Integration of orthophotographic and sidescan sonar imagery: an example from Lake Garda, Italy

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ABSTRACT

Digital orthophotos of Lake Garda basin area are available at the scale of up to 1:10,000 from a 1994 high altitude (average scale of 1: 75,000) air photo coverage of Italy collected with an RC 30 camera and Panatomic film. In October 1994 the lake bed was surveyed by USGS and CISIG personnel using a SIS 1000 Sea-Floor Mapping System. Subsystems of the SIS-1000 include high resolution sidescan sonar and sub-bottom profiler. The sidescan imagery was collected in ranges up to 1500m, while preserving a 50cm pixel resolution. The system was navigated using differential GPS. The extended operational range of the sidescan sonar permitted surveying the 370km^2 lake area in 11 days. Data were compiled into a digital image with a pixel resolution of about 2m and stored as 12 gigabytes in exabyte 8mm tape and converted from WGS84 coordinate system to the European Datum (ED50) and integrated with bathymetric data digitized from maps.The digital bathymetric model was generated by interpolation using commercial software and was merged with the land elevation model to obtain a digital elevation model of the Lake Garda basin.The sidescan image data was also projected in the same coordinate system and seamed with the digital orthophoto of the land to produce a continuous image of the basin as if the water were removed. Some perspective scenes were generated by combining elevation and bathymetric data with basin and lake floor images. In deep water the lake's thermal structure created problems with the imagery indicating that winter or spring is best survey period. In shallow waters, ≤ 10 m, where data are missing, the bottom data gap can be filled with available images from the first few channels of the Daedalus built MIVIS, a 102 channel hyperspectral scanner with 20 channel bands of 0.020 μm width, operating in the visible part of the spectrum. By integrating orthophotos with sidescan imagery we can see how the basin morphology extends across the lake, the paths taken by the lake inlet along the lake bed and the areal distribution of sediments. An extensive exposure of debris aprons were noted on the western side of the lake. Various anthropogenic objects were recognized: pipelines, sites of waste disposal on the lake's bed, and relicts of Venitian and Austrian (?) boats.

1.0 Introduction

Being able to "see" the floor of bodies of water as if the water were not there is of interest to many research scientists from a variety of disciplines and also to governmental agencies working on land use problems near water bodies.

Occasionally a geologic formation that is found on land cannot be traced with confidence to the other side of a body of water without some knowledge of the configuration of its bed. Often much can be learned about the dynamics of coastal sediment formation by being able to trace onshore features to morphological characteristics of the bed. A variety of environmental problems can be addressed much more successfully if the shore data can be correlated with the images of the offshore bottom. The project described here was undertaken to answer some of these questions.

2.0 The lake Garda project

The CISIG had contemplated the possibility of carrying out a project of trying to merge images of lake beds with onshore aerial photography for some time but it was only the advent of extended coverage sidescan sonar instrumentation and the development of a collaborative agreement with the US Geological Survey that made this possible.

Choice of Lake Garda as project area was dictated by the size of the lake, the largest in Italy, and by the fact that another remote sensing project with a hyperspectral scanner was also being carried out on part of the lake at the same time.

An outline of the project area is given in **Figure 1**.

The lake Garda is a Quaternary-age glacial lake that formed along the geomorphic expression of a major Cenozoic-age thrust fault which was associated with the formation of the Alps (Petrucci and Valloni, 1981). The fault extends along the eastern shore of the lake and is believed to continue south along the lake bed to the peninsula of Sirmione, thus dividing the southern lobe of the lake into two parts, a deeper one on the west, and a relatively shallow segment on the east. The succession of quaternary glaciations and their successive retre

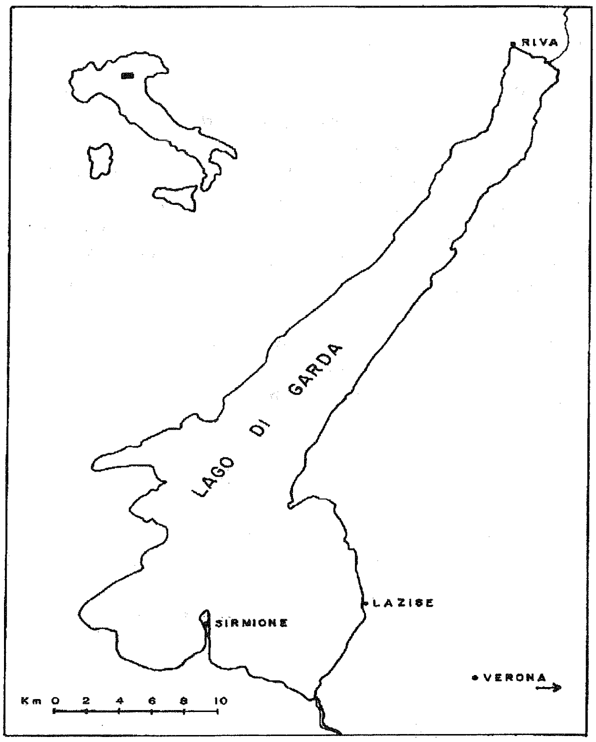

Figure 1 - Location of Lake Garda project area and cities referenced in the text

ats are responsible for the topography of the lake basin and of its bed, its valley sides, and the downstream morainal deposits.

Table 1 - Technical data concerning the high altitude aerial photo coverage of Italy of 1994

Item	Data
Area covered	301,200Km^2 (all of Italy)
Direction of flight axes	E-W and W-E superimposed on the axes of the 1:25000 scale maps of the national cartographic agency (IGM)
Km of flight	about 31,000
Relative flight altitude	11,500m
Average photo scale	1 : 75,000
Number of photos	5,500 (overlap 60%, sidelap 20%)
Film used (negative)	KODAK PANATOMIC X
Camera	WILD RC 30 equipped with FMC, f = 152.82mm
Aircraft	Lear Jet 25C
Image resolution	Between 0.5 and 1m

3.0 High altitude airphoto coverage of Italy

The aerial photography needed for the preparation of the digital orthophotos of the lake Garda basin were taken from high altitude photography executed in 1994 by the Compagnia Generale Ripreseaeree of Parma. Although in 1988-89, for the first time, all of Italy was photographed from about 12.000m it was only in 1994, in a period of about 90 calendar days, and therefore almost synchronously, that the best photographic coverage was acquired with the material and equipment described in table 1.

The quality of the photographs was such that it was possible to achieve operational cartographic quality anywhere in Italy at the scale of 1:10.000 while meeting the standard specifications required for that scale.

4.0 Sidescan sonar imagery of lake Garda's bottom

In October, 1994 the floor of lake Garda.was surveyed during a collaborative project between the US Geological Survey and the CISIG using a SIS-1000 Seafloor Mapping system and echosounder. SIS-1000 subsystem include s a sidescan sonar and Chirp subbottom profiler. The sidescan sonar operated in the 100kHz band and provided ranges up to 750m to each side of the sonar vehicle. The data were logged digitally, and pixel size varied with the swath width used, but was less than 50cm in the across track direction. The chirp subbottom was a swept-frequency system with a central frequency of 3.5kHz. Bathymetry was measured with an ODOM DF 3200 digital fathometer with the depths being logged with the navigational information. Ship navigation was done by differential GPS with two shore stations; one near Riva at the northern end of the lake and the second at Sirmione at the southern end of the lake.

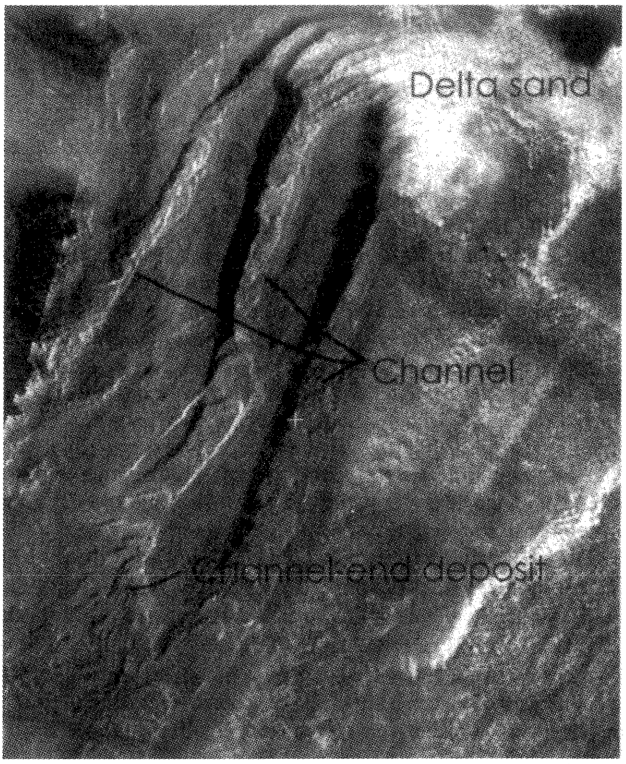

Figure 2 - Sidescan sonar image of upper lake Garda floor showing traces of its inlet. Notice the patterns of sand dunes formed in the channels.

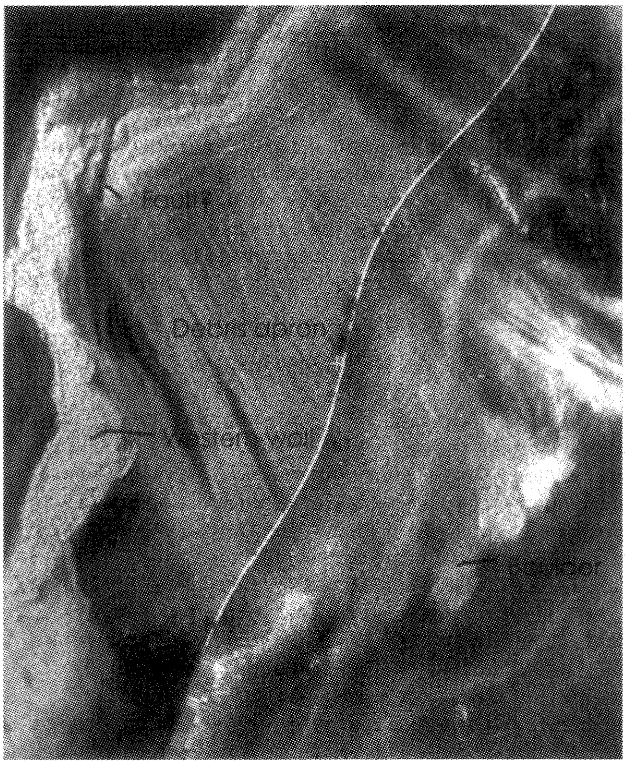

Figure 3 - Sidescan sonar images of large debris apron on western side of upper lake Garda

The position of the sidescan sonar vehicle, relative to the ship, was measured with a Benthos DS 7000 acoustic ranging system. The acoustic ranges were merged with the ship's GPS navigation to compute a sidescan vehicle navigation.

Because of the wide swathwidths of the SIS-1000 sidescan sonar system and the depth of the lake, the entire 370 km^2 section of the lake that is deeper than 10m was surveyed in 11 days. The thermocline in the lake caused some degradation of the sidescan image in some places, and future surveys perhaps should be conducted in winter or early spring when lake would be more isothermal.

The sonar images revealed a wide variety of processes that are shaping the lake floor. A few examples of these different processes are summarized here and are illustrated with sonar images.

The Sarca river, the lake inlet, supplies a large volume of sediment to the northern end of Lake Garda, and extending 7km southward along the lake floor from the delta at the river's mouth are several channels with large sand waves in their floors (see **figure 2**). The presence of sand waves in the channel floors suggests active transport of sand through these channels, and high-backscatter areas at the end of the channels are interpreted to be deposits transported to the deep lake floor by these flows.

Along the steep sides of the northern part of the lake, and especially on the western side of he lake are several large debris aprons (see **figure 3**). These aprons are particularly large off the mouths of rivers, and they are interpreted to be grain-flow deposits comprised of sand and gravel derived from rivers that drain into the lake. Large boulders are seen on some of these debris aprons, and they probably continue to be active sites of sediment accumulation otherwise they would be partially buried under sediments that are accumulating in the central part of the lake.

The tectonic history of the lake is still reflected in the lake floor geology. Small faults were seen in a few places along the eastern wall of the lake and the steep western wall of the lake probably represents a series of large fault scarps that were associated with the original formation of the lake. Whether these faults are still active is unknown, however, the presence of slump scarps (see **figure 4**) and slump deposits in the Holocene sediments of the lake floor suggests that the lake continues to be a tectonically active area.

Evidence of anthropogenic activity in the lake is present in the sonar images as well. A pipeline or cable crossing the deep part of the lake (see **figure 5**) appears to be partially buried by one of the debris aprons which suggests that understanding the geological processes acting on the lake floor will be important for proper environmental management of the lake. The presence of two sunken ships, a Venetian galleon and a military vessel (Austrian from 1st World War ?), on the lake floor suggests that a more detailed analysis of the sonar image may show it to be valuable as an archaeological tool as well.

5.0 Merging of digital orthophotos with sidescan data

The high altitude photography around the area of Riva ,at the northern end of the lake, was used to create a digital orthophoto at the scale of 1:10000 and a ground pixel resolution of 2m to make it comparable with that of the final mosaic of the sidescan data. The DTM used in the orthorectification was a grid with a cell size of 40m and elevations derived from contour lines and spot elevations digitized from existing maps at the scale of 1:10000. The software employed in the orthophoto production and the DTM calculation was, respectively, the Phodis of Carl Zeiss

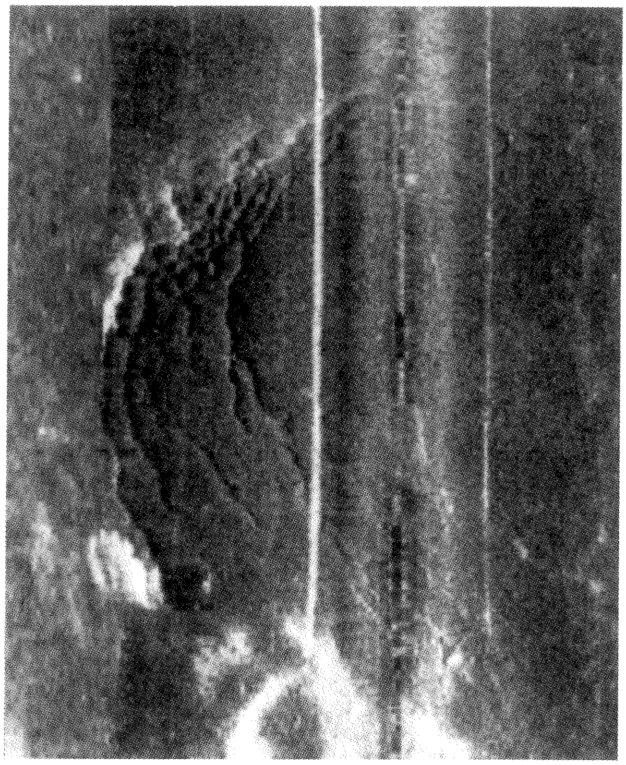

Figure 4 - Sidescan sonar images of slump scarps seen of the eastern side of upper lake Garda

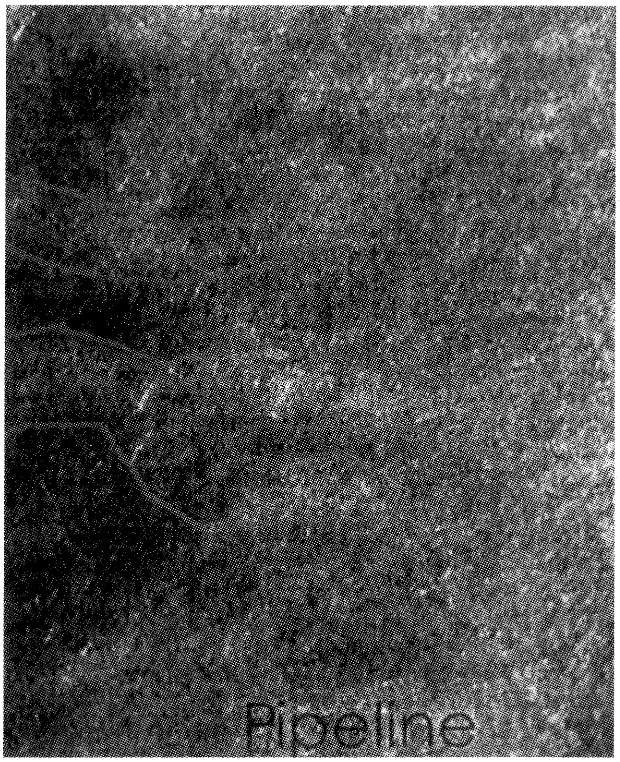

Figure 5 - Sidescan sonar image of pipelines or cables crossing upper lake Garda

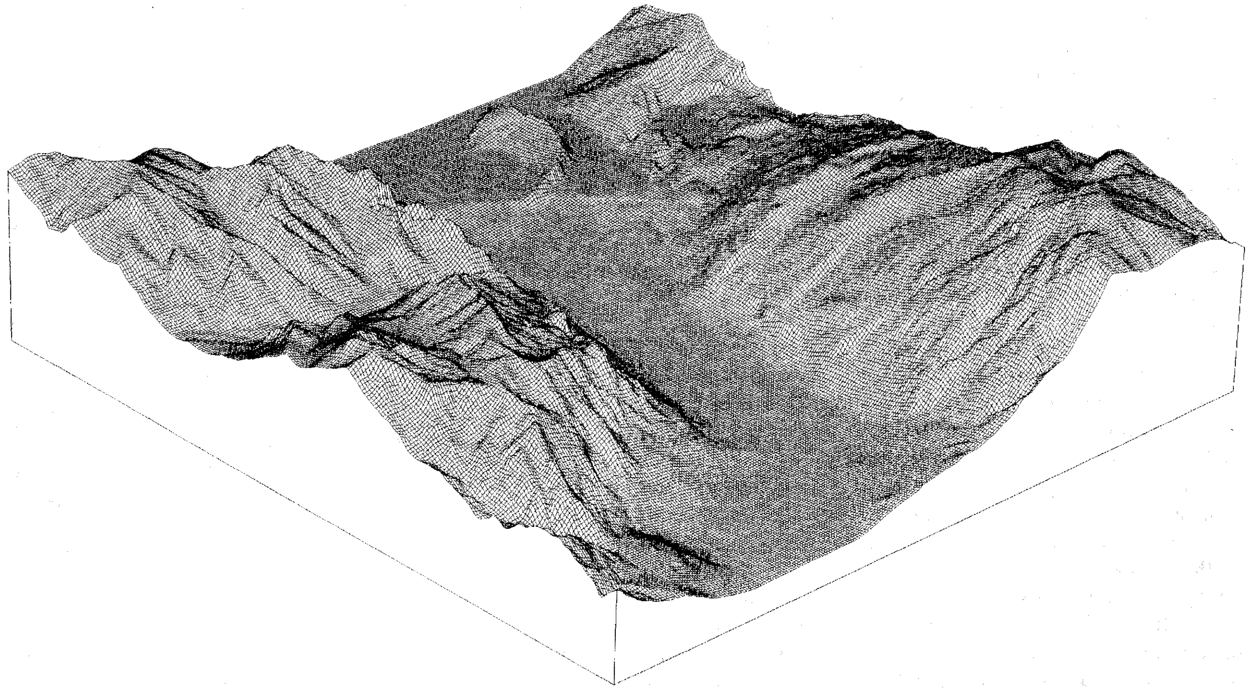

Figure 6 - Isometric view of basin model of Lake Garda obtained by integration of lake bathymetry with basin DTM

and SCOP by INPHO.

The bathymetric data collected along the track of the boat towing the sidescan sonar and published bathymetric data measured by the Italian Navy in 1966 (Istituto Idrografico della Marina, 1967). were used to generate a DTM for the lake bottom. To accomplish this it was necessary to effect a datum conversion as the bathymetry from the sidescan sonar survey was registered by GPS in the WGS 84 system while the 1966 data were referenced in the European datum (ED 50). To determine the conversion parameters six control points of known geodetic coordinates, thus referenced in the ED 50 system, were established around the lake and surveyed with a GPS instrument to record its position in the WGS 84 system. The Molodensky-Badekas model formulas were used to compute the transformation parameters for datum conversion. The R.M.S. values were less than 12 cm. A comparison of the 1966 bathymetric data with that of 1994 indicated that in the northern part of the lake, near the lake's inlet, the bottom elevations were up to 20m higher while in agreement in the deeper parts of the lake. The discrepancies noted near the inlet are possibly due to sediment deposition over the 28 year period that separates the two surveys.

For the final lake bathymetry the 1966 data were used for the shallow waters where no 1994 data were available. Perspective scenes can be obtained by combining the elevation and the bathymetric data with the basin and the sidescan sonar images; an example is shown in **figure 6.**

To integrate the sidescan sonar imagery with the onshore digital orthophoto another datum conversion was needed from the Clarke 1866 ellipsoid to the ellipsoid of Hayford used in the ED 50 system. This became necessary because while the sidescan data are collected and georeferenced in the WGS 84 system they are projected in a cartographic plane by means of the 1866 Clarke ellipsoid during their post processing.

The same procedure was used with the image data: the sidescan sonar images of the lake floor were projected in the ED 50 coordinate system and seamed with the digital orthophoto of the land to produce a continuous image of the entire lake basin as if the water were removed. The attachment of the sidescan sonar data with the shoreline as derived from the orthophoto was not a simple matter because the programs that make the geometric correction of the acoustic data collected over a slanting range assume a flat floor. This may not be of great concern with regional data at sea or with gently sloping shores but introduces distortions when trying to fit sidescan sonar data to steep shores. Because of this the procedure of tying in sidescan sonar images to shorelines becomes almost as much of an art as a science. The technique relies on identifying tie points on the shore for which the sidescan data fit well and to wrap (and warp) the rest of the sidescan images around the neighboring shoreline assuming that the orthophoto is the geometrically corrected source image and the sidescan imagery is the uncorrected one. These procedures are executed by GCP works of PCI by means of a polynomial interpolation.The registered sidescan image is then mosaicked on to the orthophoto image with a seamline coinciding with the shoreline illustration of this for the upstream (northern) part of the lake is shown in **figure 7.**

6.0 Filling of bottom imagery in shallow water

In shallow water, with depths equal to or less than about 10m, near the shoreline where the vessel could not go there is no information on the lake floor. However the data gap can be filled by integrating available images from the first few channels of the MIVIS hyperspectral scanner, with the sidescan data. Similar results could be obtained with low altitude areal

Figure 7 - Two-dimensional view of the upper part of Lake Garda basin. In this illustration the sidescan sonar image of the lake's bottom has been merged with an onshore digital othophoto to obtain a continuous view of the terrain as if the water of the lake were removed from the image.

photography, particularly if in color.

The Daedalus built MIVIS is a modular sensor comprising 4 spectrometers with 102 channels that register symultaneously the radiation emitted by the earth surface. This hyperspectral scanner has 20 channel bands of 0.02 µm width operating in the visible between 0.43 and 0.83 µm, 8 bands in the near infrared between 1.15 and 1.55µm, 64 bands in the mid infrared between 2.0 and 2.5µm, and 10 bands in the thermal infreredbetween 8.2 and 12.7µm. The MIVIS is mounted on a CASA C 212 aircraft which functions as an aerial laboratory as it is large enough to accommodate the instrumentation needed to produce data and images in real time. The MIVIS-CASA system was used in 1994 to collect lake imagery from the southeastern part of lake Garda. Of particular interest here are the data collected in the lower part of the visible part of the spectrum which enables one to visualize the configuration of the bottom of the lake in depths up to 10m.

An example of the appearance of the floor of the lake in an area near Lazise, in the southeastern part of lake Garda is shown in **Figure 8.** One can clearly assess the bottom vegetation as well as the general morphology of the lake floor. The merging of the MIVIS data with that from the sidescan sonar results in a complete coverage of the lake bottom imagery up to the shoreline as is shown in **Figure 9.**

6.0 Conclusions

In the future, through the Ufficio Studi of the Comunità del Garda, the association that groups together the local governments of the lake, it is planned to provide each lake municipality with digital orthophotos at the scale of 1:10.000 and fitted within the national cartographic grid system to serve as the baseline for a Geographic Information System for lake Garda. The orthophotos will contain elevation and bathymetric data as well as the information traditionally included with topographic maps

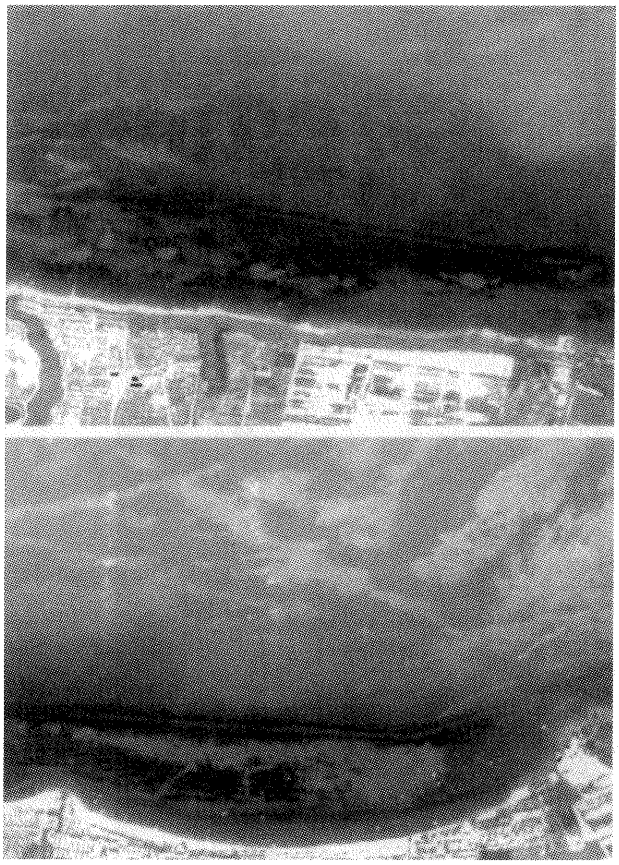

Figure 8 - Imagery of lake Garda, in the vicinity of Lazise, from the MIVIS hyperspectral scanner bands 6/12 (0.530-0.550 / 0.653-0.672 μm).

7.0 References

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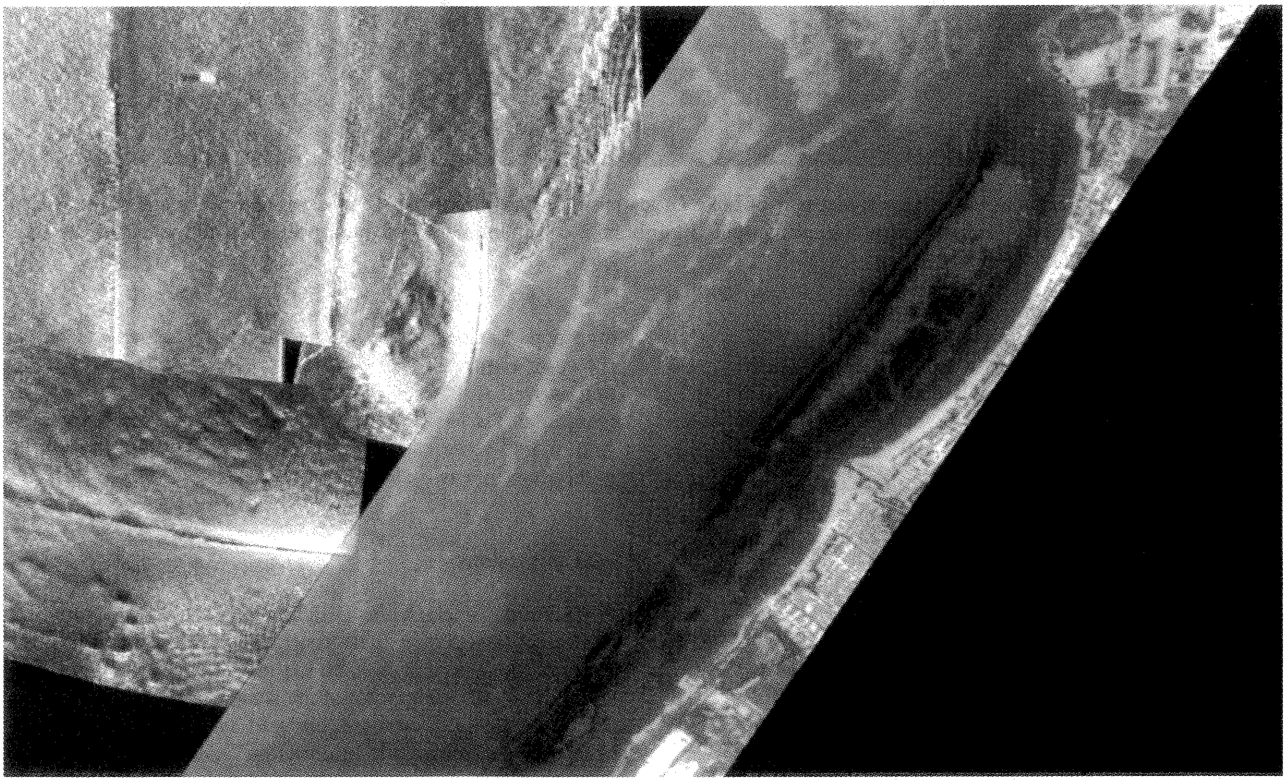

Figure 9 - Merging of MIVIS data over water with sidescan sonar data