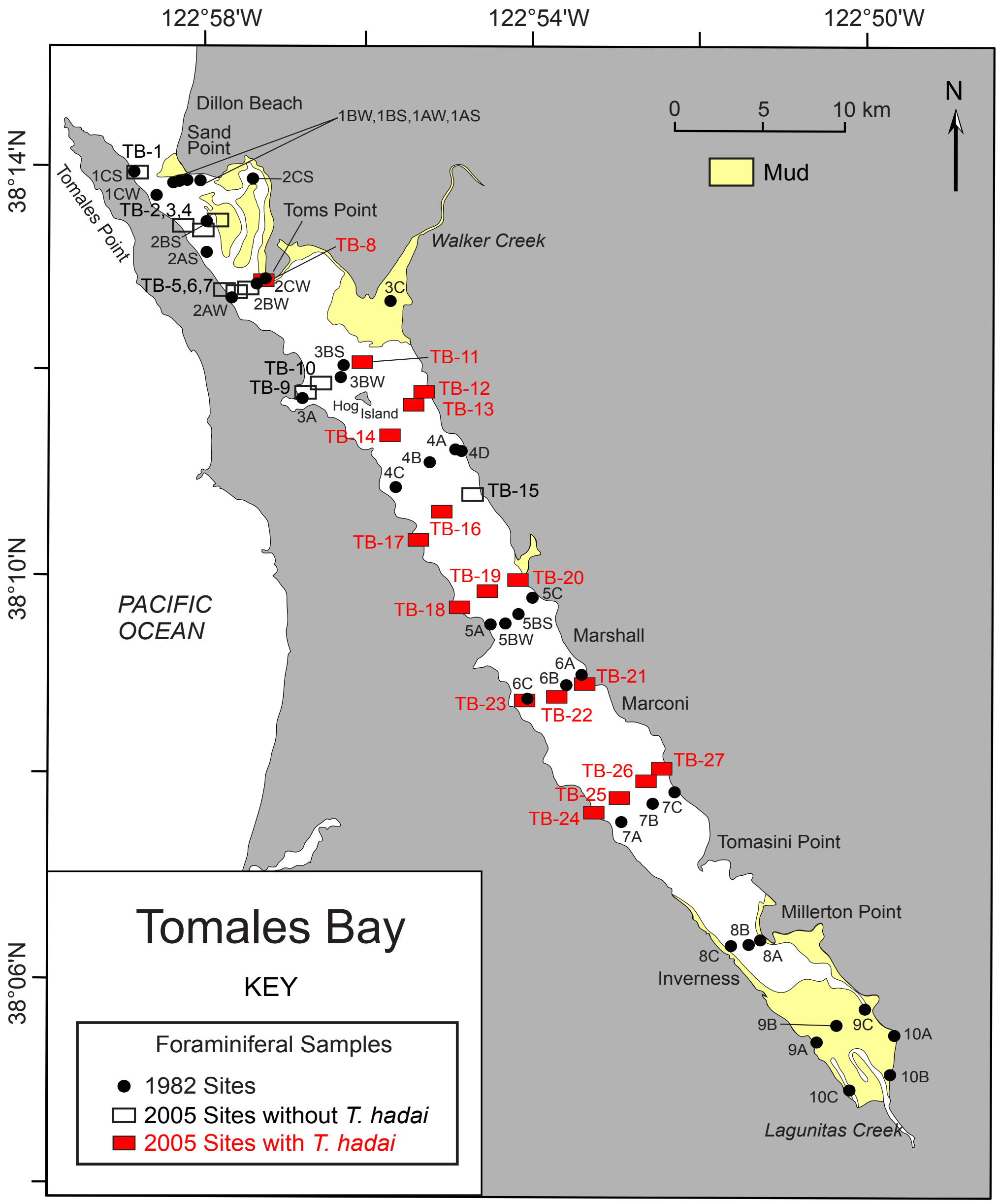


Figure 3-1. Location of the 1982 (McCormick et al., 1994) and 2005 sample sites in Tomales Bay. 2005 samples containing the invasive species Trochammina hadai are highlighted in red.

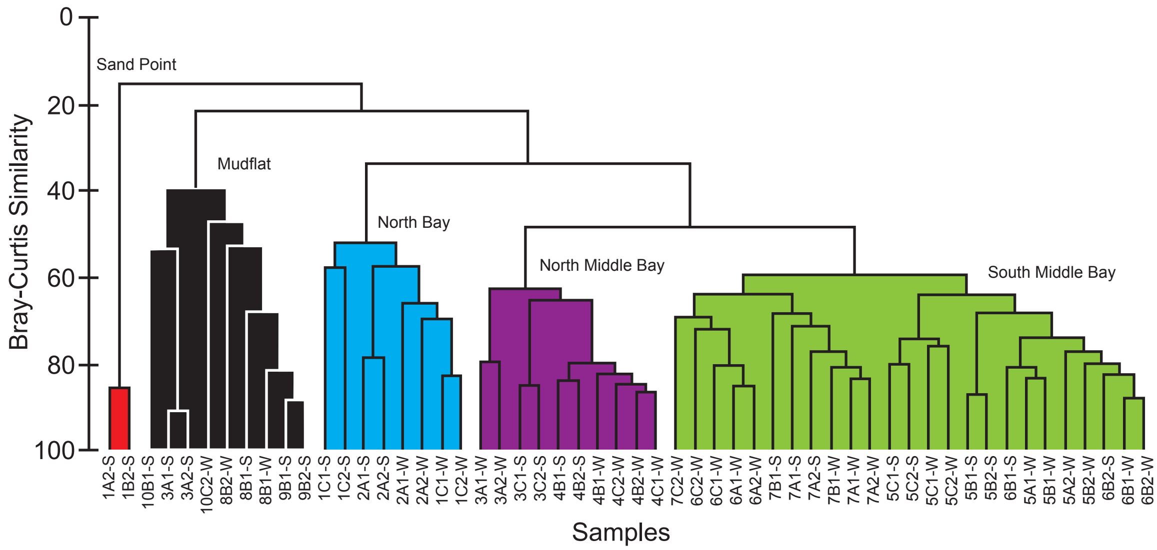


Figure 3-2. Dendrogram of the Q-mode cluster analysis based on the 1982 quantitative (percent frequencies) foraminiferal abundances of Tomales Bay from McCormick et al., 1994. Five assemblages are recognized.

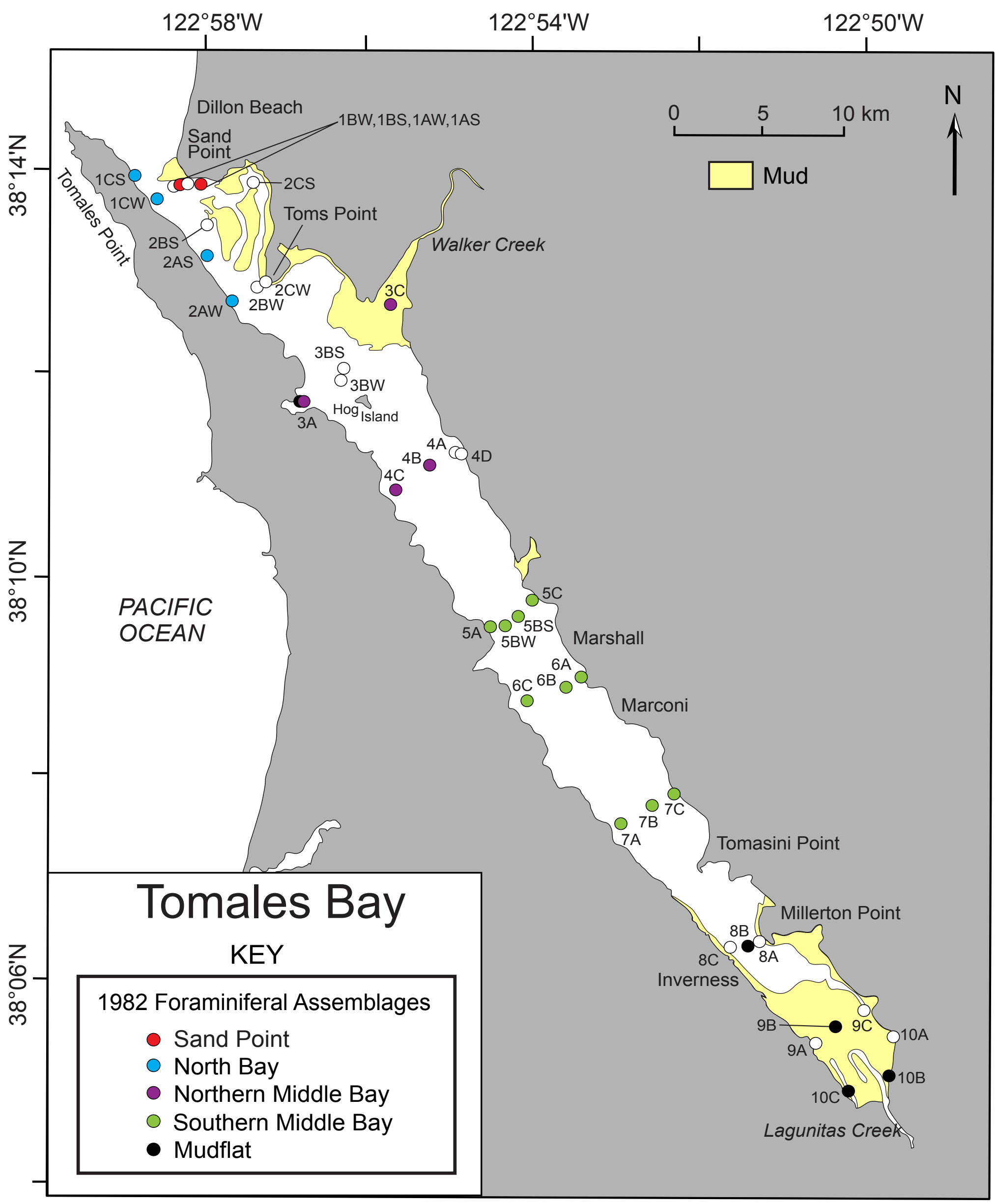


Figure 3-3. Distribution of the 1982 foraminiferal assemblages of Tomales Bay.

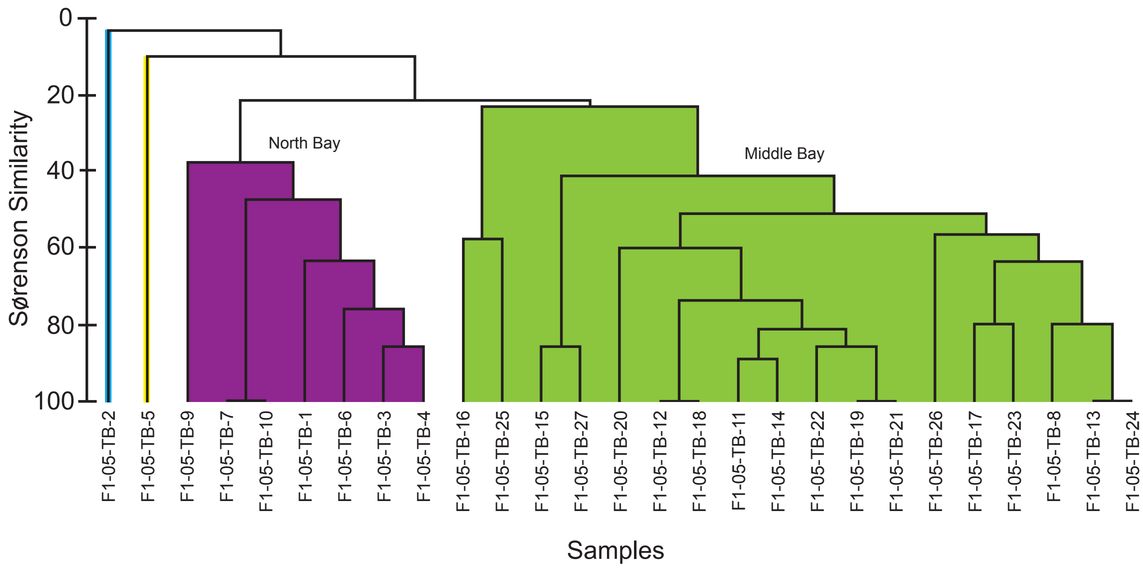


Figure 3-4. Dendrogram of the Q-mode cluster analysis based on the 2005 qualitative (presence/absence) distribution of foraminifera of Tomales Bay. Two assemblages and two outliers are recognized.

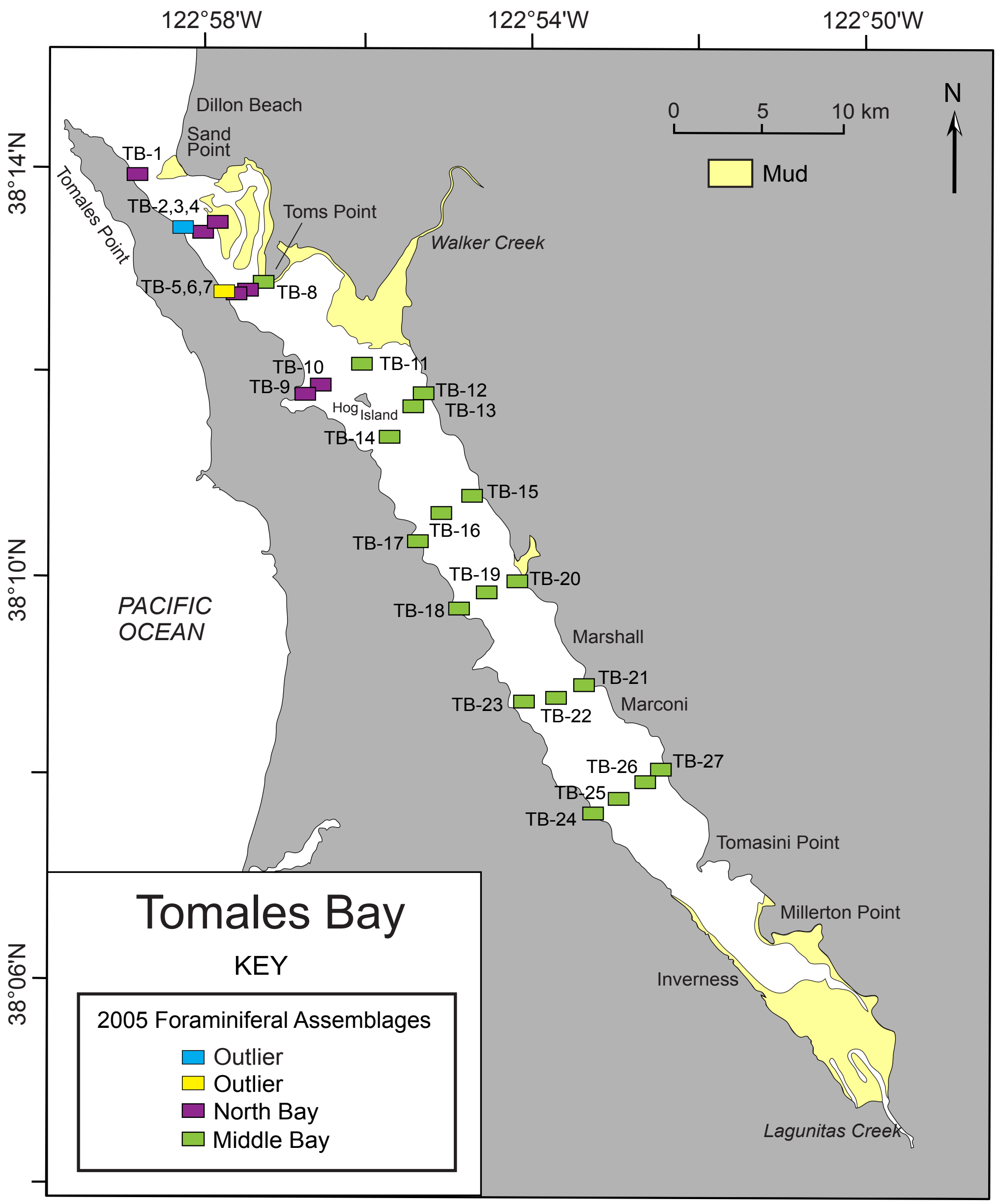


Figure 3-5. Distribution of the 2005 foraminiferal assemblages of Tomales Bay.

Station	% Gravel	% Sand	% Silt	% Clay	% Mud	Gravel/Sand	Sand/Silt	Silt/Clay	Sand/Clay	Sand/Mud	Gravel/Mud
TB-1	5.98	94.02	0.00	0.00	0.00	0.06	INFINITE	N/A	INFINITE	INFINITE	INFINITE
TB-2	0.00	100.00	0.00	0.00	0.00	0.00	INFINITE	N/A	INFINITE	INFINITE	N/A
TB-3	2.19	97.81	0.00	0.00	0.00	0.02	INFINITE	N/A	INFINITE	INFINITE	INFINITE
TB-4	0.00	100.00	0.00	0.00	0.00	0.00	INFINITE	N/A	INFINITE	INFINITE	N/A
TB-5	13.39	84.28	1.70	0.62	2.33	0.16	49.48	2.73	134.99	36.21	5.75
TB-6	0.00	99.30	0.70	0.00	0.70	0.00	141.71	INFINITE	INFINITE	141.71	0.00
TB-7	0.00	94.04	4.39	1.57	5.96	0.00	21.43	2.80	59.98	15.79	0.00
TB-8	0.00	93.49	4.83	1.69	6.51	0.00	19.37	2.86	55.42	14.35	0.00
TB-9	0.00	94.36	3.63	2.01	5.64	0.00	25.97	1.81	47.04	16.73	0.00
TB-10	0.00	78.81	15.72	5.47	21.19	0.00	5.01	2.87	14.41	3.72	0.00
TB-11	0.00	70.79	22.48	6.72	29.21	0.00	3.15	3.35	10.53	2.42	0.00
TB-12	0.00	1.15	75.35	23.50	98.85	0.00	0.02	3.21	0.05	0.01	0.00
TB-13	0.00	10.73	69.65	19.61	89.27	0.00	0.15	3.55	0.55	0.12	0.00
TB-14	0.00	94.61	3.33	2.06	5.39	0.00	28.41	1.62	45.91	17.55	0.00
TB-15	2.37	88.57	6.85	2.21	9.06	0.03	12.93	3.10	40.12	9.78	0.26
TB-16	0.00	8.92	61.20	29.88	91.08	0.00	0.15	2.05	0.30	0.10	0.00
TB-17	0.00	23.31	52.26	24.42	76.69	0.00	0.45	2.14	0.96	0.30	0.00
TB-18	0.00	1.19	66.41	32.40	98.81	0.00	0.02	2.05	0.04	0.01	0.00
TB-19	0.00	0.44	60.76	38.80	99.56	0.00	0.01	1.57	0.01	0.00	0.00
TB-20	0.00	93.82	3.68	2.51	6.18	0.00	25.50	1.47	37.45	15.17	0.00
TB-21	0.00	0.00	56.20	43.80	100.00	0.00	0.00	1.28	0.00	0.00	0.00
TB-22	0.00	0.00	54.10	45.90	100.00	N/A	0.00	1.18	0.00	0.00	0.00
TB-23	26.21	46.50	13.53	13.76	27.28	0.56	3.44	0.98	3.38	1.70	0.96
TB-24	0.00	1.73	51.37	46.90	98.27	0.00	0.03	1.10	0.04	0.02	0.00
TB-25	0.00	0.00	49.70	50.30	100.00	N/A	0.00	0.99	0.00	0.00	0.00
TB-26	0.00	0.03	54.47	45.50	99.97	0.00	0.00	1.20	0.00	0.00	0.00
TB-27	15.80	76.64	5.11	2.44	7.55	0.21	14.99	2.09	31.39	10.15	2.09

Station	F-W Median	F-W Mean	F-W Sorting	F-W Skewness	F-W Kurtosis	F-W Kurtosis	Inman Mean	Inman Sorting	Inman Skew 16-84
TB-1	0.37	0.35	0.47	-0.30	1.88	1.88	0.34	0.34	-0.10
TB-2	1.35	1.33	0.20	-0.11	1.17	1.17	1.32	0.19	-0.17
TB-3	1.43	1.36	0.56	-0.29	1.27	1.27	1.33	0.51	-0.20
TB-4	1.89	1.82	0.53	-0.12	1.33	1.33	1.79	0.47	-0.23
TB-5	1.52	1.32	1.33	-0.36	1.10	1.10	1.22	1.26	-0.24
TB-6	1.62	1.62	0.54	-0.10	1.42	1.42	1.63	0.46	0.02
TB-7	2.26	2.46	0.52	0.85	1.90	1.90	2.56	0.46	0.66
TB-8	2.17	2.29	0.60	0.59	3.06	3.06	2.35	0.35	0.52
TB-9	1.97	2.14	0.63	0.63	2.43	2.43	2.22	0.45	0.56
TB-10	2.41	3.11	1.53	0.88	1.92	1.92	3.46	1.19	0.88
TB-11	3.30	3.78	1.50	0.69	2.02	2.02	4.02	1.19	0.61
TB-12	6.16	6.53	1.86	0.32	0.83	0.83	6.72	1.98	0.28
TB-13	5.45	6.01	2.00	0.41	0.84	0.84	6.29	2.11	0.39
TB-14	2.75	2.79	0.43	0.47	3.13	3.13	2.81	0.24	0.24
TB-15	1.91	1.91	1.48	0.14	1.73	1.73	1.90	1.23	-0.01
TB-16	6.80	6.79	2.35	-0.07	0.99	0.99	6.78	2.28	-0.01
TB-17	6.03	5.74	2.78	-0.06	0.87	0.87	5.60	3.16	-0.14
TB-18	7.02	7.02	1.97	0.05	0.78	0.78	7.03	2.15	0.00
TB-19	7.49	7.45	1.83	-0.02	0.88	0.88	7.43	1.94	-0.03
TB-20	2.50	2.51	0.94	0.24	1.50	1.50	2.52	0.72	0.02
TB-21	7.74	7.76	1.69	0.00	0.95	0.95	7.76	1.76	0.01
TB-22	7.84	7.87	1.63	0.01	0.94	0.94	7.88	1.69	0.02
TB-23	1.50	2.32	4.42	0.25	0.78	0.78	2.73	4.96	0.25
TB-24	7.88	7.79	1.79	-0.10	1.02	1.02	7.75	1.82	-0.07
TB-25	8.01	8.05	1.56	0.01	0.93	0.93	8.06	1.62	0.03
TB-26	7.82	7.83	1.66	0.00	0.93	0.93	7.84	1.72	0.01
TB-27	0.89	0.86	1.69	0.12	2.29	2.29	0.85	1.09	-0.04

Station	Inman Skew 05-95	Inman Kurtosis	Trask Median	Trask Mean	Trask Sorting	Trask Skewness	Trask Kurtosis	Mean Phi	Mean mm
TB-1	-1.46	1.92	0.77	0.79	1.16	1.01	0.23	0.25	0.84
TB-2	-0.09	0.85	0.39	0.39	1.09	1.00	0.21	1.30	0.41
TB-3	-0.75	1.01	0.37	0.39	1.26	1.07	0.17	1.27	0.41
TB-4	-0.03	1.06	0.27	0.28	1.23	1.08	0.21	1.85	0.28
TB-5	-0.88	0.86	0.35	0.42	1.83	1.02	0.10	1.31	0.40
TB-6	-0.48	1.21	0.33	0.33	1.23	0.99	0.22	1.58	0.33
TB-7	2.17	1.08	0.21	0.19	1.15	0.82	0.17	2.62	0.16
TB-8	2.62	2.93	0.22	0.22	1.14	0.94	0.16	2.47	0.18
TB-9	2.08	1.97	0.26	0.25	1.17	0.93	0.19	2.34	0.20
TB-10	2.26	1.59	0.19	0.14	1.58	0.44	0.28	3.31	0.10
TB-11	1.92	1.50	0.10	0.09	1.52	0.70	0.26	4.02	0.06
TB-12	0.51	0.45	0.01	0.02	2.66	0.65	0.31	6.58	0.01
TB-13	0.63	0.47	0.02	0.03	2.86	0.50	0.33	6.04	0.02
TB-14	3.03	3.36	0.15	0.14	1.10	0.92	0.19	3.01	0.12
TB-15	0.67	1.33	0.27	0.33	1.60	1.24	0.18	2.06	0.24
TB-16	-0.25	0.74	0.01	0.02	3.11	1.16	0.24	6.69	0.01
TB-17	0.02	0.25	0.02	0.03	3.65	0.92	0.12	5.98	0.02
TB-18	0.12	0.38	0.01	0.01	2.93	1.14	0.26	7.04	0.01
TB-19	0.00	0.46	0.01	0.01	2.48	1.08	0.20	7.46	0.01
TB-20	1.19	1.62	0.18	0.19	1.43	1.00	0.27	2.75	0.15
TB-21	-0.02	0.53	0.00	0.01	2.24	0.94	0.20	7.76	0.00
TB-22	-0.01	0.53	0.00	0.01	2.19	0.92	0.20	7.86	0.00
TB-23	0.32	0.29	0.35	1.13	10.38	0.37	0.17	2.22	0.21
TB-24	-0.20	0.59	0.00	0.01	2.24	1.00	0.15	7.77	0.00
TB-25	-0.02	0.54	0.00	0.00	2.14	0.91	0.20	8.04	0.00
TB-26	-0.02	0.53	0.00	0.01	2.23	0.93	0.20	7.83	0.00
TB-27	0.94	2.47	0.54	0.60	1.60	1.00	0.10	1.06	0.48

Station	Variance	Std. Dev.	Skewness	Kurtosis
TB-1	0.34	0.58	-2.83	14.15
TB-2	0.05	0.23	-0.68	4.31
TB-3	0.46	0.68	-1.66	6.73
TB-4	0.31	0.56	0.26	4.01
TB-5	2.76	1.66	0.29	6.71
TB-6	0.38	0.62	-0.07	6.12
TB-7	1.38	1.17	4.00	21.45
TB-8	1.56	1.25	3.91	20.26
TB-9	1.77	1.33	3.89	19.61
TB-10	3.78	1.94	2.02	6.40
TB-11	3.29	1.81	1.96	6.16
TB-12	3.30	1.82	0.60	2.35
TB-13	3.93	1.98	0.70	2.46
TB-14	1.33	1.15	4.37	23.26
TB-15	3.28	1.81	1.78	8.26
TB-16	4.90	2.21	-0.21	2.49
TB-17	6.47	2.54	-0.04	2.00
TB-18	3.53	1.88	0.20	2.00
TB-19	3.00	1.73	0.01	2.17
TB-20	2.02	1.42	3.08	14.41
TB-21	2.57	1.60	-0.02	2.27
TB-22	2.40	1.55	0.00	2.26
TB-23	16.04	4.00	0.53	2.23
TB-24	2.93	1.71	-0.31	2.48
TB-25	2.23	1.49	-0.04	2.25
TB-26	2.49	1.58	-0.04	2.28
TB-27	4.69	2.17	1.67	7.72

Appendix - Sediment grain size analyses, Tomales Bay, California: weight percent in each quarter-phi interval

Station	Total Weight	-3.75	-2.75	-2.00	-1.75	-1.50	-1.25	-1.00	-0.75	-0.50	-0.25	0.00
TB-1	44.02	0.00	0.64	0.71	0.00	0.73	1.76	2.14	0.00	0.00	2.16	7.89
TB-2	46.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-3	43.36	0.00	0.00	0.00	0.00	0.78	0.59	0.82	0.00	0.00	0.68	4.30
TB-4	43.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-5	45.07	0.00	0.00	4.47	1.56	2.04	2.88	2.45	0.00	0.00	0.00	4.04
TB-6	42.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	2.30
TB-7	25.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-8	42.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-9	42.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-10	18.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-11	17.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-12	8.19											
TB-13	7.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-14	40.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-15	37.83	0.00	0.00	0.00	0.30	0.38	0.89	0.81	0.00	0.00	1.33	3.89
TB-16	6.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-17	7.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-18	6.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-19	6.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-20	39.02							0.00	0.00	0.00	0.00	0.00
TB-21	6.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-22	7.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-23	10.95	0.00	9.08	11.24	0.19	1.04	2.80	1.87	0.00	0.00	0.00	1.16
TB-24	5.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-25	7.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-26	7.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-27	41.35	0.00	0.97	3.29	1.59	3.28	3.02	3.65	0.00	0.00	4.39	0.00

Station	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75
TB-1	20.47	31.18	23.29	8.27	0.75	0.00	0.00	0.00	0.00	0.00	0.00
TB-2	0.00	0.60	1.30	7.01	25.73	48.85	15.42	1.10	0.00	0.00	0.00
TB-3	1.76	2.25	3.33	8.31	13.89	20.25	22.01	14.77	4.79	1.47	0.00
TB-4	0.00	0.80	2.00	4.10	6.90	9.20	14.00	26.90	19.80	7.10	3.30
TB-5	2.69	2.77	4.29	5.89	7.65	8.74	5.97	4.29	7.90	21.77	5.63
TB-6	1.40	1.40	1.60	3.90	9.01	19.22	24.22	16.62	10.31	6.61	1.30
TB-7	0.00	0.00	0.00	0.00	0.00	0.00	0.57	8.58	42.26	20.38	7.26
TB-8	0.00	0.00	0.00	0.00	0.66	1.68	3.74	20.97	40.72	12.54	4.49
TB-9	0.00	0.00	0.00	0.00	0.00	3.13	16.50	38.02	17.35	6.26	3.98
TB-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.16	34.48	17.44	6.44
TB-11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	2.70	8.68
TB-12											
TB-13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.26
TB-14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	1.61	8.89	38.58
TB-15	3.36	2.30	4.42	5.84	4.69	6.55	7.26	14.51	13.63	6.64	3.36
TB-16	0.00	0.00	0.00	0.00	0.00	0.16	1.07	1.86	1.92	0.78	0.40
TB-17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.22	10.85	3.96	1.87
TB-18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-20	0.00	0.00	0.00	0.00	1.97	3.75	8.53	11.72	13.03	10.97	10.03
TB-21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-23	1.02	1.35	2.83	4.69	5.62	7.10	6.69	6.36	4.50	2.97	1.25
TB-24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-27	5.45	9.01	10.00	9.70	10.00	8.79	6.89	5.15	2.73	1.67	0.45

Station	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75
TB-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-4	2.20	1.50	1.20	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-5	1.09	0.00	0.42	0.92	0.21	0.17	0.15	0.13	0.13	0.12	0.10	0.09
TB-6	0.00	0.00	0.00	0.80	0.00	0.70	0.00	0.00	0.00	0.00	0.00	0.00
TB-7	4.62	3.68	2.45	2.26	1.98	1.10	0.39	0.31	0.28	0.26	0.22	0.19
TB-8	2.81	1.97	1.50	1.22	1.19	1.07	0.48	0.37	0.32	0.30	0.26	0.22
TB-9	2.65	2.18	1.80	1.61	0.89	0.69	0.24	0.22	0.20	0.19	0.19	0.17
TB-10	4.48	3.46	2.98	2.36	3.01	2.79	1.63	1.27	1.09	1.03	0.92	0.79
TB-11	18.64	18.07	8.18	5.83	8.33	6.44	2.39	1.73	1.47	1.36	1.13	0.89
TB-12				0.00	1.15	2.93	5.32	6.80	7.20	6.80	6.30	5.70
TB-13	0.30	0.67	2.41	1.81	5.23	8.16	7.94	7.21	6.20	5.66	5.02	4.20
TB-14	32.90	7.37	1.32	0.66	2.71	0.15	0.23	0.23	0.21	0.20	0.20	0.19
TB-15	2.57	2.48	1.86	1.59	2.30	1.58	0.59	0.51	0.48	0.42	0.37	0.31
TB-16	0.30	0.28	0.24	0.16	1.75	3.09	4.03	4.12	4.07	3.79	3.79	3.61
TB-17	0.98	0.67	0.58	0.53	1.65	1.91	2.75	3.58	3.89	3.81	3.50	3.50
TB-18	0.00	0.00	0.00	0.00	1.19	2.82	4.49	5.10	4.90	4.50	4.10	3.80
TB-19	0.00	0.00	0.00	0.00	0.44	0.82	1.94	3.11	3.51	3.18	3.10	3.50
TB-20	14.25	10.03	4.31	2.34	2.89	0.21	0.29	0.26	0.21	0.20	0.21	0.21
TB-21	0.00	0.00	0.00	0.00	0.00	0.07	0.50	1.64	2.58	2.60	2.40	2.71
TB-22	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.51	1.84	2.83	2.82	2.68
TB-23	0.00	0.00	0.00	0.28	0.67	0.09	0.23	0.42	0.49	0.42	0.44	0.60
TB-24	0.00	0.00	0.00	0.00	1.73	1.12	1.37	1.92	2.16	1.90	1.80	2.20
TB-25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.62	1.79	2.70	2.85
TB-26	0.00	0.00	0.00	0.00	0.03	0.04	0.34	1.32	2.11	2.21	2.22	2.73
TB-27	0.00	0.45	0.53	0.53	0.90	0.55	0.45	0.38	0.37	0.32	0.28	0.25

Station	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	8.25	8.50	8.75
TB-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-5	0.09	0.08	0.08	0.08	0.09	0.09	0.10	0.09	0.09	0.08	0.08	0.07
TB-6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-7	0.17	0.17	0.16	0.17	0.18	0.19	0.20	0.21	0.20	0.19	0.18	0.16
TB-8	0.20	0.19	0.19	0.19	0.20	0.21	0.22	0.22	0.20	0.20	0.19	0.17
TB-9	0.16	0.16	0.15	0.16	0.19	0.21	0.23	0.24	0.24	0.22	0.21	0.20
TB-10	0.71	0.67	0.64	0.64	0.69	0.71	0.73	0.73	0.69	0.64	0.60	0.56
TB-11	0.78	0.75	0.69	0.75	0.78	0.81	0.84	0.84	0.84	0.78	0.75	0.69
TB-12	5.00	4.40	4.00	3.80	3.60	3.60	3.40	3.40	3.10	2.90	2.60	2.50
TB-13	3.56	3.01	2.83	2.74	2.65	2.74	2.65	2.65	2.46	2.37	2.10	2.10
TB-14	0.19	0.17	0.17	0.19	0.21	0.23	0.25	0.26	0.25	0.24	0.22	0.21
TB-15	0.30	0.28	0.28	0.28	0.28	0.30	0.30	0.30	0.29	0.27	0.25	0.23
TB-16	3.52	3.33	3.42	3.61	3.89	4.26	4.35	4.26	4.07	3.79	3.42	3.05
TB-17	3.34	3.19	3.03	3.11	3.27	3.34	3.42	3.42	3.19	3.03	2.72	2.57
TB-18	3.80	3.60	3.60	3.70	4.10	4.40	4.60	4.60	4.30	4.10	3.70	3.40
TB-19	3.60	3.70	3.70	4.10	4.70	5.20	5.60	5.60	5.40	5.10	4.50	4.20
TB-20	0.19	0.18	0.18	0.19	0.23	0.25	0.28	0.29	0.29	0.28	0.26	0.26
TB-21	3.40	3.50	3.60	4.30	4.90	5.70	6.10	6.20	6.00	5.60	5.10	4.60
TB-22	2.90	3.30	3.60	4.10	4.90	5.70	6.20	6.40	6.30	5.80	5.30	4.80
TB-23	0.74	0.71	0.74	0.90	1.15	1.42	1.64	1.78	1.75	1.70	1.59	1.48
TB-24	2.70	2.60	2.70	3.30	4.20	5.10	5.90	6.20	6.20	5.90	5.40	5.10
TB-25	2.78	2.80	3.20	3.80	4.70	5.50	6.10	6.40	6.40	6.00	5.60	5.20
TB-26	3.40	3.50	3.70	4.10	4.90	5.50	6.10	6.20	6.10	5.60	5.20	4.80
TB-27	0.25	0.25	0.24	0.25	0.28	0.30	0.32	0.31	0.31	0.30	0.27	0.25

Station	9.00	9.25	9.50	9.75	10.00	10.25	10.50	10.75	11.00	11.25	11.50
TB-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-5	0.06	0.06	0.05	0.05	0.05	0.04	0.03	0.03	0.02	0.01	0.00
TB-6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TB-7	0.16	0.14	0.14	0.13	0.12	0.10	0.09	0.07	0.05	0.02	0.01
TB-8	0.16	0.15	0.15	0.14	0.13	0.12	0.10	0.08	0.06	0.03	0.01
TB-9	0.19	0.19	0.18	0.18	0.16	0.15	0.12	0.10	0.07	0.03	0.01
TB-10	0.54	0.51	0.49	0.47	0.43	0.39	0.32	0.24	0.17	0.09	0.02
TB-11	0.69	0.63	0.61	0.58	0.52	0.46	0.38	0.29	0.20	0.12	0.03
TB-12	2.30	2.20	2.10	1.90	1.80	1.60	1.30	1.10	0.70	0.40	0.10
TB-13	1.92	1.82	1.73	1.64	1.55	1.28	1.19	0.91	0.55	0.36	0.09
TB-14	0.20	0.19	0.19	0.18	0.16	0.15	0.12	0.10	0.07	0.03	0.01
TB-15	0.21	0.21	0.19	0.18	0.17	0.15	0.13	0.10	0.06	0.04	0.01
TB-16	2.87	2.78	2.59	2.41	2.31	2.04	1.76	1.30	0.93	0.56	0.09
TB-17	2.33	2.26	2.18	2.02	1.87	1.71	1.40	1.09	0.78	0.39	0.08
TB-18	3.10	3.00	2.90	2.70	2.40	2.20	1.90	1.40	1.00	0.50	0.10
TB-19	3.80	3.60	3.40	3.10	2.90	2.60	2.10	1.60	1.20	0.60	0.10
TB-20	0.24	0.24	0.23	0.23	0.20	0.18	0.15	0.11	0.08	0.04	0.01
TB-21	4.30	4.10	3.80	3.60	3.30	2.90	2.50	1.80	1.30	0.70	0.20
TB-22	4.50	4.30	4.10	3.80	3.50	3.00	2.60	2.00	1.30	0.70	0.20
TB-23	1.39	1.31	1.26	1.15	1.07	0.90	0.74	0.55	0.38	0.19	0.05
TB-24	4.70	4.50	4.20	4.00	3.50	3.10	2.50	1.90	1.30	0.60	0.20
TB-25	5.00	4.80	4.60	4.30	3.90	3.50	2.80	2.20	1.40	0.80	0.20
TB-26	4.50	4.30	4.10	3.80	3.50	3.00	2.60	1.90	1.30	0.70	0.20
TB-27	0.24	0.23	0.22	0.21	0.19	0.17	0.14	0.10	0.08	0.04	0.01