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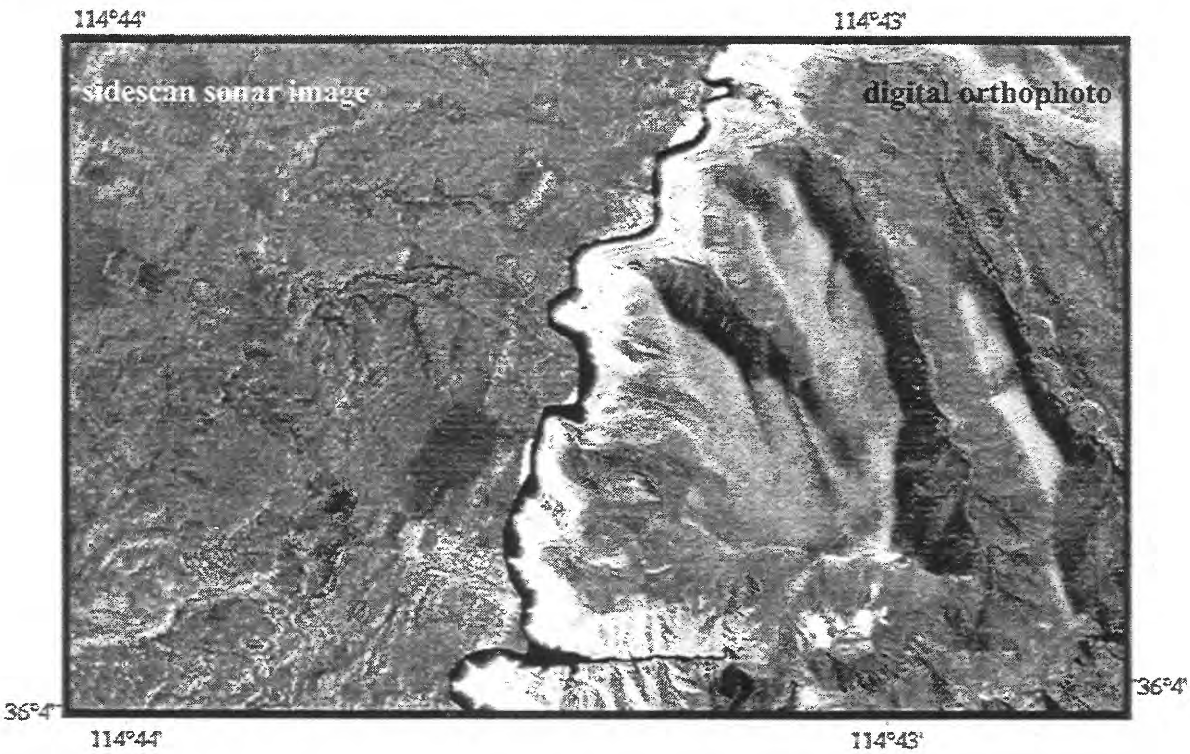

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SURFICIAL GEOLOGY AND DISTRIBUTION OF POST-IMPOUNDMENT SEDIMENT OF THE WESTERN PART OF LAKE MEAD BASED ON A SIDESCAN SONAR AND HIGH-RESOLUTION SEISMIC-REFLECTION SURVEY

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ABSTRACT

Sidescan sonar imagery and high-resolution seismic-reflection profiles were collected in Las Vegas Bay and Boulder Basin of Lake Mead to determine the surficial geology as well as the distribution and thickness of sediment that has accumulated in these areas of the lake since the completion of Hoover Dam in 1935 (Gould, 1951). Results indicate that the accumulation of post-impoundment sediment is restricted to the original Colorado River bed which runs down the axis of Boulder Basin from Boulder Canyon to Hoover Dam, and the old Las Vegas Creek bed that bisects Las Vegas Bay. The sediment cover along the original Colorado River bed is continuous and is typically greater than 10-m thick throughout much of its length with the thickness in some areas exceeding 35 meters. The flat-lying nature of the deposits suggests that they are the result of turbidity currents that flow the length of the lake. The sediment cover in Las Vegas Bay is much thinner (rarely exceeding 2 m in thickness) and more discontinuous. The source for these sediments presumably is Las Vegas Wash and a series of other ephemeral washes that empty into this part of the lake. The presence of sediments along the entire length of the Las Vegas Creek bed suggests that turbidity currents probably are active here as well, and that sediment has been transported from these streams at least 10 km down the axis of this valley to where it enters Boulder Basin. Alluvial deposits and rock outcrops are still exposed on large parts of the lake floor.

INTRODUCTION

Lake Mead is a large interstate reservoir located in the Mojave Desert of southeastern Nevada and northwestern Arizona (Fig. 1). It was impounded in 1935 by the construction of Hoover Dam and is one of a series of multi-purpose reservoirs on the Colorado River. The lake extends 183 km from the mouth of the Grand Canyon to Black Canyon, the site of Hoover Dam, and is surrounded by Precambrian through Tertiary aged volcanic and intrusive rocks as well as Tertiary sedimentary strata and Quaternary alluvial deposits (Fig. 2). It provides water for residential, commercial, industrial, recreational, and other non-agricultural users in communities across the southwestern U.S.

The Colorado River, via discharges from Lake Powell, supplies approximately 98% of the annual inflow to Lake Mead (Preissler et al, 1998, Water Resources Data, Arizona, Water Year 1998, 1998). The remainder is derived from the Virgin and Moapa Rivers which discharge into the Overton Arm, the Las Vegas Wash which discharges into

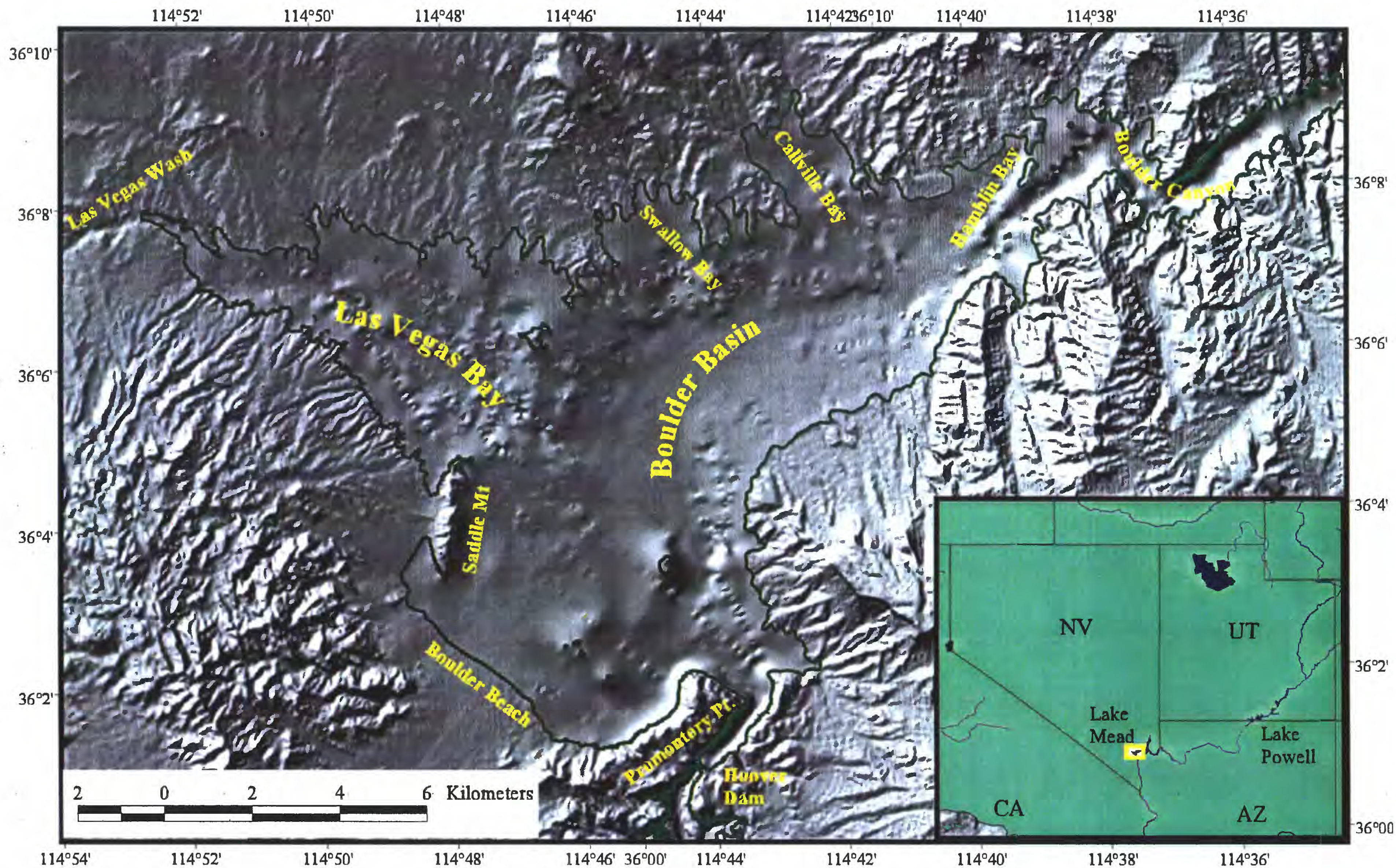


Figure 1. Location map showing the morphology of the western part of Lake Mead and the surrounding area. Morphology is shown as a shaded-relief image that was derived from combining a digital elevation model of the surrounding landscape (USGS, 1999) with a gridded version of the bathymetry collected during this survey. Green line is the approximate location of the shoreline (360 m contour), and names are places referred to in the text. Inset shows the location of the study area (yellow box).

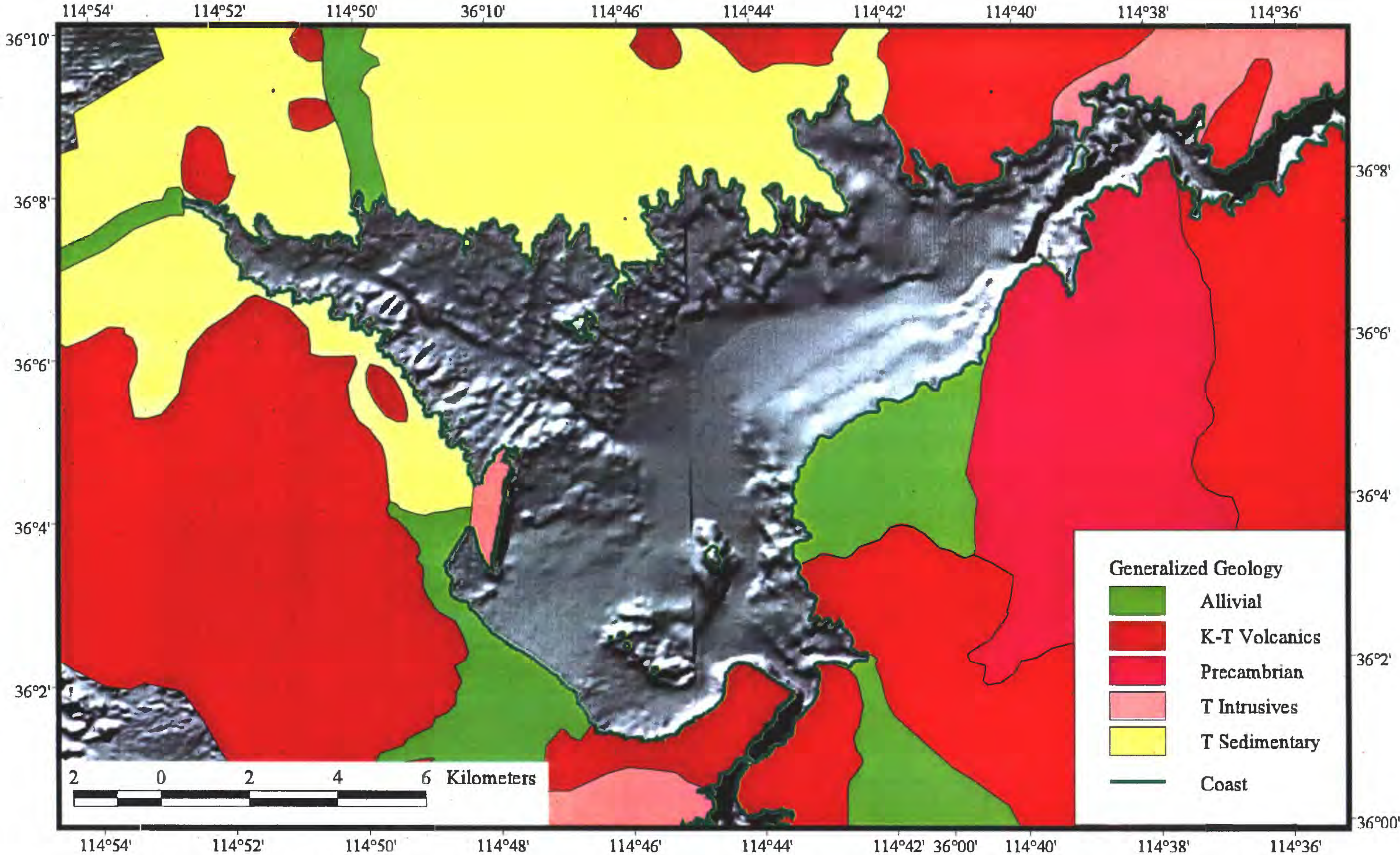


Figure 2. Generalized geology of the area surrounding Lake Mead. Geology of Arizona is modified from Wilson et al. (1969), and geology of Nevada is modified from Stewart and Carlson (1978). Alluvial is mostly Quaternary and recent unconsolidated alluvial gravel, sand and silt. K-T Volcanics are mostly Cretaceous and Tertiary andesitic and basaltic flows. T Intrusives are mostly Tertiary aged rhyolitic flows and shallow intrusive rocks including diorite and granite. T Sedimentary are Tertiary aged tuffaceous sedimentary rocks. Precambrian includes gneiss and some areas of undivided schist and granite of Precambrian age.

Las Vegas Bay, and a number of desert washes which surround the lake. Outflows from Lake Mead include the Colorado River (below Hoover Dam) and water diversions located at Saddle Mountain (Fig. 1) and in the Overton Arm. These diversions provide water for municipal and industrial uses for the greater Las Vegas Metropolitan area and Moapa Valley, respectively.

The impact of these inflows on the ecosystem of Lake Mead has been well documented (Pressler, et al., 1998; Bevans et al, 1996; Bevans et al., 1998; Covay and Leiker, 1998; LaBounty and Horn, 1997; Paulson, 1981). Much of the work has been conducted in Las Vegas Bay and Boulder Basin of Lake Mead (Fig. 1) due to the proximity to the potable water intakes at Saddle Mountain. A majority of the studies involved determining levels of anthropogenic contaminants such as synthetic organic compounds, heavy metals and dissolved ions, furans/dioxins, and nutrient loading in lake water, sediment, and biota. However, little work has focused on the transportation and deposition of sediments in Las Vegas Bay and Boulder Basin. These sediments are known to be largely silts that have been transported along the lake floor by turbidity currents active in the original Colorado River bed (Gould, 1951). By 1947, in excess of 30 m of sediment had accumulated behind Hoover Dam (U.S. Bureau of Reclamation, 1947; Gould, 1951; Vetter, 1953). In 1965, the Glen Canyon Dam was built on the Colorado River approximately 300 km upstream of Lake Mead (Lucchita and Leopold, 1999). The effect of this dam on sedimentation in Lake Mead is not well understood. The purpose of this exploratory study is to utilize sidescan sonar imagery and high-resolution seismic reflection profiles to determine the surficial geology as well as the distribution and thickness of sediment that has accumulated in Las Vegas Bay and Boulder Basin of Lake Mead.

METHODS

A two-week sidescan sonar and high-resolution seismic-reflection survey was completed during May 12-26, 1999. Geophysical data were collected along approximately 335 km of survey tracklines (Fig. 3). The grid of survey lines, spaced 500-1000 m apart, provide complete sidescan sonar coverage of the study area except in some of the shallow parts of the lake, and allow a detailed mapping of the thickness and distribution of post-impoundment sediments within the study area. The survey was conducted aboard a 19-m houseboat. A Datasonics Inc. SIS-1000[1] sidescan sonar and chirp subbottom profiling system was used to collect the sidescan imagery and subbottom profile information. The sound source for the subbottom data was a chirp system with a central frequency of 3.5 kHz. Minimum resolution based on this frequency and the sampling interval used to log the data is approximately 50 cm. The sidescan imagery and subbottom data were logged digitally using an ISIS[1] digital acquisition system developed by Triton-Elics Industries[1]. Both data types were collected on all tracklines. Single-beam bathymetry was collected along all the survey tracklines as well. All navigation was done with a P-Code GPS receiver with an estimated accuracy of +/- 10 m. The navigation information is stored every 10 seconds and includes Julian day, hour, minute,

[1] The use of trade names is for descriptive purposes only and does not indicate endorsement by the U. S. Geological Survey, nor the University of Nevada, Las Vegas.

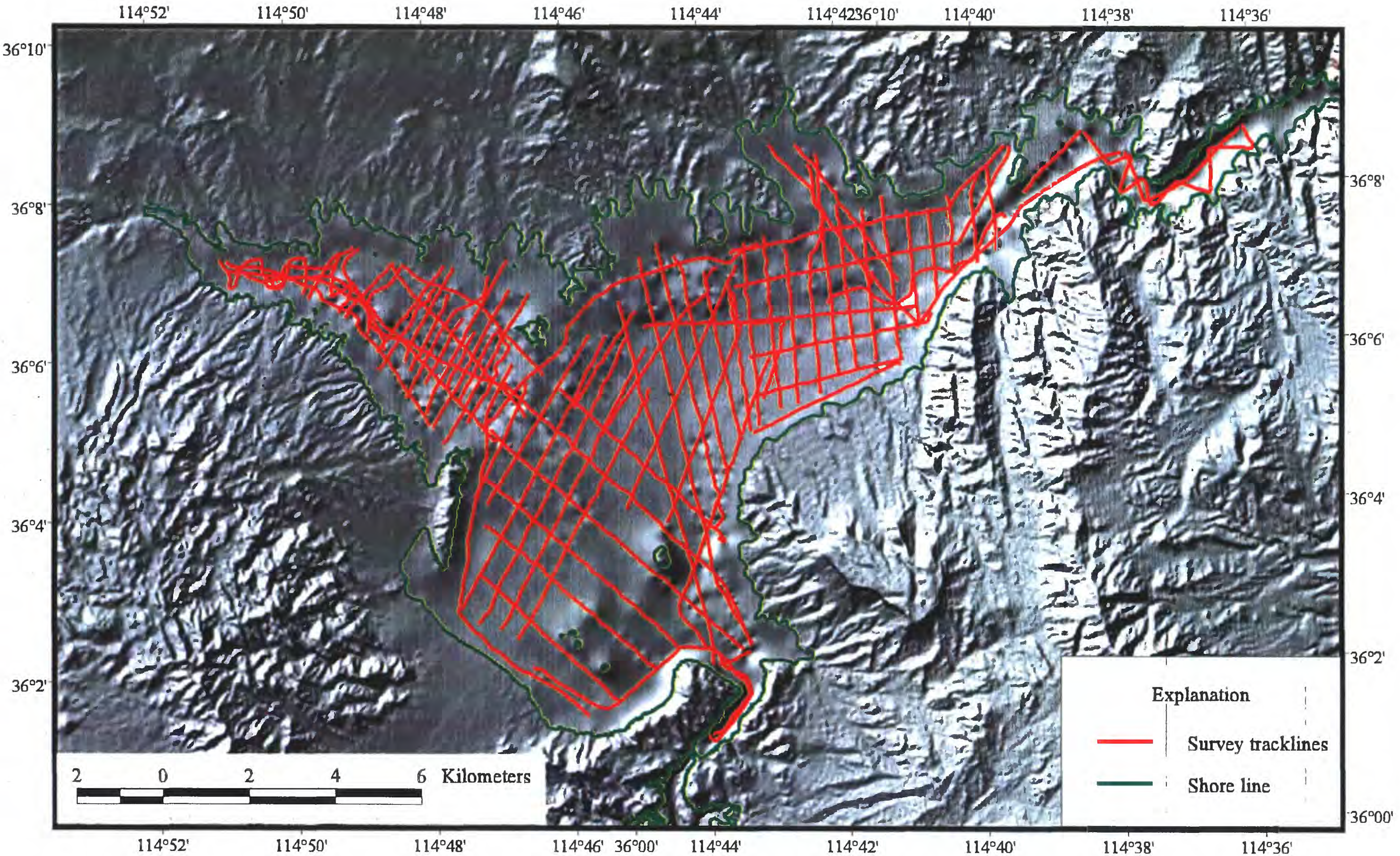


Figure 3. Tracklines in the Boulder Basin and Las Vegas Bay parts of Lake Mead along which sidescan sonar, subbottom seismic-reflection profiles, bathymetry, and navigation were collected. All four types of data were continuously collected along all of these lines.

second, longitude, latitude, and depth. The time recorded with the navigation information is in UTC.

During the field operation, the sidescan sonar data were processed and a digital mosaic was completed. The sidescan imagery was demultiplexed, corrected for slant-range distortions and signal attenuation using techniques summarized by Danforth et al (1991). These strips of image data were then mapped into their proper geographic location using software described by Paskevich (1996). Once the individual strips were mapped, they were combined together into a composite digital mosaic using a remote sensing software package developed by PCI (Anonymous, 1992). The techniques for generating the composite digital sidescan mosaic are summarized by Paskevich (1992). The completed mosaic has a pixel size of 2 m, and the image is in a UTM projection, zone 11 using the WGS-84 ellipsoid. The sidescan sonar mosaic was imported into ESRI's ArcView GIS package where the image shown in Figure 4 and the interpretation shown in Figure 5 were generated. On the sidescan images presented in this report, a strong acoustic return, also referred to as high backscatter, appears as white and light gray tones. A weak acoustic return, low backscatter, is black or dark gray.

Processing of the seismic data involved two steps. The first step was to convert the seismic files from the ISIS format to SEG-Y format. This step also included correcting for the depth of the transducer since the sonar vehicle was not towed at the surface. This was accomplished using a conversion utility developed by the US Geological Survey which converts the data to a standard 16-bit unsigned integer SEG-Y format. This format is described in detail by Barry et al. (1975). The SEG-Y files consist of shot files with one trace per shot. Most of the data was collected using a 0.5 sec. firing rate, but some was collected using a 1.0 sec. firing rate. For the data collected at the 1 sec. fire rate, there were 2072 samples per trace with a sample interval of 488 microseconds. For the data collected at the 0.5 sec fire sate, there were 2144 samples per trace and the sample interval was 244 microseconds. Because the combined water depth and sediment thickness in the lake did not exceed 270 milliseconds, only the upper 300 milliseconds of each trace were used. The second step was to use the seismic processing package, SEISMIC UNIX (Cohen and Stockwell, 1997), to generate a postscript file of each seismic data file. This postscript file was then converted to 'GIF' format and down-sampled to 25% of the original size for analysis in the field.

After the cruise, the SEG-Y files were imported into Seisworks[1] (Landmark Graphics Corp) where the interpretation of the profiles was completed. Figure 6 shows a part of one of the seismic profiles, and highlights the different horizons that were identified on each of the profiles. A velocity of sound of 1500 m/sec was used to convert travel times on the seismic profiles to depths. The present lake floor and the pre-impoundment surface were identified on each of the seismic profiles (Fig. 6), and the difference between these two reflectors was used to measure the thickness of the post-impoundment sediments (Fig. 7). In addition to these two horizons, four other horizons were identified within the post-impoundment sedimentary section (Fig. 6). The thickness of sediment that has accumulated in the lake since impoundment was derived independently by subtracting a low-resolution version of the pre-impoundment elevation from the modern lake floor elevation. The thickness derived from the seismic-reflection profiles and that derived from subtracting the two elevations provided similar results except along the Colorado River. The pre-impoundment topography did not include river

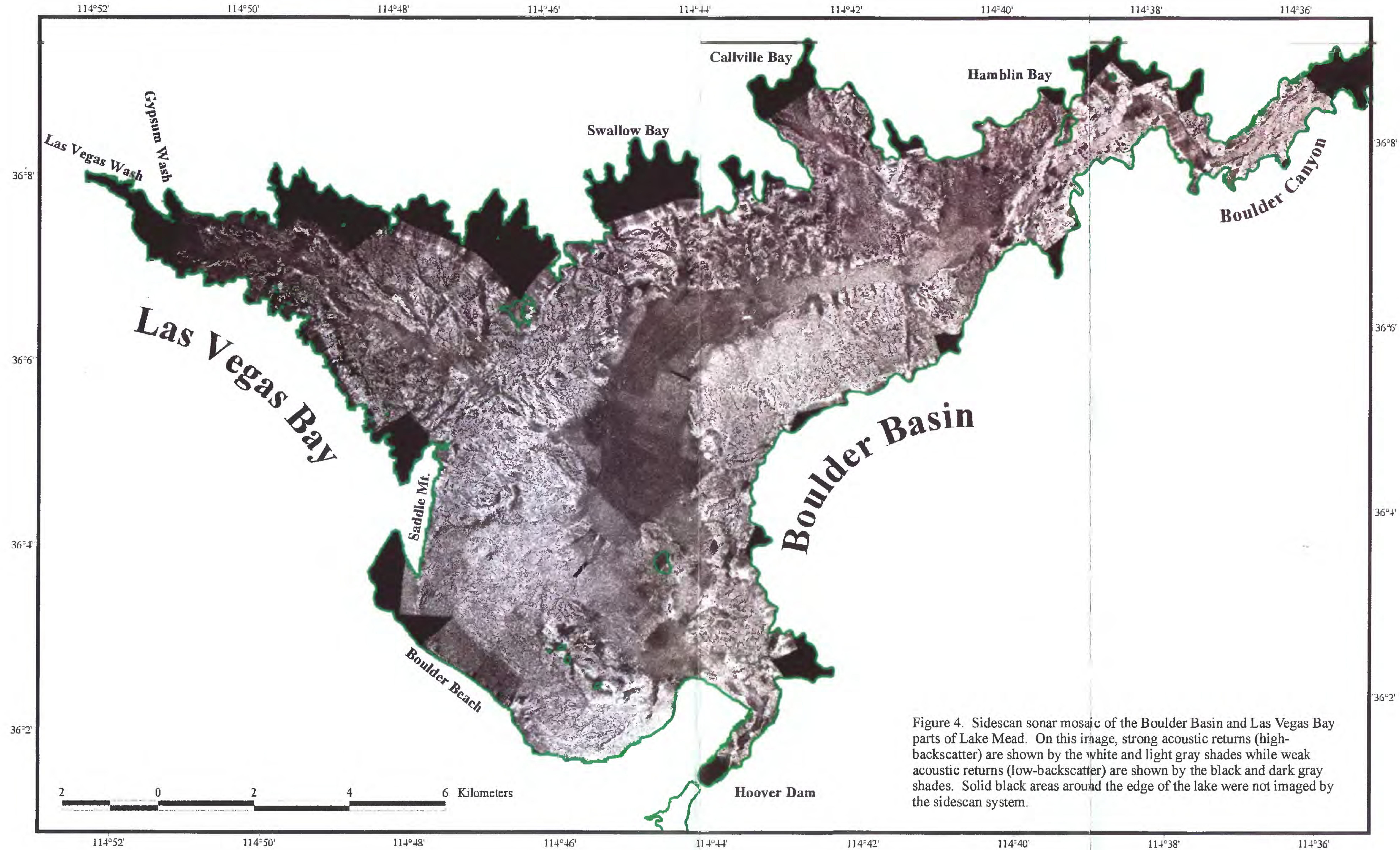


Figure 4. Sidescan sonar mosaic of the Boulder Basin and Las Vegas Bay parts of Lake Mead. On this image, strong acoustic returns (high-backscatter) are shown by the white and light gray shades while weak acoustic returns (low-backscatter) are shown by the black and dark gray shades. Solid black areas around the edge of the lake were not imaged by the sidescan system.

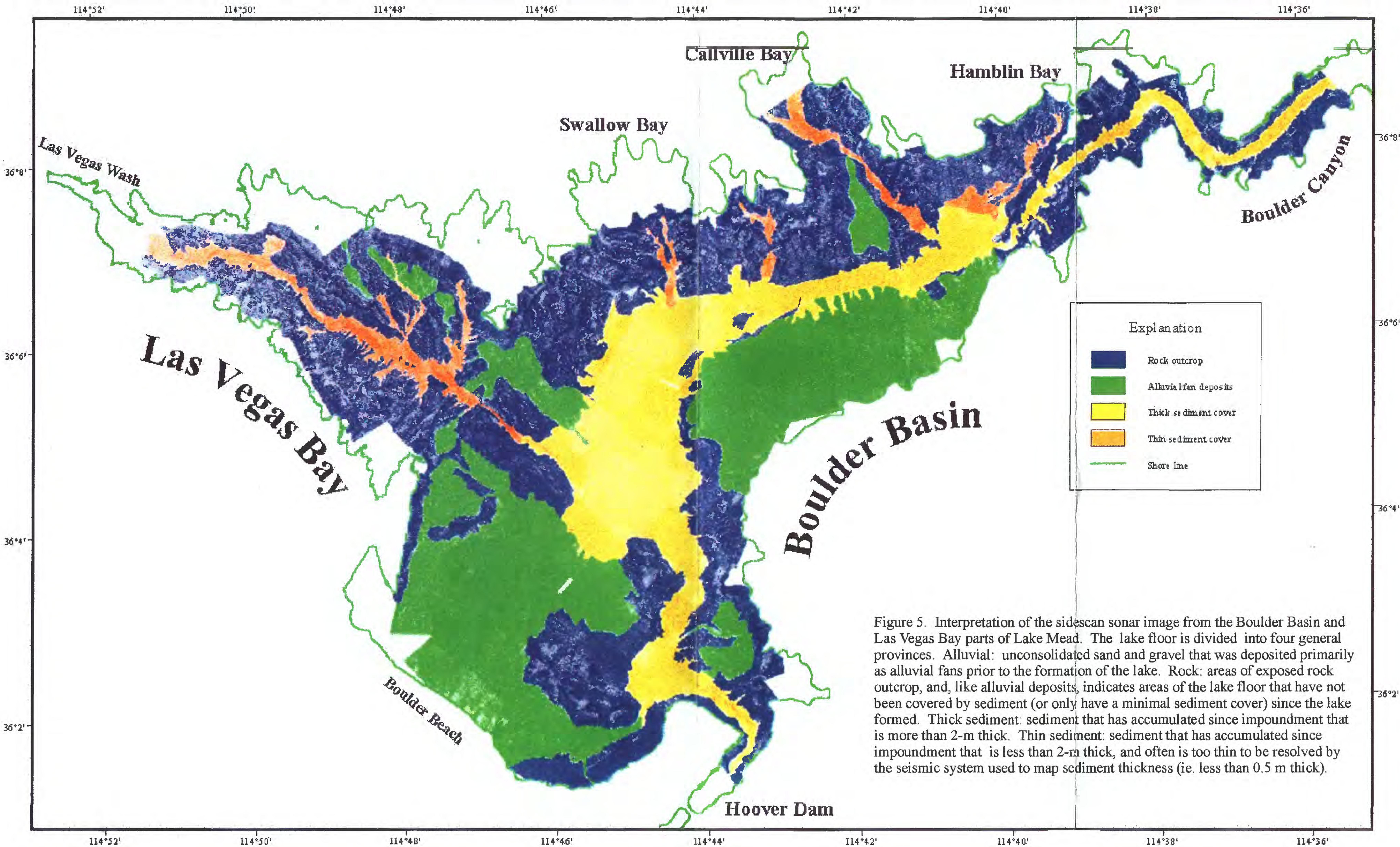


Figure 5. Interpretation of the sidescan sonar image from the Boulder Basin and Las Vegas Bay parts of Lake Mead. The lake floor is divided into four general provinces. Alluvial: unconsolidated sand and gravel that was deposited primarily as alluvial fans prior to the formation of the lake. Rock: areas of exposed rock outcrop, and, like alluvial deposits, indicates areas of the lake floor that have not been covered by sediment (or only have a minimal sediment cover) since the lake formed. Thick sediment: sediment that has accumulated since impoundment that is more than 2-m thick. Thin sediment: sediment that has accumulated since impoundment that is less than 2-m thick, and often is too thin to be resolved by the seismic system used to map sediment thickness (ie. less than 0.5 m thick).

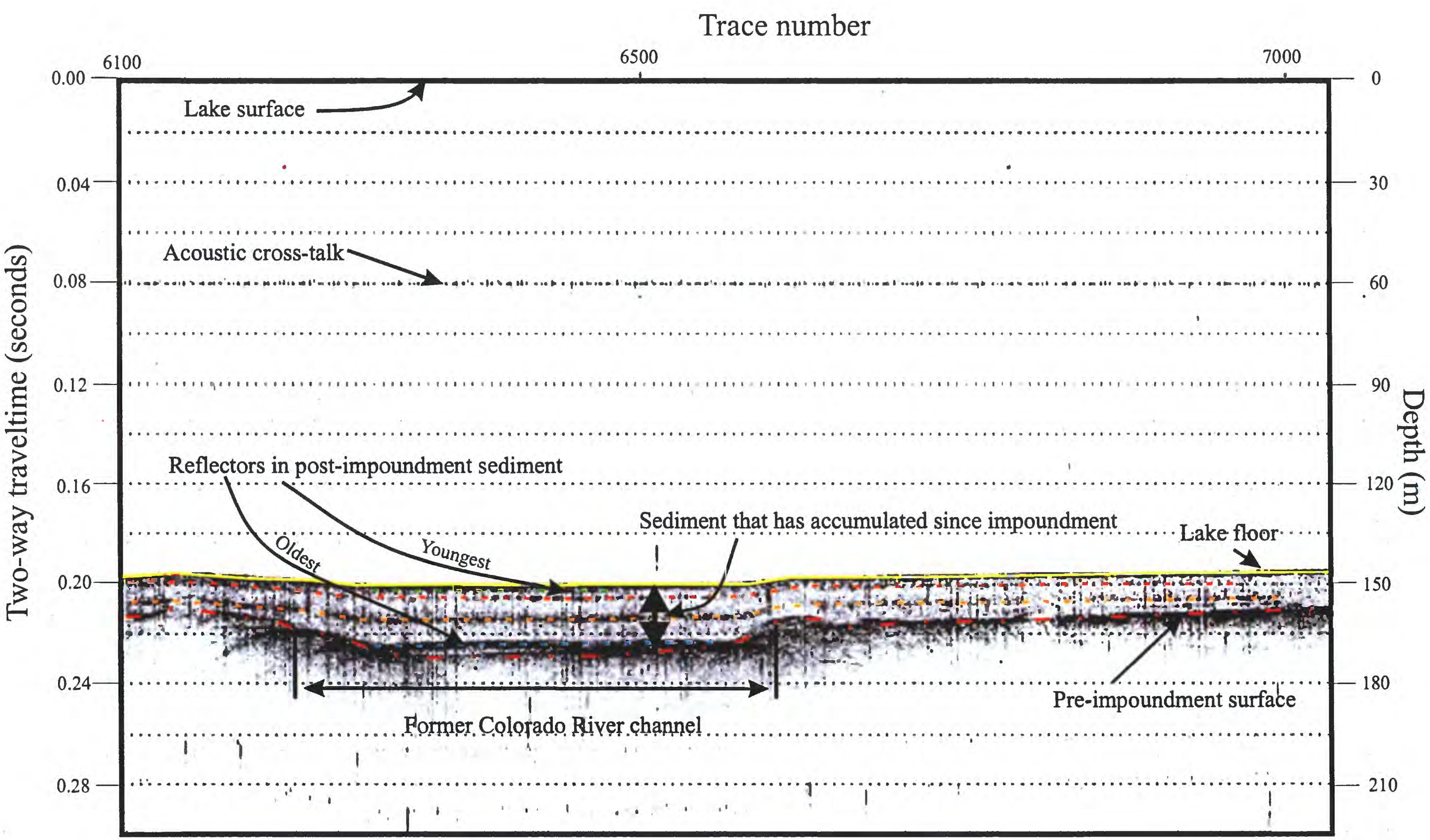
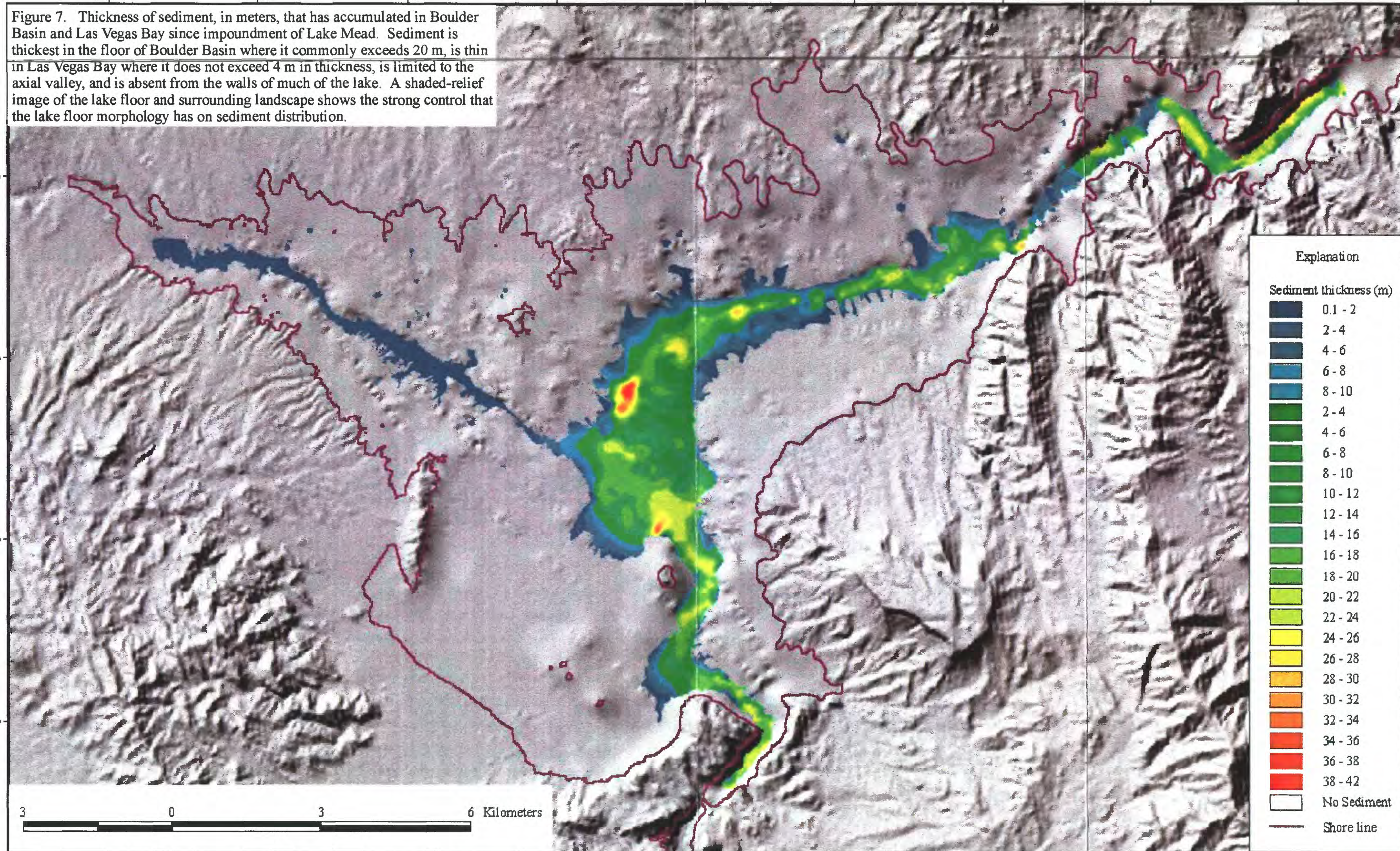


Figure 6. Enlarged section of a seismic profile showing the different features identified on the profiles. The numbers across the top of the profile represent the shot or trace number (shots here are 1.0 seconds apart). The depth on the left side of the profile is in seconds, and on the right depth has been converted to meters assuming a constant speed of sound of 1500 m/sec. The lake surface is at the top of the profile. Acoustic cross-talk, or interference, between the sidescan sonar and subbottom profiler shows in the water column. The lake floor is the first reflector (yellow), and the reflector representing the pre-impoundment surface is the deepest reflector (red). Four reflectors within the sediment that has accumulated since impoundment show as flat-lying horizons that pinch out against the pre-impoundment surface.

Figure 7. Thickness of sediment, in meters, that has accumulated in Boulder Basin and Las Vegas Bay since impoundment of Lake Mead. Sediment is thickest in the floor of Boulder Basin where it commonly exceeds 20 m, is thin in Las Vegas Bay where it does not exceed 4 m in thickness, is limited to the axial valley, and is absent from the walls of much of the lake. A shaded-relief image of the lake floor and surrounding landscape shows the strong control that the lake floor morphology has on sediment distribution.



depths, so the sediment thickness along the former path of the Colorado River derived from the seismic profiles is significantly thicker. Because the seismic profiles information in the Colorado River bed, sediment thickness discussed in this report is only based on the seismic-reflection profiles.

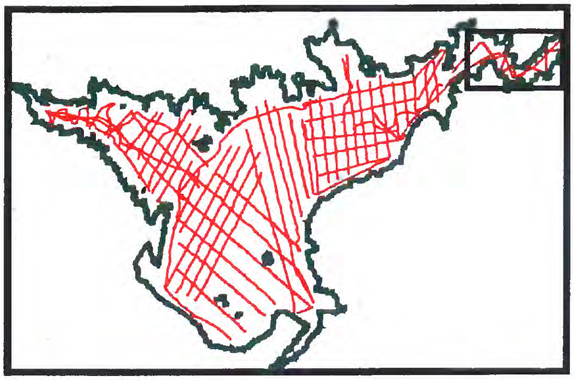
RESULTS

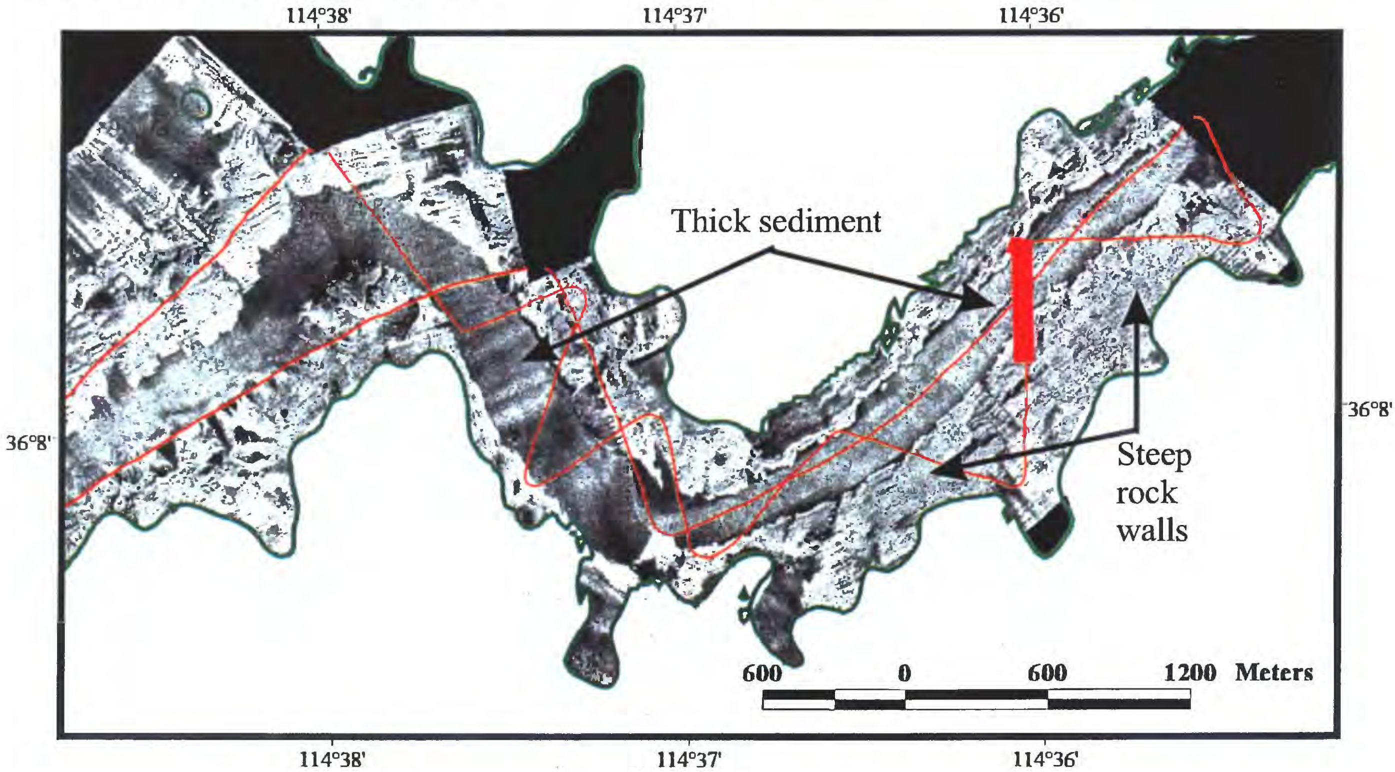
The generalized morphology of the lake and the surrounding area is shown in Figure 1. The lake walls are steep in Boulder Canyon and near Hoover Dam. These steep cliffs coincide with exposures of Precambrian gneiss and Cretaceous and Tertiary volcanic and intrusive rocks (Wilson et al, 1969; Stewart and Carlson, 1978) around the margins of the lake (Fig. 2). In Boulder Basin, the gradient of the lake walls is gentler off areas where alluvial deposits and Tertiary-aged sedimentary strata are present. The axis of the basin is flat, and the gradient between Boulder Canyon and Hoover Dam is remarkably gentle. Water depth, based on the bathymetry collected during this survey, on the easternmost line in the axis of Boulder Canyon was 142 m while, near Hoover Dam, 26 km to the southwest, the lake is 147 m deep. Las Vegas Bay has a narrow, steep-sided valley running down its axis that opens into Boulder Basin northeast of Saddle Mountain (Fig. 1). Several smaller tributaries feed into this axial valley showing a well-defined dendritic drainage pattern that was cut in the Tertiary sedimentary strata prior to formation of the lake. This morphology characterizes the northern flank of the lake with Swallow, Callville, and Hamblin Bays having dendritic drainage networks in their floors as well. This northern section of the lake presumably is underlain by the Tertiary sedimentary strata that is exposed onshore which has the same distinctive morphology (Fig. 2).

The sidescan sonar image shows four distinctive geologic provinces on the lake floor (Fig. 4 and 5). Two of these provinces, rock outcrop and alluvial deposits, reflect the pre-impoundment geology of the area while the other two, thin and thick sediment show the distribution of deposits that are interpreted to have accumulated in the lake since its formation.

Areas of rock outcrop show on the sidescan image either as high-backscatter or as alternating bands of high and low backscatter. The high-backscatter signature represents steep rock walls that face the sonar, while the alternating high- and low-backscatter bands appear to represent terraced outcrops. The terraces probably are controlled by bedding of the underlying strata. The distribution of these two signatures coincides with the distribution of different rock types surrounding the lake. The areas of rock outcrop associated with uniform high backscatter (Fig. 8) closely correspond with the distribution of Precambrian gneiss, Cretaceous through Tertiary volcanic and intrusive rocks around the lake (Fig. 2). These rocks are resistant to erosion and form the steep cliffs that surround the lake. These cliffs are prevalent east of Hamblin Bay (especially in Boulder Canyon), in the southwestern part of the lake surrounding Promontory Point, and also off of Saddle Mountain. Areas of alternating bands of high and low backscatter that have an extensive network of valleys cut through them (Fig. 9) occur in Las Vegas Bay and along the northern side of Boulder Basin from Las Vegas Bay eastward to Hamblin Bay. North of this part of the lake, the rocks consist of a mix of Tertiary fluvial deposits and tuffs

Figure 8. Sidescan sonar image showing the steep, smooth rock walls in the Narrows (see inset map for figure location) with the post-impoundment sediment lapping up against these cliffs. The seismic profile (location is the heavy red line on the sidescan image) shows the thick sediment covering the floor of the lake and lapping up against the steep rock walls. Note that the surface of the sediment is flat and that no sediment drape is apparent on the adjacent rock faces. On the seismic profile, 0.02 sec. two-way travel time is approximately 15-m.





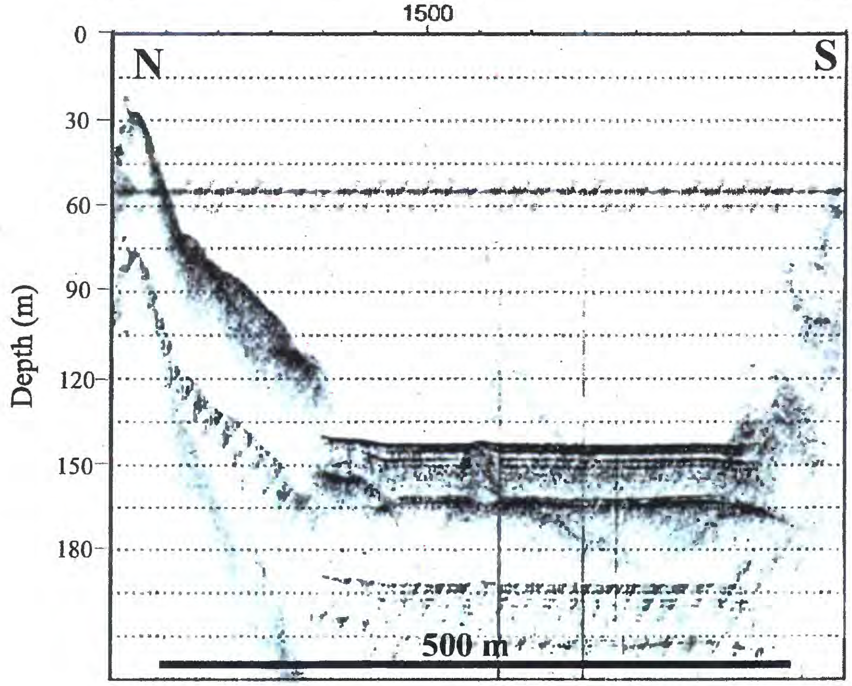
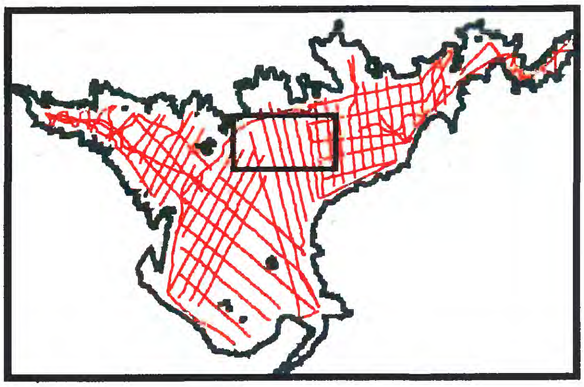
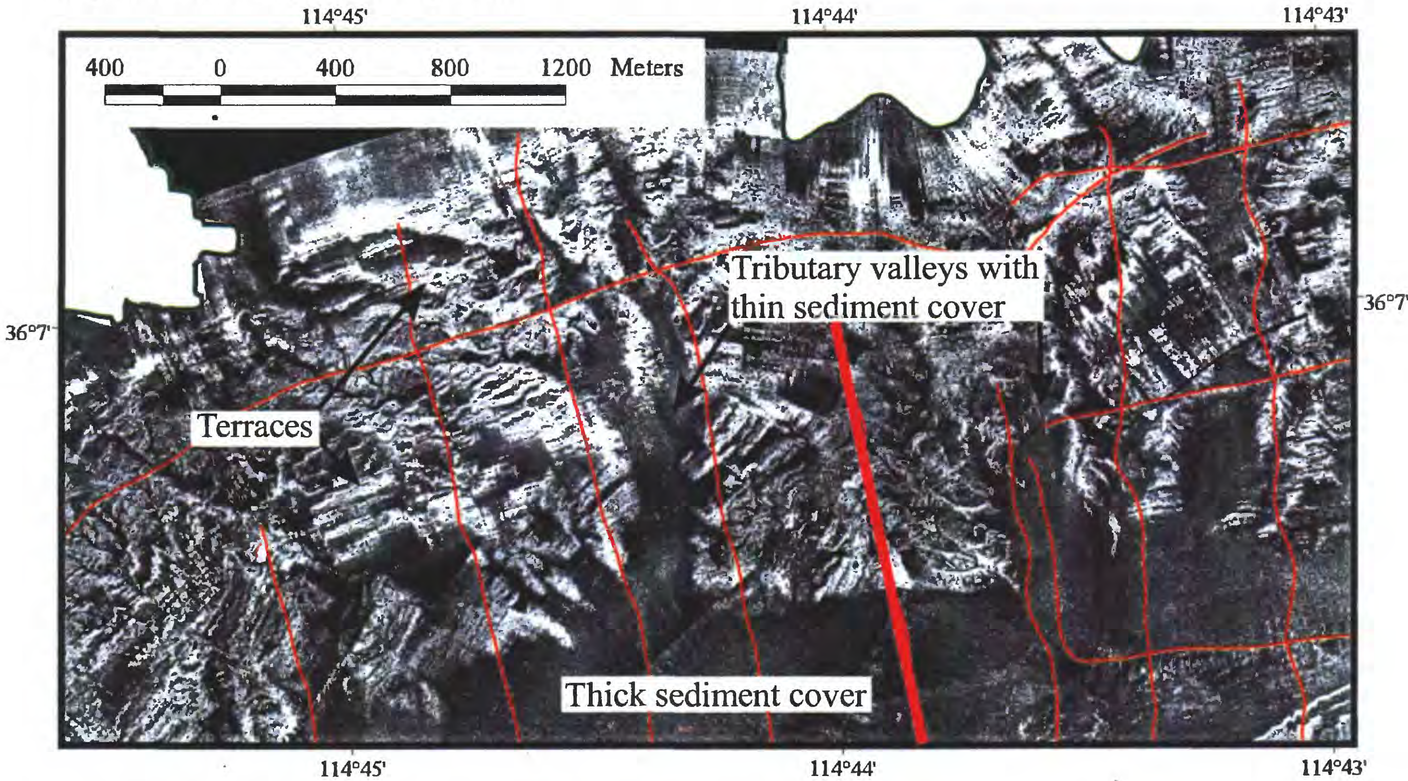
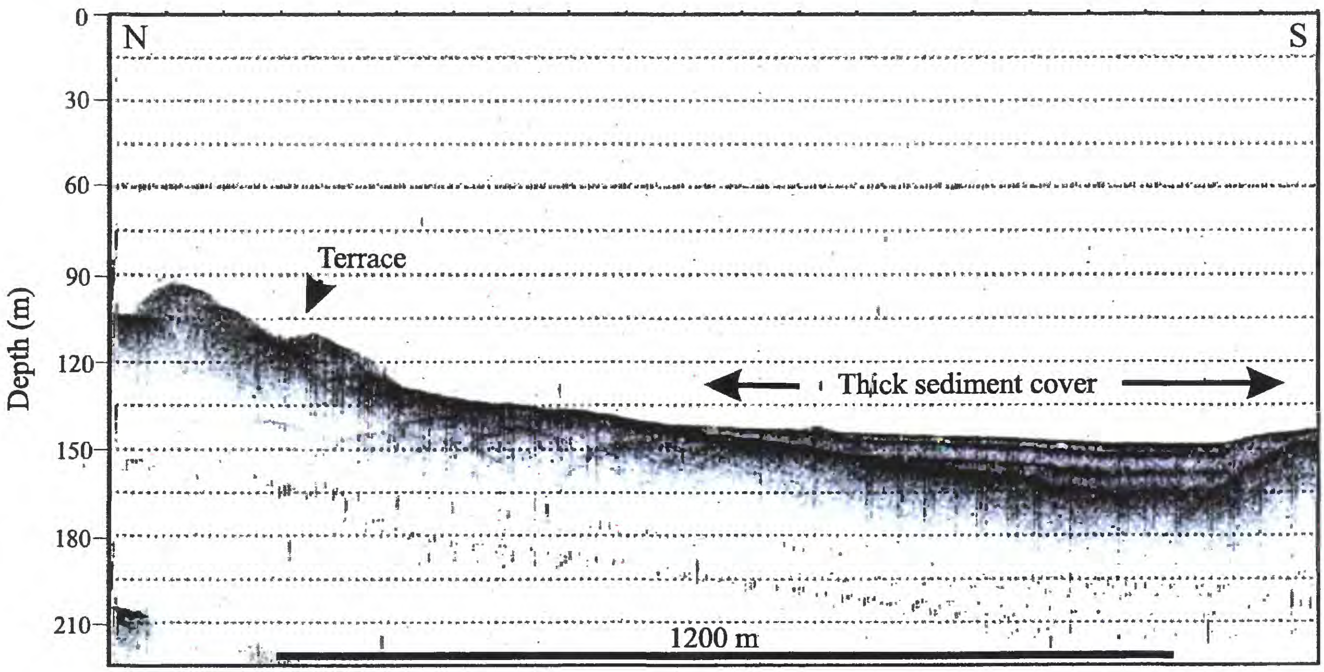


Figure 9. Sidescan sonar image of part of the terraced rock outcrop that characterized much of the northern side of the lake (location in inset map). Terraces show as alternating bands of high and low backscatter on the sidescan while uniform low-backscatter along southern part of image is post-impoundment sediment. Small tributary valleys with low-backscatter floors have thin sediment cover. Seismic profile (heavy red line on sidescan image) shows the gentler gradient and terraced nature of this side of the lake as well as post- impoundment sediment onlapping and burying this older surface. On the profile, 0.02 sec. Two-way travel time is approximately 15 m.







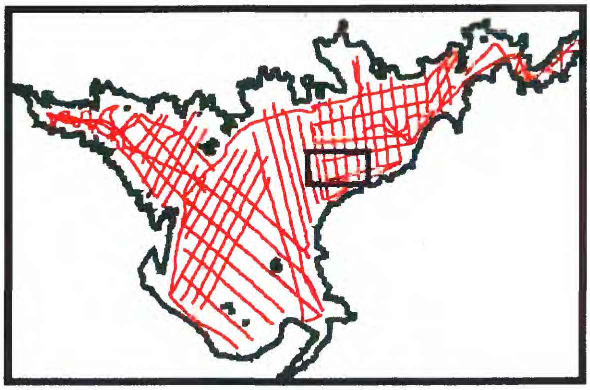
(Stewart and Carlson., 1978) which were extensively eroded by fluvial processes prior to formation of the lake.

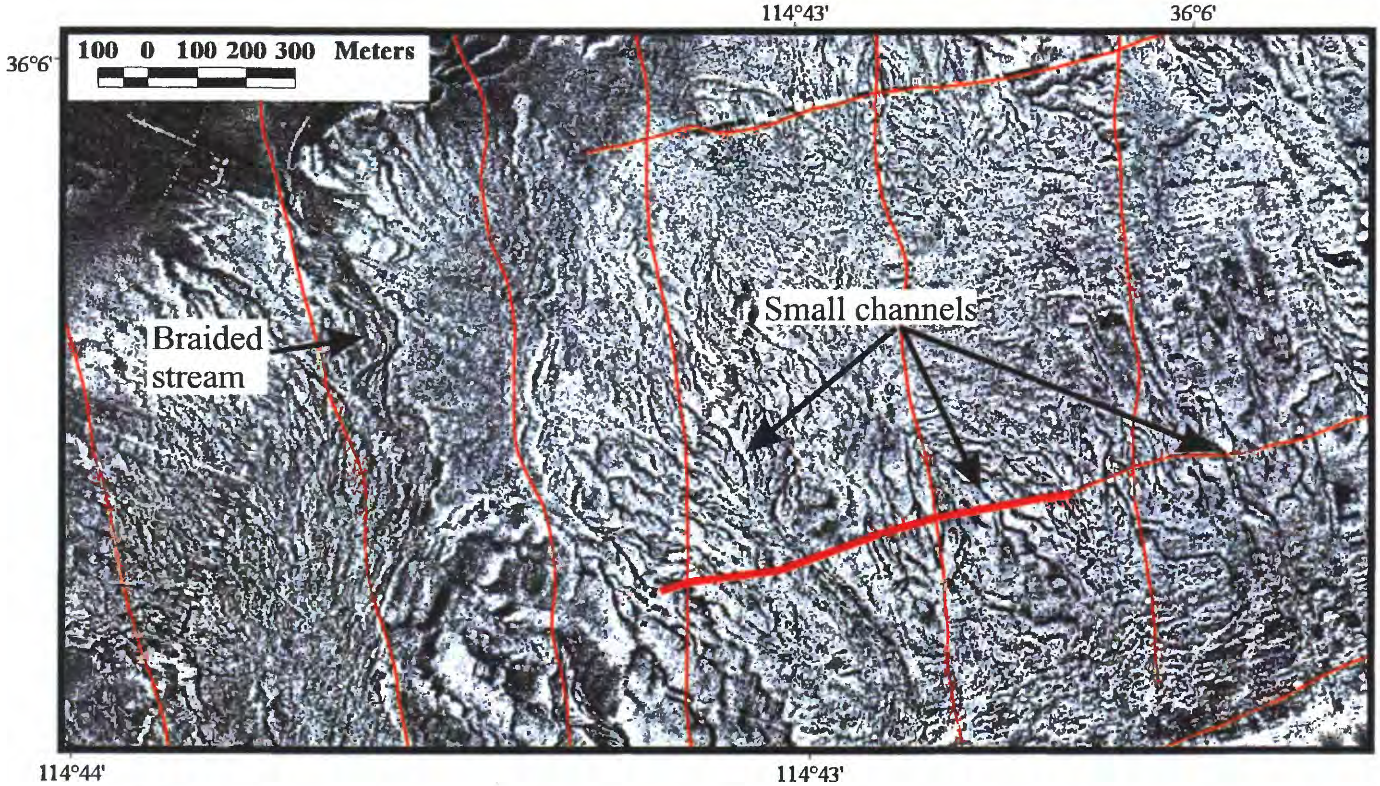
Alluvial deposits are the second pre-impoundment geologic province that is still preserved along large sections of the flanks of the lake (Figs. 4, 5). These deposits show on the sidescan sonar image as areas of uniform moderate backscatter which are dissected by an intricate network of small channels (Fig. 10). These channels coalesce downslope, and in some cases form larger braided streams (Fig. 10). Two large areas of alluvial deposits occur adjacent to alluvial fan deposits that have been mapped on land (Fig. 2). These large areas of alluvial deposits occur along the southeastern side of Boulder Basin and off of Boulder Beach (Fig. 5). Smaller areas of alluvial deposits are also found in Las Vegas Bay and Callville Bay.

The sediment that has accumulated in the lake since impoundment has a uniform low-backscatter signature associated with its surface (Fig. 4). This sediment fill has been divided into two provinces based on the seismic-reflection data; namely thin and thick sediment cover (Fig. 5). Sediment thickness will be discussed more in the description of the seismic data. Because of the continuous coverage of the lake floor provided by the sidescan mosaic, the outline of the post-impoundment deposits can be mapped in more detail than can be derived from the seismic profiles that are spaced several hundred meters apart. The thick sediment fills the former Colorado River channel and laps up against the older rock and alluvial units that are exposed along the flanks of the lake (Figs. 9, 11). Because of the dramatic contrast in acoustic signatures, the edge of the thick sediment unit is easy to identify. This deposit has an irregular edge with embayments and promontories coinciding with tributary valleys and spurs that were formed prior to the lake being formed (Fig. 5). Along the contact with alluvial deposits, the narrow embayments coincide with small valleys in the surface of the alluvial fans that have been partially filled. Within the area of thick sediment cover, the backscatter signature is not uniform. Discontinuous patches of slightly higher backscatter such as the area south of Callville Bay or at the mouth of the channel that originates in Las Vegas Bay may reflect areas where surface sediments are slightly coarser grained (Fig. 4). This inference awaits confirmation by direct sampling. In addition to these broader patches of moderate backscatter, there are also two parallel bands of moderate backscatter that are most clearly expressed in the area of thick sediments immediately south of Swallow Bay (Fig. 11). These two moderate backscatter bands occur on the flanks of an extremely subtle channel that is evident in the seismic profiles that cross it (Fig. 11). The seismic profiles suggest that the surface expression of this channel is in the same location as the original Colorado River channel, and that the channel on the lake floor only has about 2-m relief.

The thin sediment cover is not as extensive as the thick sediment cover, and is limited to the floors of the tributary valleys in the axes of Las Vegas, Swallow, Callville, and Hamblin Bay (Fig. 5). The seismic profiles show that sediment cover in these valley floors is patchy (especially in Swallow, Callville and Hamblin Bays) and rarely exceeds 2-m in thickness. The uniform nature of the low-backscatter signature from these valley floors suggests that, at most, only a thin veneer of sediment has accumulated in these areas since impoundment (Fig. 12). The fact that many of the seismic profiles in these areas show no sediment cover suggests that it is too thin to be resolved by the seismic system (Fig. 12). Therefore it is probably less than about 0.5 m thick. High-backscatter

Figure 10. Sidescan sonar image showingpart of a submerged alluvial fan (location in inset map). The fine, downslope-trending, low backscatter lineations represent the floors of a network of small channels that sculpt the surface of this alluvial fan. One of the larger channels appears to be a braided stream. Seismic profile shows that these channels mostly have less than 5-m relief (0.2 sec. TWT is approximately 15 m), and that there is no sediment cover on the alluvial fan.





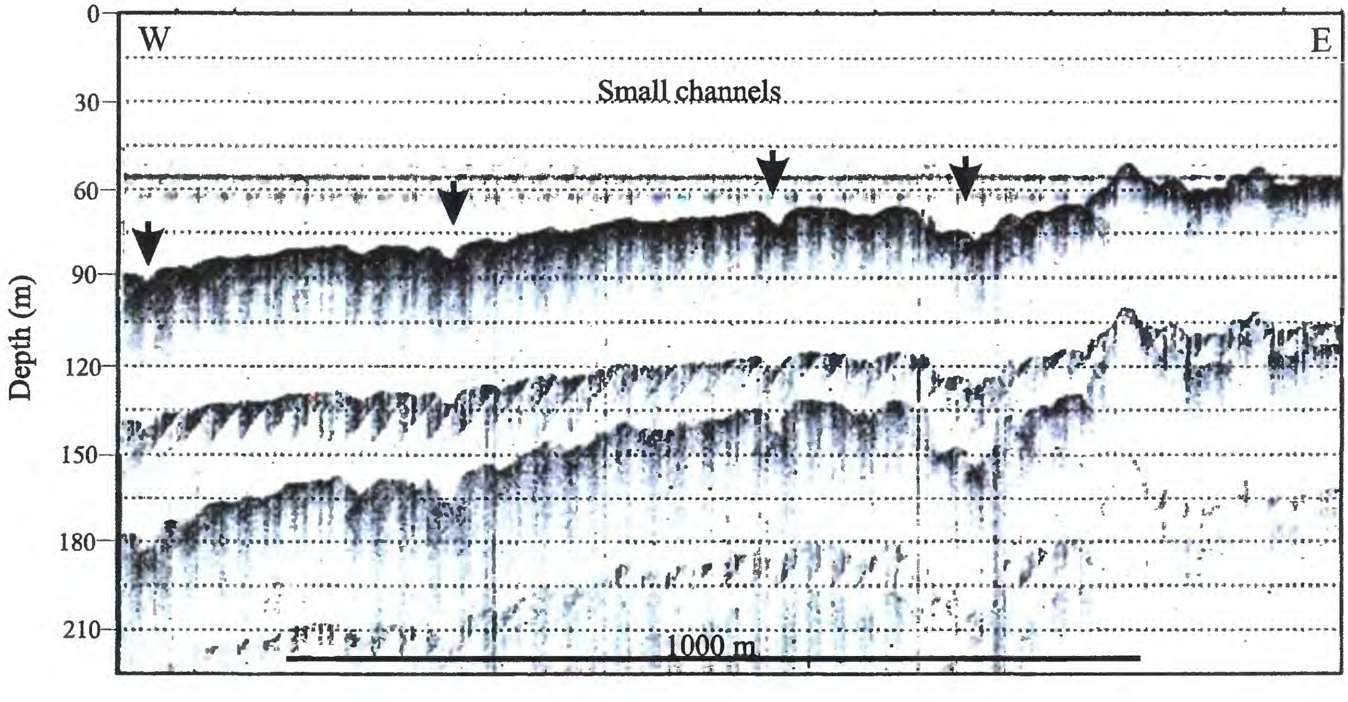
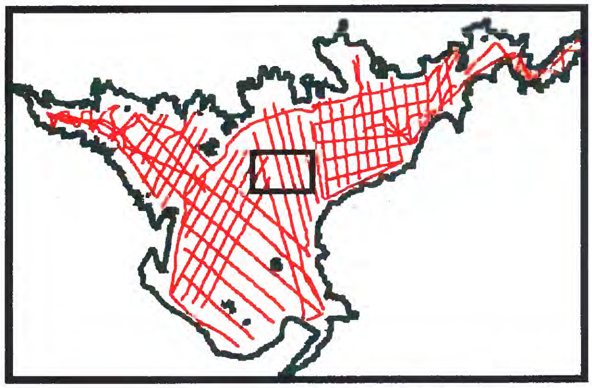
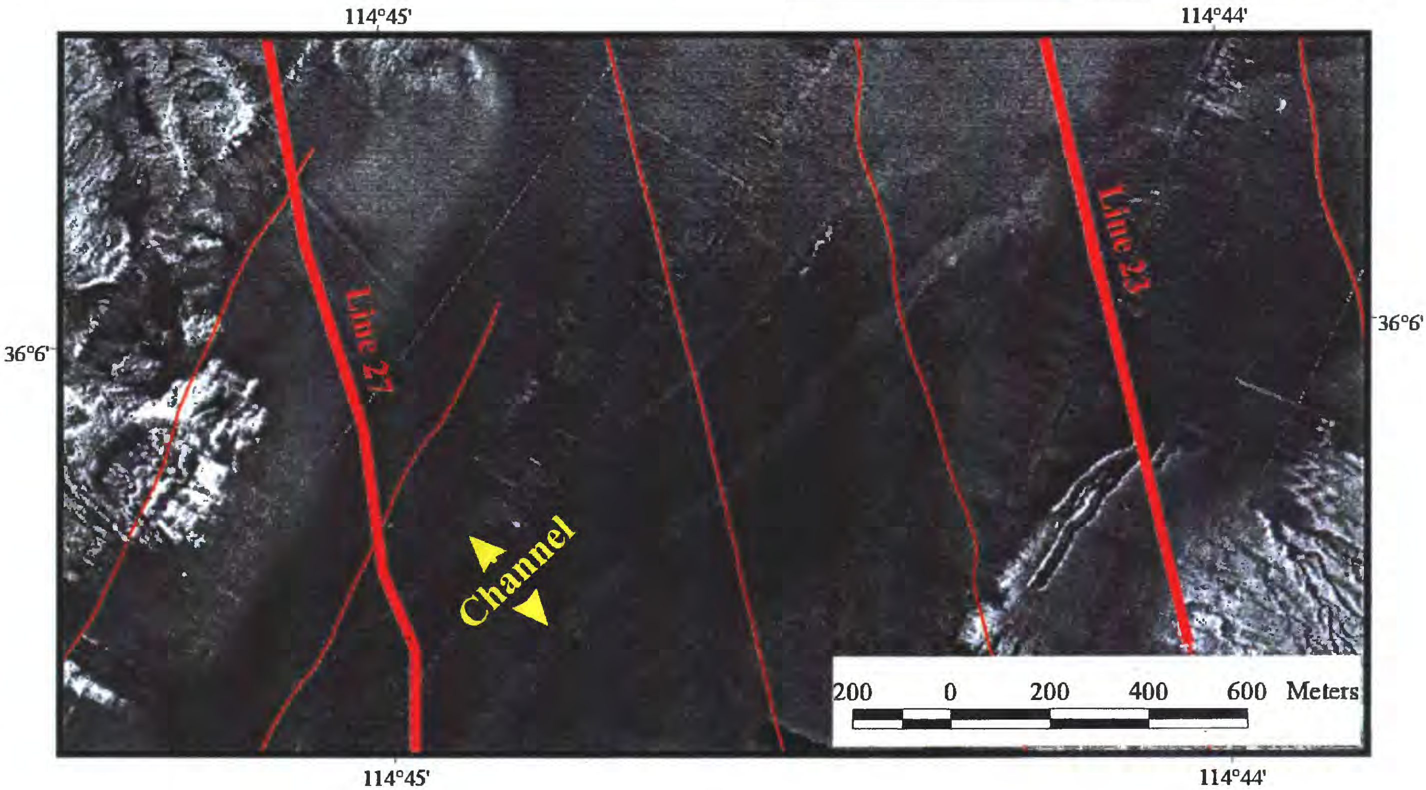
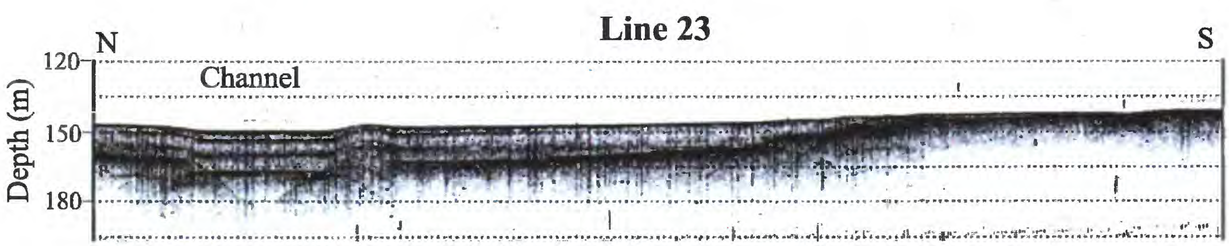


Figure 11. Central part of Boulder Basin (location in inset map) showing a subtle channel expressed on the lake floor in the sidescan mosaic as well as on two seismic profiles. Profile locations shown on sidescan mosaic. Profiles show that the channel has less than 2-m relief. Note also that sediment filling the basin floor is remarkably flat. The sediment, where it pinches out along the edge of the basin, is less than 5 m shallower than it is in the channel axis.







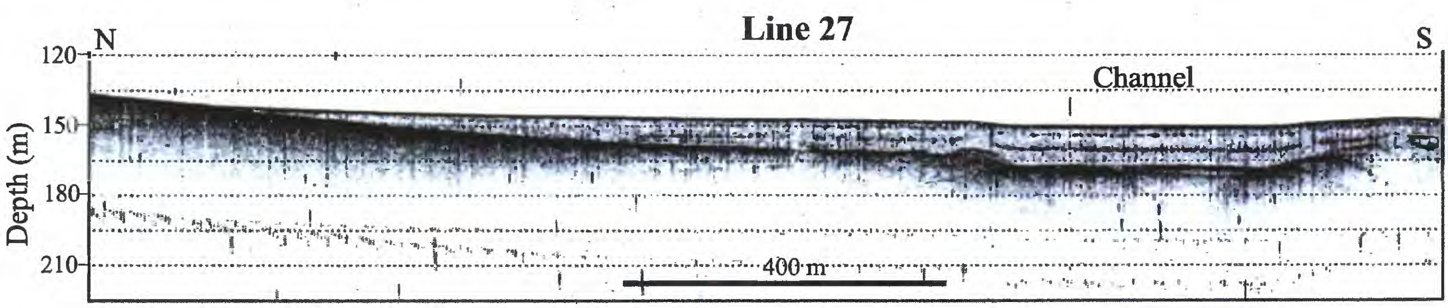
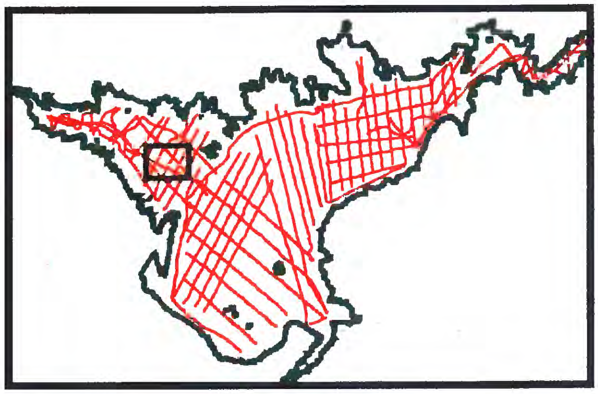
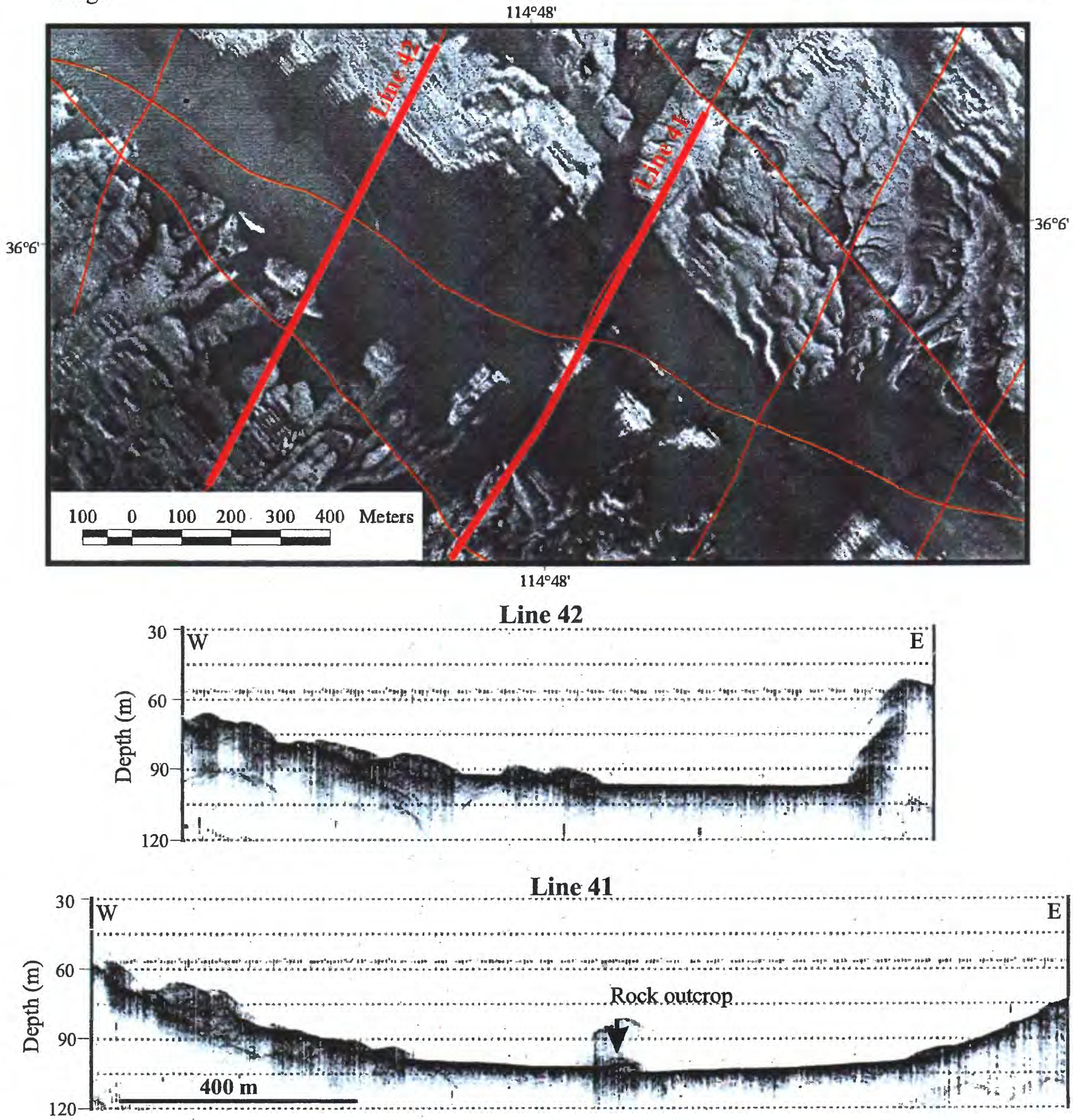


Figure 12. Sidescan sonar image from Las Vegas Bay (location in inset) showing the low-backscatter sediment cover in the narrow valley floor and the high-backscatter signature from the rock faces adjacent to the floor. Sediment cover is thin as patches of high-backscatter rock outcrop are present in the floor of the valley. Seismic profiles (locations shown on sidescan image) show the flat-floored nature of the valley and that sediment here is less than 2 m thick. Note rock outcrop on line 41 that also shows on the sidescan image.





targets in places along this channel floor are probably boulders, and their presence further supports thin sediments that have not completely covered the pre-existing geology (Fig. 12).

Seismic-reflection profiles were used to map the thickness of sediment that has accumulated on the lake floor (Figs. 6, 7). Sediment that is interpreted to have accumulated since formation of the lake shows as an unit with some continuous internal reflectors on these subbottom profiles (Figs. 6, 8, 11, 13). The top of this transparent unit is flat, and it fills the deepest parts of the valleys in the lake floor (Figs. 8, 13A). This transparent unit rests on top of a high-amplitude reflector that merges with the present lake floor where the transparent unit pinches out (Figs. 9, 11, 13B). Where the transparent unit pinches out consistently coincides with the transition from sediment cover to rock or alluvial deposits on the sidescan imagery (Figs. 8, 9, 11). Although cores are not yet available to confirm this interpretation, the close correlation of the sediment distribution based on the seismic profiles with that derived from the sidescan imagery further supports the interpretation of this transparent unit being the post-impoundment sedimentary section. The post-impoundment sedimentary unit sometimes has as many as four discontinuous reflectors within it (Fig. 6). The origin of these reflectors is unknown, and will require cores for the explanation.

The sediment thickness map shows that post-impoundment sediment is limited to a relatively small part of the lake floor (Fig. 7). It is thickest and most continuous in the deep, flat central part of Boulder Basin where water depths exceed 125 m. The sediment in Las Vegas Bay and Callville Bay by contrast is thin and discontinous. Much of the lake floor has no post-impoundment sediment covering it at all (Fig. 7). Sediment in the floor of Boulder Basin locally exceeds 30 m in thickness, but in most of this area it is less than 20 m thick. It is thickest over the channel of the former Colorado River (Figs. 8, 9, 11, 13D). Although rare, there were a few places along the axis of the former Colorado River where the post-impoundment sediments were too thick to be penetrated by the chirp subbottom profiler. In these areas, sediment generally exceeded 35-m in thickness. In the narrow parts of the lake, specifically near Hoover Dam and in Boulder Canyon, the sediment thins abruptly against the steep rock walls that flank these parts of the lake, but is a fairly constant thickness along the axis of the channel. Exceptions to the thick sediment cover do occur locally in Boulder Canyon where it thins to less than 4 m thick (Fig. 7). In the central part of Boulder Basin, where the flanks of lake floor have gentler gradients, the extent of post-impoundment sediment is broader, and it thins gradually rather than abruptly at its edges (Fig. 7, 9, 11, 13B). Here, large areas of the deposit are less than 10 m thick.

Four reflectors have been identified in this post-impoundment deposit (Figs. 6, 13C). These reflectors all are flat-lying. The youngest one is 1-2 m below the lake floor and the older ones are 4-5 m, 7-8 m, and 18-19 m below the lake floor respectively (Fig. 13). The oldest reflector, because of the shape of the basin has a more limited extent than the younger ones. The horizontal nature of these reflectors results in the oldest reflector being limited to the central part of the basin while the younger ones have a broader extent (Fig. 13). No places were observed where these older reflectors were exposed on the lake floor. A shallow channel, with less than 2-m relief, is present on the floor of Boulder Basin (Fig. 11). This channel can also be seen in each of the reflectors in the subsurface

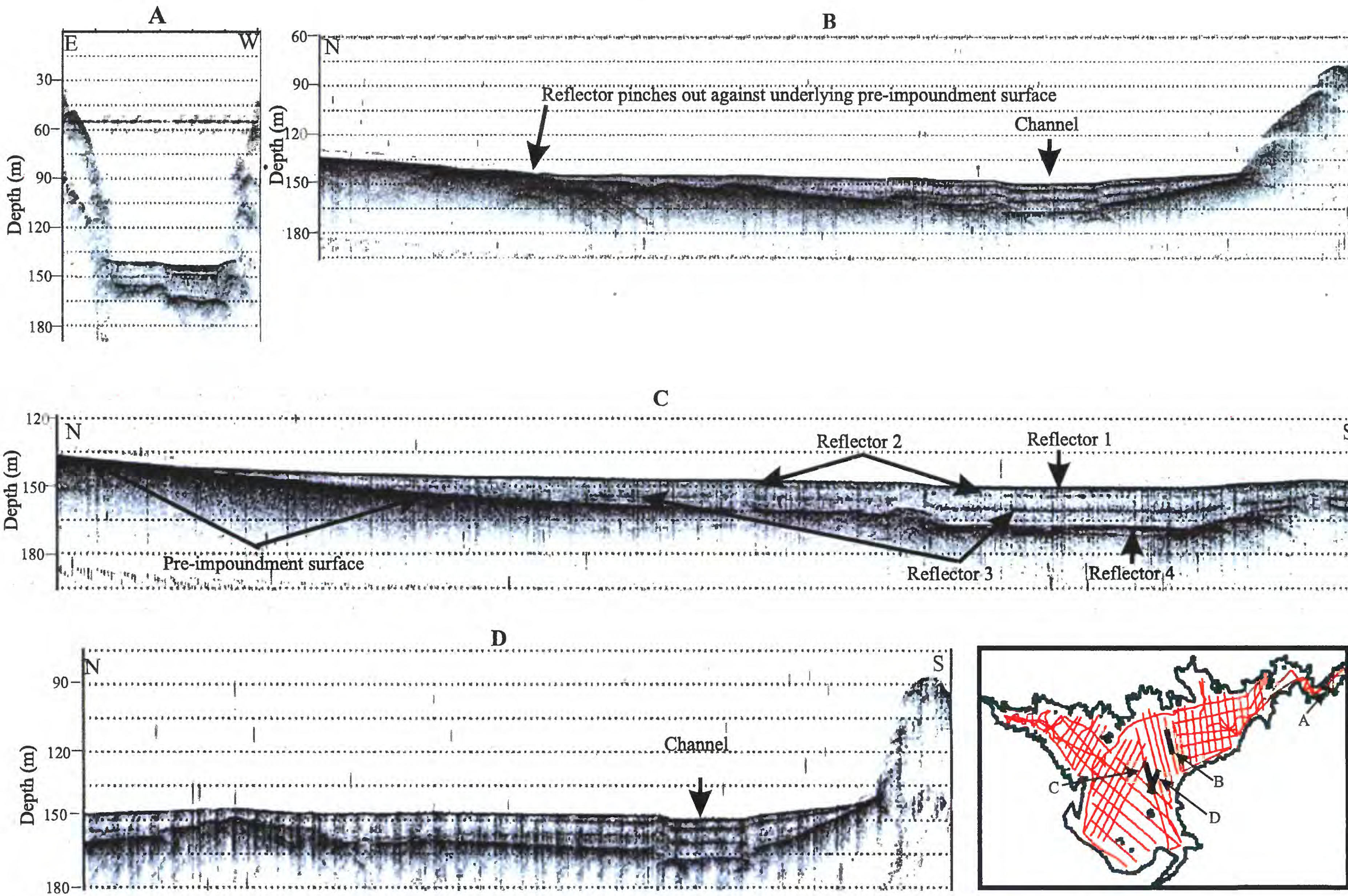


Figure 13. Four seismic profiles showing the acoustic stratigraphy of the sediments filling the lake. A: profile form Boulder Canyon showing flat-lying sediments abutting the steep canyon walls. B: profile immediately south of Callville Bay showing the channel and pinching out of sediment against the gentle northern slope. C: profile south of Swallow Bay showing four reflectors in the post-impoundment section. Note that all of them are nearly horizontal and that the deeper ones are not laterally as extensive as the shallower ones. D: profile in the western part of Boulder Basin showing that the channel is still present here. Profile locations shown on inset map.

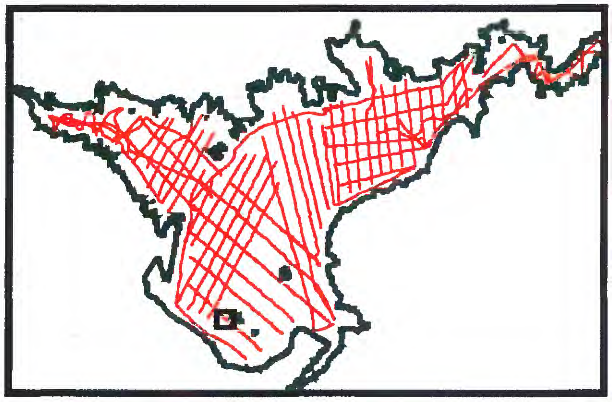
which suggests that this channel has been present throughout the filling of the lake (Figs. 11, 13).

DISCUSSION

The sidescan sonar imagery and high-resolution seismic-reflection profiles provide a detailed overview of the lake-floor geology and the thickness and distribution of sediments that have accumulated in the lake since its initial formation. Because no cores or surface sediment samples are available, the interpretation presented here is based exclusively on the geophysical data and undoubtedly will be refined with the addition of ground-truth information. Even without ground-truth information, however, certain observations can be made as to the distribution of sediment within the lake and as to the processes by which it was deposited.

Much of the lake-floor geology mimics the geology of the surrounding landscape. Adjacent to steep rock cliffs the seismic profiles and sidescan sonar imagery show steep cliffs (Fig. 8). Adjacent to alluvial fans the morphology of the lake floor mimics the on-land parts of these fans, and the sidescan imagery shows the same intricate network of channels that is seen on the subaerially exposed parts of these fans (Fig. 10). The preservation of these pre-impoundment geological features suggests that virtually no sediment has accumulated on these areas. If there were sediment covering these areas, it must be less than 0.5 m thick, otherwise it would be apparent on the seismic profiles that cross these areas (Figs. 9, 10). The distinctive distribution of post-impoundment sediments in the lake indicates processes of transport that are restricted to the axes of the submerged valley floors rather than sediment being deposited as a drape across the entire lake floor (Figs. 5, 7). Furthermore, the flat-lying reflectors in the sediments that fill the deep part of the lake indicate a vertical filling process rather than a process by which a blanket of sediment has draped the entire lake floor (Figs 8, 11).

The preservation of the morphology of the surface of the alluvial deposits is of additional interest because it implies little reworking of the lake floor during the flooding of the lake and since the lake became full. These alluvial deposits consist of unconsolidated silt, sand, and gravel (Wilson et al., 1969) that would be remobilized if strong bottom currents or large waves were present in the lake. The preservation of the alluvial surfaces and the presence of what appear to be a road and a narrow trail that were created prior to the formation of the lake indicates that processes acting on the lake floor as lake level rose and since then have been insufficient to erase these features (Fig. 14). The only evidence of pre-impoundment deposits being reworked is in water depths shallower than 18-20 m. Figure 15 shows some alluvial channels that abruptly end in about 18-m water depth. Shoreward of this depth, the lake floor has a more uniform high-backscatter appearance that suggests a continuous smooth sheet of sand. This smooth sand sheet may reflect reworking and redistribution of the unconsolidated alluvial deposits by storm waves breaking on the beach. The 18-m depth, however, is deeper than the depth to which significant reworking of sediment occurs on high-energy coasts (Komar, 1997). In Lake Mead, this depth probably is more indicative of the maximum lowering of the lake surface since initial filling rather than being an indication of wave energy.



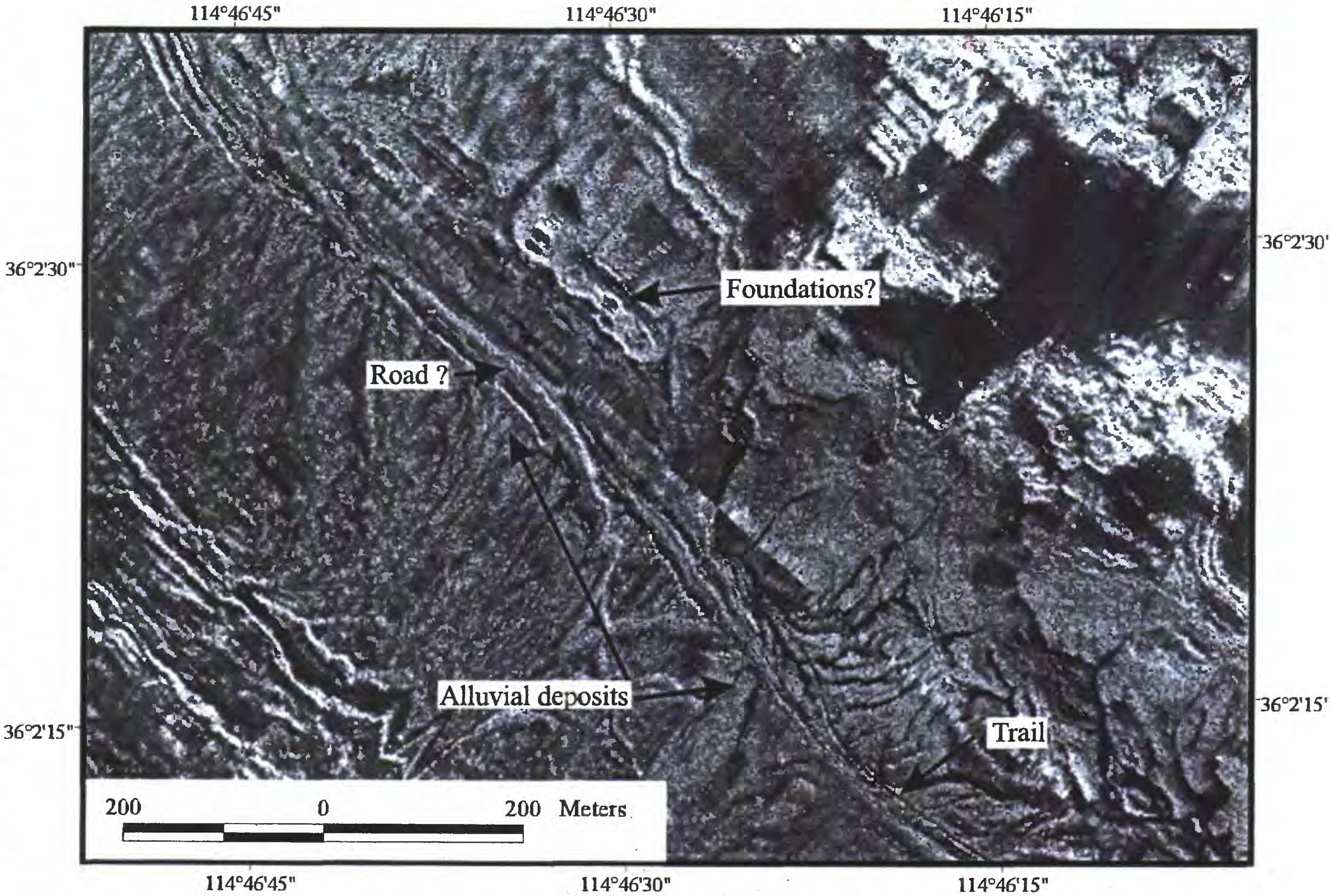
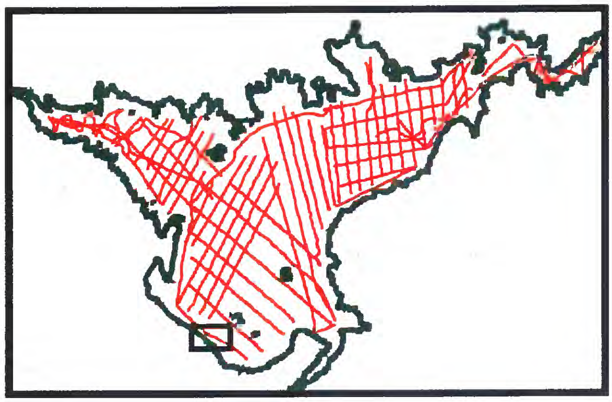
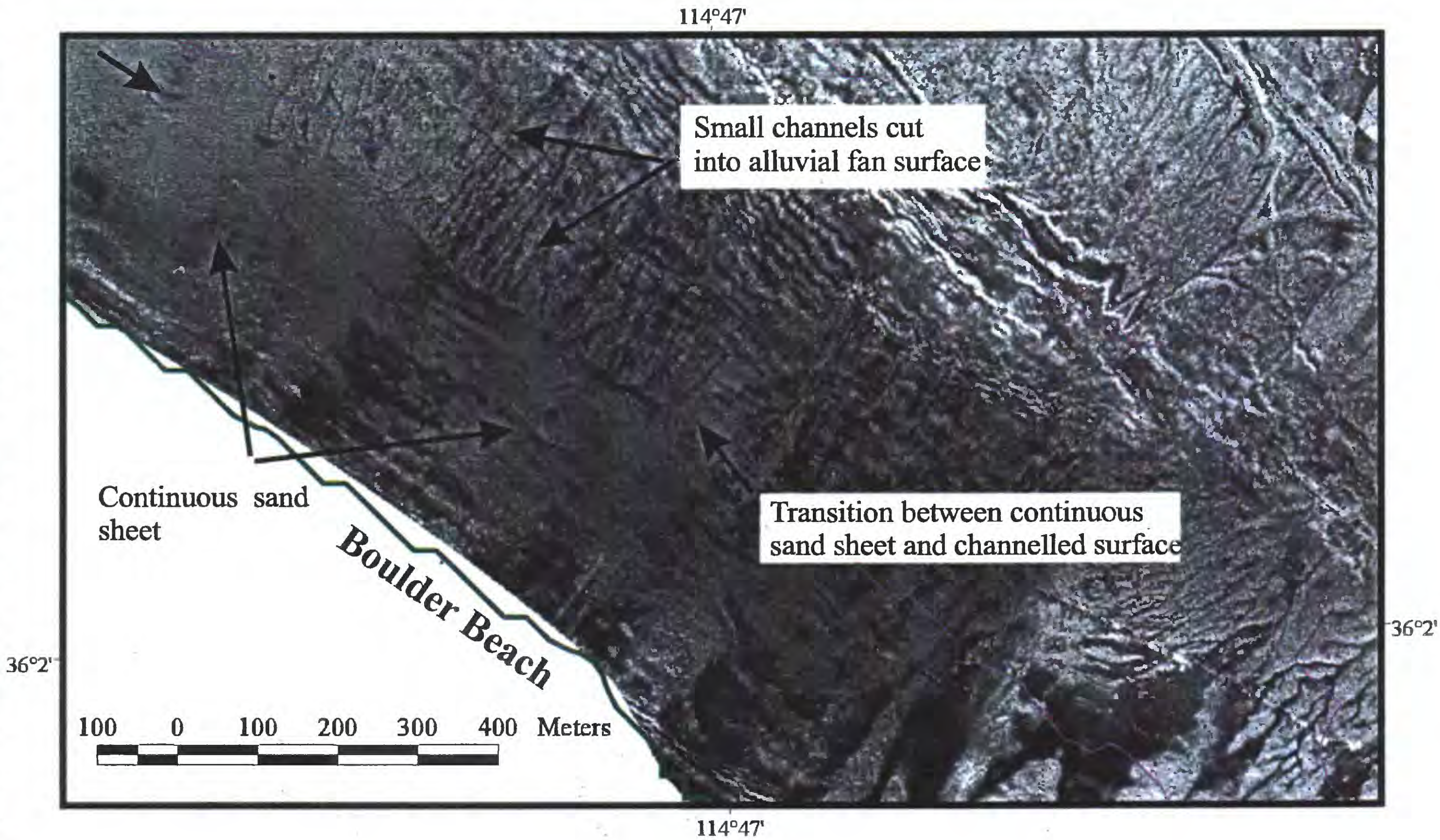


Figure 14. Sidescan sonar image of part of an alluvial fan surface in the western part of Boulder Basin (location shown in inset). The preservation of a road (about 15-m wide), trail and possibly foundations indicates that little reworking has taken place on this part of the lake floor since the area was flooded. Note also that the alluvial deposits are truncated by the road (end of arrows) which indicated that they have not been active since the lake was filled.

Figure 15. Sidescan sonar image from the southwestern side of Boulder Basin showing the transition from a continuous sand sheet to the channelled alluvial fan surface. The continuous sand sheet occurs in water less than about 18 m deep and probably represents reworking of the alluvial fan deposits by waves. The 18-m depth of this transition probably represents the maximum lowering of the lake since it initially was filled.

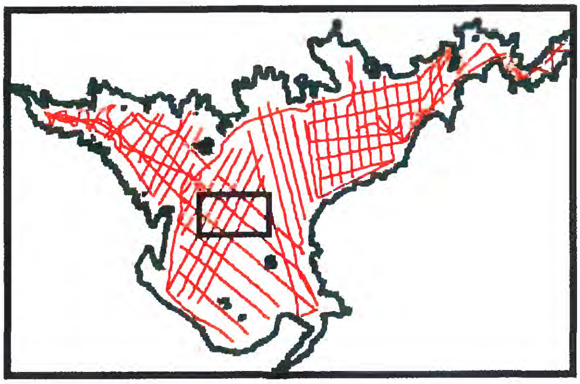


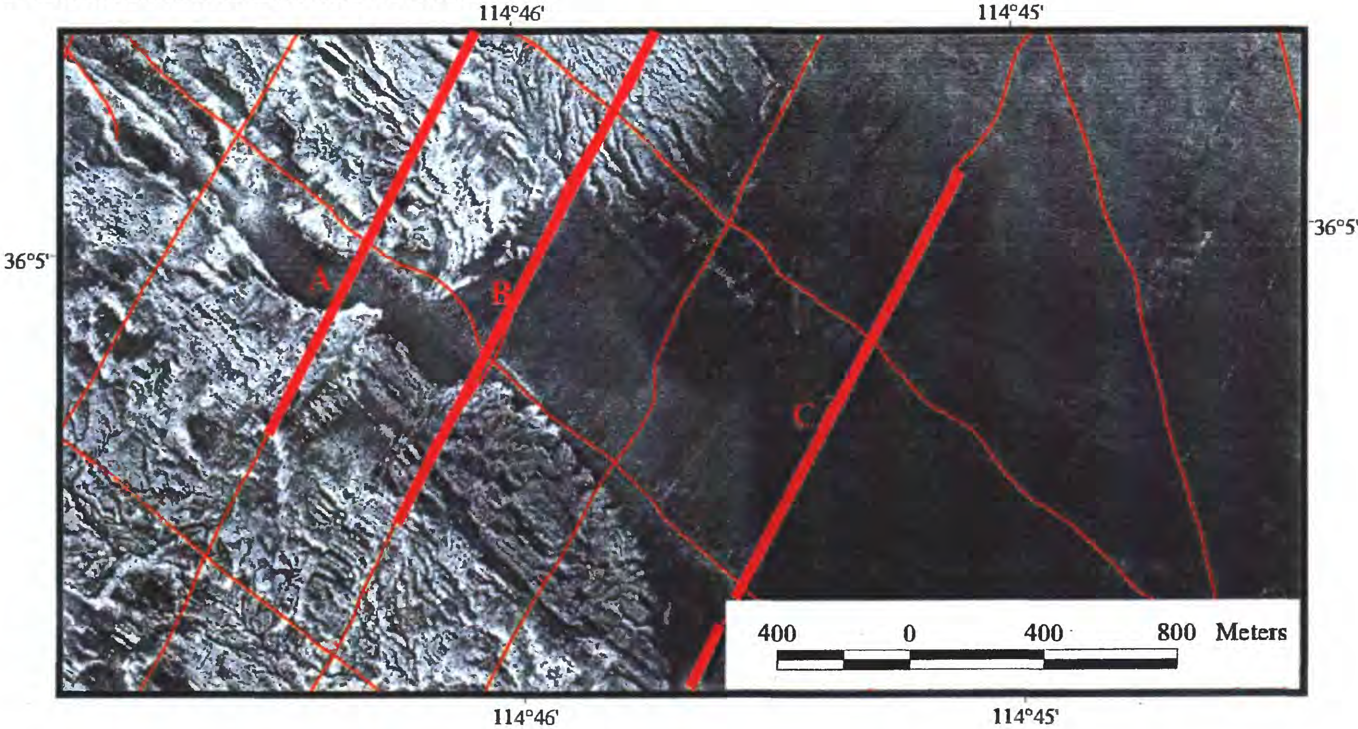


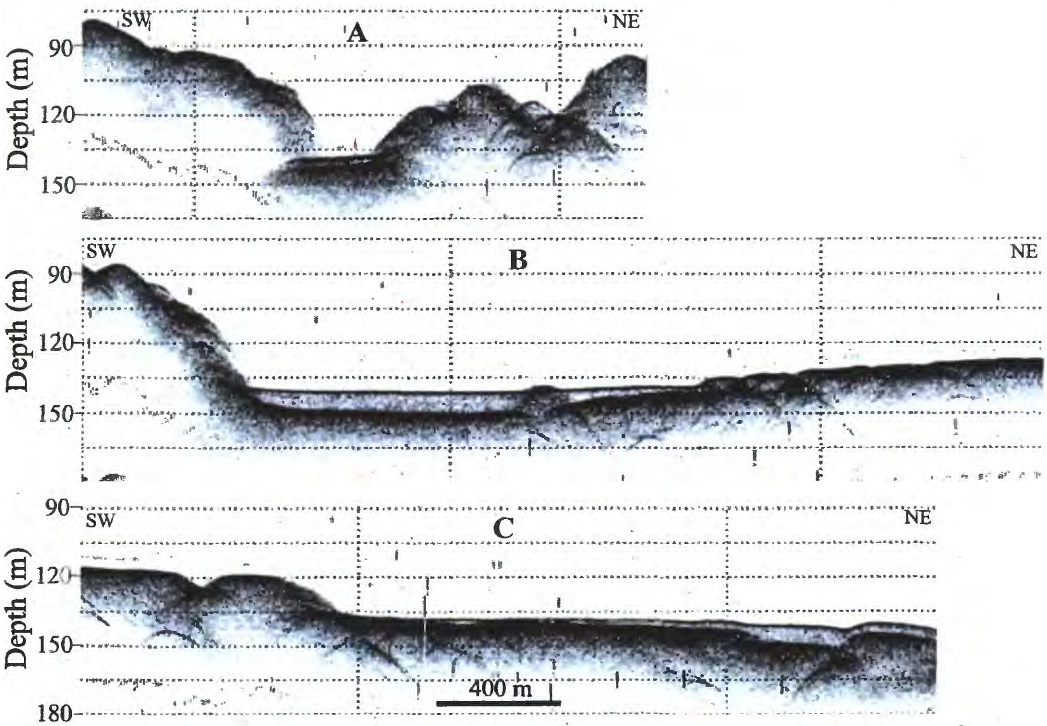
Most of the sediment that has accumulated in the lake since it formed is along the axis of the deep part of the lake (Fig. 7). This distribution suggests that sediment has been contributed to the lake from a few localized point sources rather than a general contribution from all of the surrounding landscape. If there were multiple sources, sediment pathways should be seen leading from the sources to the lake floor, or the entire lake floor would be draped with a sediment cover. Instead, most of the walls of the lake are barren of recent sediment (see seismic profiles in Figs. 8, 9, 10, 12), and sediment is only present in the floor of Boulder Basin and in the narrow valley floor of Las Vegas Bay (Fig. 7). Only discontinuous, thin patches of sediment are seen in the axial valley floors of Swallow Bay, Callville Bay, and Hamblin Bay (Fig. 7). The flat surface of the sediment that fills Boulder Basin, the gentle downslope gradient of this surface from Boulder Canyon to Hoover Dam, and the shallow channel extending westward from Boulder Canyon suggests that the primary source for this sediment is from east of Boulder Canyon. Gould (1951) proposed that the sediments in the floor of Lake Mead were the product of dense turbid flows, derived from the Colorado River, running the full length of the lake. The geometry of the deposits on the lake floor and their internal stratigraphy are consistent with the turbidity current origin proposed by Gould (1951). The seismic profiles show four nearly flat-lying reflectors within the deposit (Fig. 6). The cause of the reflectors is presently unknown, but they could represent sandier beds within a predominantly mud deposit. These reflectors mimic each other, and all show a shallow channel overlying the deepest part of the lake (Fig. 13). Also, the reflectors that extend away from the channel onlap the underlying surface along the basin edge. Where the walls are steep this onlapping is abrupt (Fig. 8), and where the underlying surface has a gentler gradient the reflectors can be seen pinching out against this surface (Fig. 13 C and D). This pattern is similar to the geometry of other turbidity current deposits that have been extensively mapped in deep-sea settings (Walker, 1992). The stacking of the channels in the four reflectors, one on top of the other, suggests that turbidity currents have continued to be the dominant process of sedimentation in the lake during its 65-year history. If not, the geometry of the reflectors would have changed. The sediment in the lake floor is nearly, but not perfectly flat, but the difference in elevation between the channel floor and the edge of the sediment is consistently less than 5 m (Figs. 11, 13B). The fact that the surface of these deposits only slightly laps up on the flanks of the lake suggests that the turbidity flows were thin. This difference in elevation between the channel floor and the edge of the sediment suggests that the turbidity current flows were less than 6-8 m thick.

Minor contributions of sediment have been supplied to Lake Mead from Las Vegas Wash as well. Sediment supplied from this source probably was transported as turbulent flows as well because the sediment distribution is limited to the axis of the valley In Las Vegas Bay (Fig. 7). The Las Vegas Wash source is viewed as minor because the thickness of sediment in this valley floor is much thinner than that in the central part of Boulder Basin (Figs. 7, 12). Additionally, if large amounts of sediment were passing through this valley and being deposited in the floor of Boulder Basin, a fan-like deposit would be present at the mouth of this valley. Figure 16 shows three profiles across the mouth of the valley extending out of Las Vegas Bay, and no fan or channel is present in this area. The discontinuous sediment cover along the length of the channel

Figure 16. Sidescan sonar image and seismic profiles of the end of the valley in Las Vegas Bay where it opens into Boulder Basin. Sidescan image shows a narrow channel floor bounded by steep rock walls where it exits Las Vegas Bay and ends in Boulder Basin. The presence of sediment covering the valley floor on profile A at a depth shallower than the floor of Boulder Basin (138 m) suggests sediment is passing down this channel from the Las Vegas Wash area, but the thin sediment cover and absence of a channel or fan-like deposit where it opens onto Boulder Basin (profiles B and C) suggests the valley is not a major sediment source to the Boulder Basin area.







that floors Las Vegas Bay indicates that sediment derived from Las Vegas Wash is being transported several kilometers into the lake, but that at present, the volume is not large.

SUMMARY

A significant volume of sediment has accumulated in Boulder Basin and a lesser amount in Las Vegas Bay since the formation of Lake Mead. A detailed mapping of this sediment shows that it is not uniformly distributed throughout the lake. Instead, it occurs as flat-lying deposits that have filled only the deepest parts of the Colorado River valley and tributary valleys that were cut prior to the formation of the lake. These sediments are thickest in the floor of Boulder Basin where they are more than 20 m thick for large areas and locally exceed 35 m. The surface of the sediment filling Boulder Basin is shallowest at the eastern end of the study area in Boulder Canyon (about 128 m), and gradually deepens to the southwest to 147 m deep near Hoover Dam. The flat-lying nature of reflectors within the deposit, the gentle westward gradient of the surface of the deposit, and the presence of a shallow channel along the axis of Boulder Basin suggest that it is the result of turbidity currents that have flowed the length of the lake (Gould, 1951). The sediment that has accumulated in the floor of Las Vegas Bay also is limited to the thalweg of the former valley. Here sediment is less than 2-m thick, but probably also was transported by turbidity currents which followed the pre-existing axial valley. Understanding the distribution of sediment that has accumulated in Lake Mead since impoundment, and understanding the processes by which it is distributed through the lake are necessary information for monitoring the fate of pollutants that enter the lake.

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