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Overseas Geology Series

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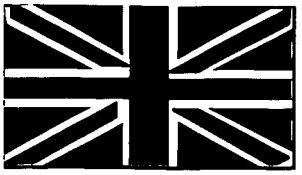
T M Williams, A C Mackenzie & J G Rees
British Geological Survey, Keyworth, Nottingham, UK.

Natural Environment Research Council

International Division
British Geological Survey
Keyworth
Nottingham
United Kingdom NG12 5GG



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BRITISH GEOLOGICAL SURVEY

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T M Williams, A C Mackenzie & J G Rees
British Geological Survey, Keyworth, Nottingham, UK.

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Cover illustration: Mombasa Harbour, viewed from the Kenya Marine and Fisheries Research Laboratory, Nyali.

1: SUMMARY

A geographic information system (GIS) for use in environmental planning and integrated coastal-zone management (ICZM) of the Mombasa coast, Kenya, has been developed as a component of the East African phase of the UK Overseas Development Administration (ODA) Land-Ocean Contamination Study (LOCS). The ODA-LOCS database holds information on a range of geochemical parameters (including metals, petroleum hydrocarbons and organochlorines) for inshore and nearshore sediments, suspended particulate matter and water, plus oceanographic and sedimentological information of relevance to the assessment of contaminant transport. It's structure adheres to that of a pre-existing database for the entire coastal region of Kenya, compiled by the United Nations Environment Programme (UNEP) under sub-programme EAF/6 of the Action Plan for the Protection, Management and Development of the Marine and Coastal Environment of the East African Region. When used in conjunction, the ODA-LOCS and EAF/6 datasets provide a powerful tool for identifying areas of potential conflict between contaminant discharges or dispersal plumes and natural resource utilisation within the coastal zone of Mombasa. This capability may be of value to planners in optimising the siting of discharge pipelines, and in the delineation of non-impacted waters for activities such as artisanal fishing, aquaculture and recreation.

2: INTRODUCTION:

In 1995, a coastal-zone pollution monitoring programme for developing countries, the Land-Ocean Contamination Study (LOCS), was initiated by the British Geological Survey (BGS) under funding from the UK Overseas Development Administration (ODA) Natural Resources Division (NRD). The central objectives of LOCS are (i) the provision of data regarding the sources, transport pathways and fates of contaminant metals and selected organic compounds along urbanised coastal margins, and (ii) promotion of the use of such data in integrated coastal-zone management (ICZM).

A systematic geochemical and hydrochemical survey of the inshore waters of Mombasa, Kenya was carried out under the ODA-LOCS programme in liaison with the Kenya Marine and Fisheries Research Institute (KMFRI) during the period September 1995 to February 1996 (Williams et al., 1996; Rees et al., 1996). The survey included assessments of heavy metal, hydrocarbon and organochlorine concentrations in water, suspended particulate matter (SPM) and sediment in all inland lagoons and the reef-fringed nearshore environment extending northward from Mombasa Island to Mtwapa. Oceanographic and sedimentological data of relevance to the interpretation of contaminant distributions and transport pathways were also collected. All data are held in relationally-linked files, accessed using the GIS package ARCVIEW.

During the period 1993-1995, an elaborate GIS holding information on land-use, industrial, recreational and fisheries activities throughout the coastal region of Kenya was developed under sub-project EAF/6 of the United Nations Environment Programme (UNEP) Action Plan for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region. The Action Plan is coordinated by the UNEP Oceans and Coastal Areas Programme Activity Centre (OCA/PAC), Nairobi, and aims to provide a regional-scale approach to coastal and marine pollution-control in the waters of nine affiliated states (Kenya, Mozambique, Comoros, Reunion, Madagascar, Mauritius, Seychelles, Somalia and Tanzania). Management of the EAF/6 Kenya database has, since 1995, been delegated to KMFRI. No detailed geochemical or marine pollution data for the inshore waters of Mombasa are currently held on this system.

The integration of the ODA-LOCS and EAF/6 databases within a single GIS offers the potential for creating a powerful tool for use in future ICZM and environmental planning for the Mombasa area. Such a system would, for example, permit the evaluation of geo-registered pollution data in conjunction with spatial information on commercial or artisanal fishing activity, recreational water use or areas prioritised for marine conservation. The approach would allow areas of direct conflict to be identified, and scarce pollution control resources to be focused into areas of greatest urgency.

This report summarises the scope and capabilities of an integrated GIS for Mombasa, incorporating both EAF/6 datafiles and new ODA-LOCS pollution data, recently developed by BGS. It is anticipated that all information compiled will ultimately be downloaded to the EAF/6 database at KMFRI. It requires emphasis that this

document is not a user manual, nor an interpreted account of the geochemical, sedimentological and oceanographic data held within the system. (details of these aspects of the ODA LOCS project are provided in two independent technical reports:- Williams et al., 1996; Rees et al., 1996). The aim is simply to outline the scope of the datasets now available, and their possible utility in ICZM.

3: SOFTWARE FOR PROCESSING ODA-LOCS DATA.

The commercial GIS package ARCVIEW has been adopted as the central tool for the compilation and analysis of ODA-LOCS data for Mombasa. The package is rapidly attaining the status of an industrial standard, the use of which has facilitated the direct interchange of raw datafiles and processed multi-component 'views' between the ODA-LOCS GIS and EAF/6 database (which utilises the same software). ARCVIEW can be run on modest work-station hardware. Basic operating requirements are an IBM or 100% compatible PC (386 or later), MS-DOS (version 5.0 or later), MS Windows (version 3.1 or later), 8 MB of available memory and 12 MB of swap space. The system facilitates the display, visualisation, and interrogation of geo-registered data, either as individual themes or as a series of simultaneously projected layers. Although designed primarily as a user-friendly front-end for ARC-INFO, ARCVIEW can also receive input files from other sources. Data processing capabilities include summary statistical analysis, delineation of geographic areas on the basis of specified attributes or attribute combinations, and the integrated presentation of maps, charts and related graphics. Export files can be utilised by a wide range of software applications such as MAP-INFO.

4: REGIONAL-SCALE DATASETS.

Geo-registered data relating to over 80 human and environmental variables within the coastal region of Kenya are held on the UNEP EAF/6 database. Approximately 30 of these themes, with particular relevance to the objectives of the ODA LOCS project, have been downloaded to the ODA-LOCS database, providing a regional-scale framework for the presentation and interpretation of LOCS pollution data. The transferred datasets depict coastal land use, industrial activity, towns and settlements, waste disposal sites, rivers, interfluves, coastal environments, areas previously impacted by oil pollution, port infrastructure, marine parks, offshore bathymetry, salinity, temperature, pelagic fisheries, sport fisheries, artisanal fisheries and shellfish beds. The coverage provided by these files is non-uniform but typically extends to the Somali border in the north, the Tanzanian border in the south, and the town of Voi at 38.5° west. A regional 'view' or multi-theme image generated through the simultaneous retrieval of three imported EAF/6 files (towns, marine national parks and offshore bathymetry) is shown in Figure 1.

5: LOCS DATA FOR THE 'MOMBASA WINDOW'.

The spatial coverage of the ODA-LOCS survey is confined to a polygon or window encompassing the administrative district of Mombasa and it's associated inshore and near-shore waters. The precise area of coverage is 3.95° - 4.15°S and 39.5° - 40°E. Data imported from the EAF/6 database can be retrieved and displayed specifically within the dimensions of this window as exemplified in Figure 2, thus simplifying the simultaneous projection of LOCS and EAF/6 data.

A relational database holding approximately 12,000 physico-chemical records for bottom sediments, suspended particulate matter (SPM) and water, plus high resolution bathymetric, residence-time and sedimentological information has been constructed from the LOCS survey data. Files are structured in a manner which permits retrieval in any combination, for example allowing the simultaneous interrogation of multi-element sediment geochemical data and surficial lithofacies data. A summary of the information currently available on the database is outlined below.

5.1: Sample locality details.

Much of the geochemical, sedimentological and hydrodynamic information within the ODA-LOCS database is derived from field measurements and subsequent laboratory analyses of material from 48 sampling stations, coded MB1-MB48, in the inshore waters of Mombasa. The position of each station was ascertained during the field survey using a non-differential GPS with an operating resolution of 30 m. A file of sample coordinates (recorded in global lat-long format), to which all other datafiles are linked, forms a fundamental component of the database. On retrieval of physico-chemical data for any MB-coded site, the appropriate easting and northing

are automatically appended to the head of the listing or file. Conversion of site coordinates to a local datum is possible interactively, thus allowing the position of sampling sites to be easily transferred onto any Kenyan map.

The distribution of sampling stations within the inshore waters of Mombasa is typically projected at the start of any interrogative ODA-LOCS GIS session (see Figs. 5-8). During the session, attribute tables of multi-element geochemical, sedimentological or hydrodynamic data for any individual site can be retrieved using the ARCVIEW 'information' facility, which is activated by clicking the appropriate icon on the site of interest using the mouse.

5.2: Sediment lithofacies data.

The surficial lithofacies information available within the ODA-LOCS GIS is summarised in Figure 3, showing descriptive facies-types based on grain size analysis of samples from stations MB1-MB48. Surficial sediments for granulometric analysis were collected using a Van Veen grab sampler. These were wet-sieved into 10 fractions ranging from >2mm- <63 μm in size. The <63 μm fraction was then further fractioned by Sedigraph. Interpolation of information between grab-sampling sites was achieved with the assistance of side-scan sonar and shallow-seismic data provided by the Proudman Oceanographic Laboratory (POL) and the UK Admiralty. These datafiles have not, however, been incorporated independently within the ODA-LOCS GIS.

5.3: Bathymetric and hydrodynamic data.

The high-resolution bathymetric data held on the ODA-LOCS GIS for the nearshore and inshore waters of Mombasa (Fig. 4) were acquired by combining pre-existing UK Admiralty and POL side-scan sonar data with soundings taken during a BGS-KMFRI survey in September 1995. Three-dimensional projection of the bathymetric data is possible, facilitating volumetric calculations for individual creek systems. This, in conjunction with available current and tidal data, provides a basis for 3-D oceanographic modelling. A synoptic map of 'hydrodynamic environments' generated using current, tidal and modelled water residence-time data, is available on the ODA-LOCS GIS. Full details of the modelling methodology used to generate this file are provided by Rees et al. (1996).

5.4: Interfacial sediment chemistry.

Datafiles depicting the chemical composition of inshore and nearshore sediments constitute the largest single component of the ODA-LOCS database. Interfacial sediment data obtained through XRF, GC and GCMS analysis of the uppermost 2 cm of gravity and piston cores for LOCS sites MB1-MB48 are held within a single attribute file (Mommsu1). Retrieval of this file automatically prompts the display of all MB sampling points within a 'view'. These can then be colour-classified interactively (typically using a five-class system) to portray the concentration of any specified element, either on a point-source basis, or as a continuous (interpolated) surface. A tabular display of locational and multi-element data for any single sampling station can be obtained by activating the ARCVIEW 'information' icon over the site of interest (as described in section 5.1 and illustrated in Figure 5). Interfacial sediment data are held for the major oxides SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O and P_2O_5, and the trace elements Ni, Cu, Zn, Cr, V, Co, Sr, Zr, Mo, Pb, Ba, Cd, As and Sn. Organic determinands include n-alkanes, polycyclic aromatic hydrocarbons and organochlorines (with limited spatial coverage).

5.5: Chemo-stratigraphic data.

Gravity or piston cores of up to 1 metre in length were recovered from approximately 40 Mombasa sampling stations during the BGS-KMFRI survey. Sub-sectioning and subsequent XRF analysis of these cores at a resolution ranging from 2-5 cm has yielded multi-element data for over 200 sub-surface sediment samples, databased in a series of discrete attribute files. Access to the downcore multi-element data for any individual station is achieved via the interfacial sediment table 'Mommsu1', by highlighting the site number of interest with the cursor as illustrated in Figure 6. The presentation of a graphic downcore profile is subsequently possible for that element originally colour coded within the 'view' (Fig. 7).

5.6: Chemistry of marine water and suspended particulate matter (SPM).

Data regarding the basic physico-chemical properties (temperature, conductivity, salinity, turbidity, pH, Eh and dissolved oxygen) of the mid-water column in the inshore and nearshore waters of Mombasa were collected using a PHOX 902 sonde and datalogger. Trace metal data for a limited suite of elements (Cd, Pb, Zn, Cu, Ni

and Cr) for 0.45 μm filtered seawaters, acquired by anodic stripping voltammetry, are incorporated alongside the physico-chemical data in a single file. All are viewed in a fashion identical to that described for interfacial sediment data. This entails (a) generation of a 'view' showing sampling localities (b) retrieval of the appropriate datafile (Mom-water) and (c) colour classification of sampling sites for any single water parameter selected.

Suspended particulate matter (SPM) was collected from the mid-water column at all Mombasa sampling stations by pressure filtration of 1 litre of water through a 0.45 μm cellulose acetate membrane. Analytical data (acquired by ICP-MS) for Mn, Co, Cr, As, Ni, Cu, Zn and V are available on the ODA-LOCS database in a discrete attribute file, accessed in the manner described above for water and interfacial sediment.

5.7: Photographic and related site information.

The storage of photographic information showing field sampling localities, core stratigraphy and related site information is possible through the downloading of scanned images as Pict-files. Examples of the range of digital photographic information available on the database are provided in Williams et al. (1996).

6: APPLICATIONS AND FUTURE DEVELOPMENT.

Although the ODA-LOCS database remains under development, a wide range of applications of direct relevance to future environmental planning and ICZM in the Mombasa coastal area can readily be identified. Areas of investigation which show particular potential include:-

(i) Evaluation of relationships between onshore contaminant point-sources and inshore/nearshore water and sediment quality. Identification of the dominant point-sources of nearshore marine contamination in the Mombasa area is a vital precursor to the formulation of effective discharge control and monitoring programmes. In addition to data depicting the position of 'hot-spots' for a range metals and organic contaminants in the inshore/nearshore zone, the ODA-LOCS database holds a full inventory of industries within Mombasa municipality, classified by activity (Fig. 8). Correlation of the geochemical signatures recorded in polluted waters or sediment against the composition of discharges from industrial installations archived on the GIS may prove useful for this purpose. Further evaluation of this application following the transfer of the ODA-LOCS database to KMFRI is strongly recommended.

(ii) Modelling and prediction of contaminant dispersal pathways and their significance to present and future coastal-zone/water use planning. Hydrodynamic models relating to the dispersal of aqueous and particulate contaminants emanating from industrial point-sources in the inshore creek systems of Mombasa have been developed by Rees et al (1996) and can be accessed in simplified form via the ODA-LOCS GIS. These modelled contaminant flow-paths may prove particularly valuable in the siting of outlets for treated domestic waste or other contaminant discharges. Within the context of ICZM, the delineation of inshore waters impacted by contaminant dispersal plumes may be of value when designating appropriate areas for aquaculture, artisanal fisheries or recreational water use. The potential of the ODA-LOCS GIS for identifying and avoiding environmental conflicts in this manner should be emphasised during marketing of the system to local and central government planning agencies.

The ODA-LOCS GIS is scheduled to be transferred to KMFRI during 1997, following a formal demonstration and workshop in Kenya. Following transfer, it is anticipated that the utility of the system will be progressively increased through regular updating of existing datafiles and the installation of additional geoscientific, environmental and land/water datasets.

7: ACKNOWLEDGEMENTS

All field surveys undertaken by BGS in Mombasa were supported both logistically and scientifically by staff of the Kenya Marine and Fisheries Research Institute. Particular thanks are due to Mr K K Kairu, Kenyan coordinator of the LOCS programme, and Mr A C Yobe, principal scientific counterpart. Data from the EAF/6 database was provided for BGS use by courtesy of UNEP OCA/PAC and KMFRI. Special thanks are extended to Mr D Van Speybroek for kindly assisting in the digital transfer of this information, and for the provision of useful advice and guidance to BGS staff working in Kenya. Funding for all work carried out under the LOCS project was provided by the UK ODA

(Environment Division) under R&D contract R6191.

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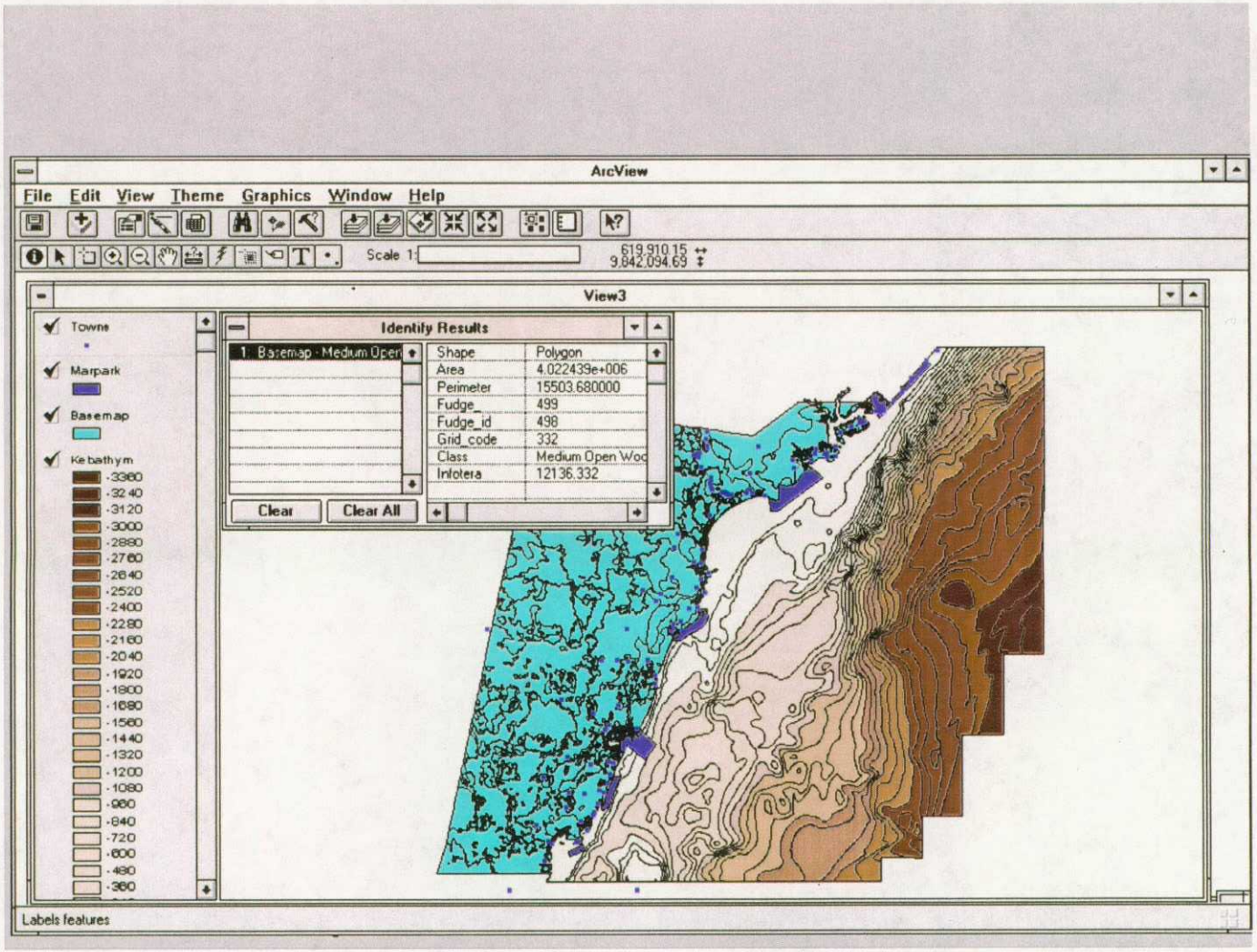

Figure 1: Multiple theme 'view' of regional datasets imported to the ODA-LOCS GIS from the EAF/14 database: (i) offshore bathymetry, (ii) location of towns and settlements, (iii) marine national parks.

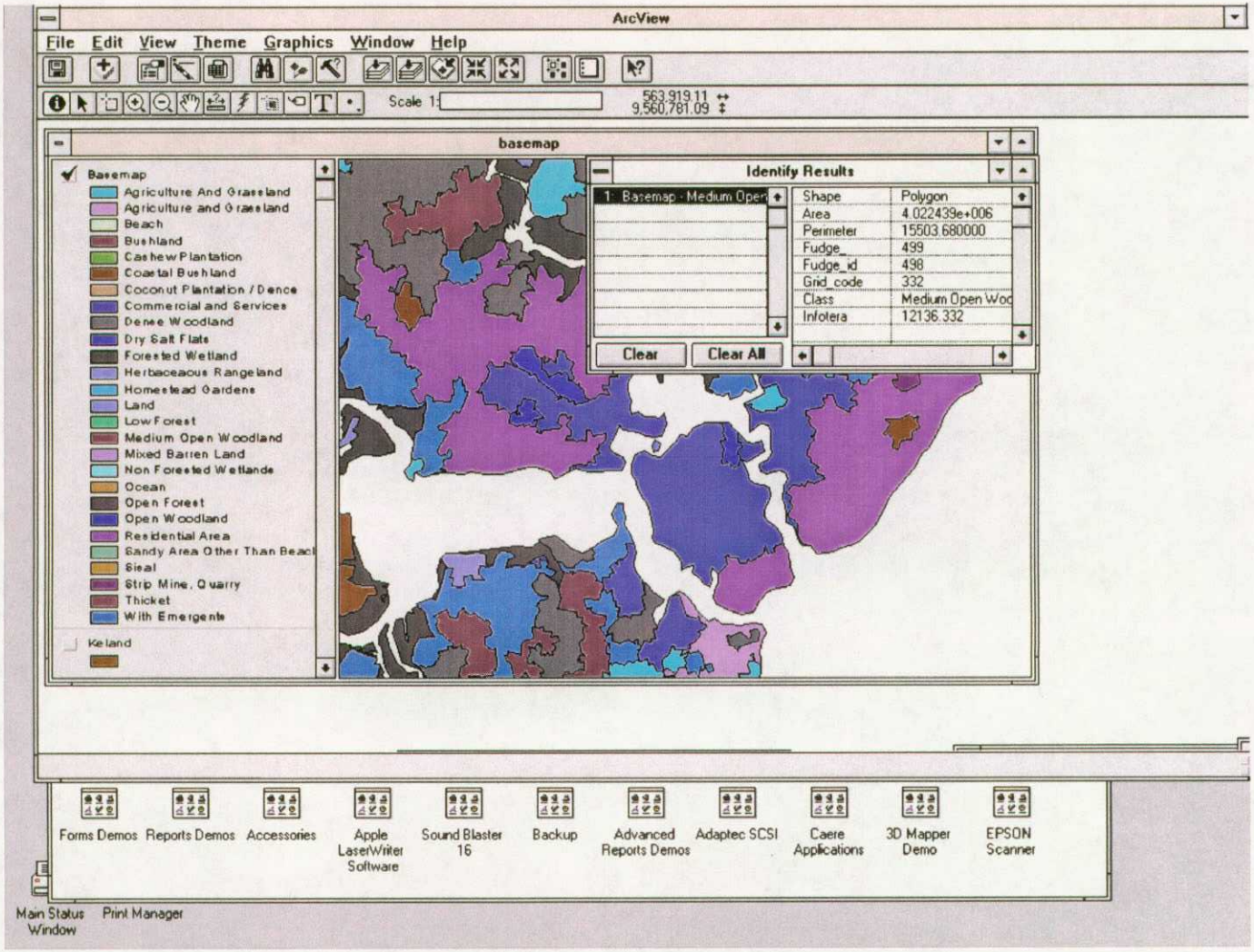

Figure 2: Land use classification file imported from the EAF/14 database, displayed on the ODA-LOCS GIS within the confines of the Mombasa 'window' covered by the LOCS survey.

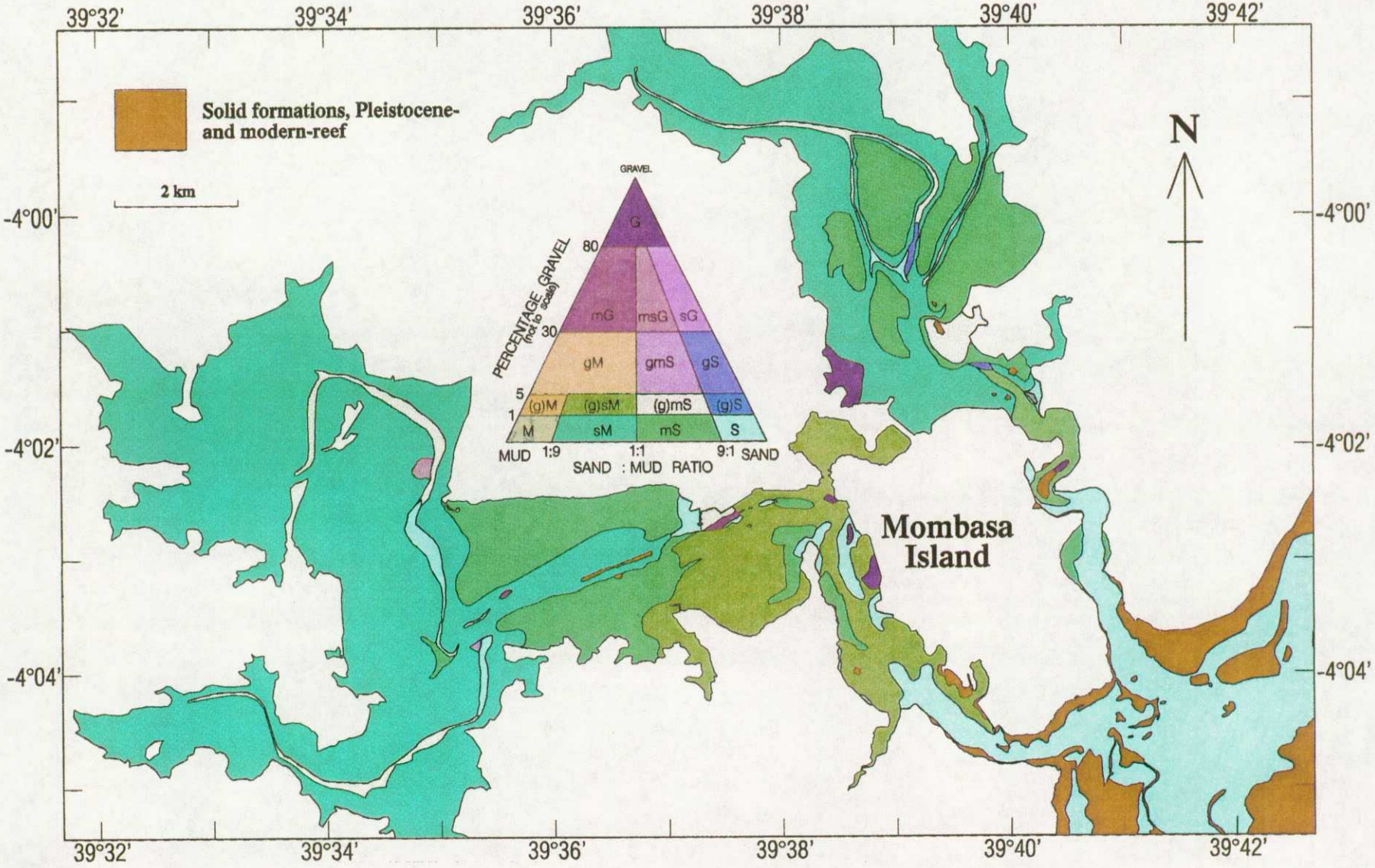

Figure 3: Sediment lithofacies in the inshore waters of Mombasa.

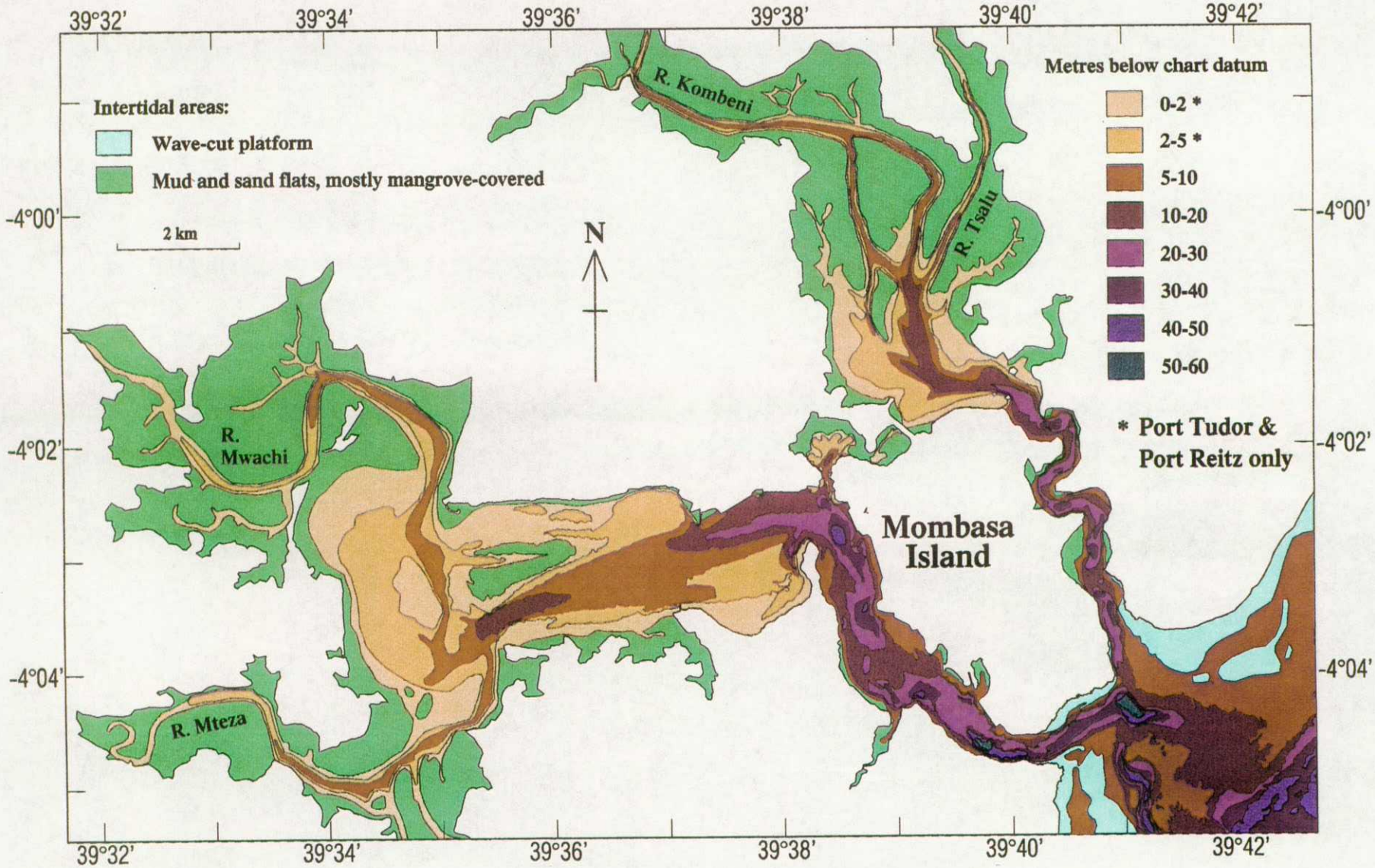

Figure 4: Bathymetry of the inshore waters of Mombasa.

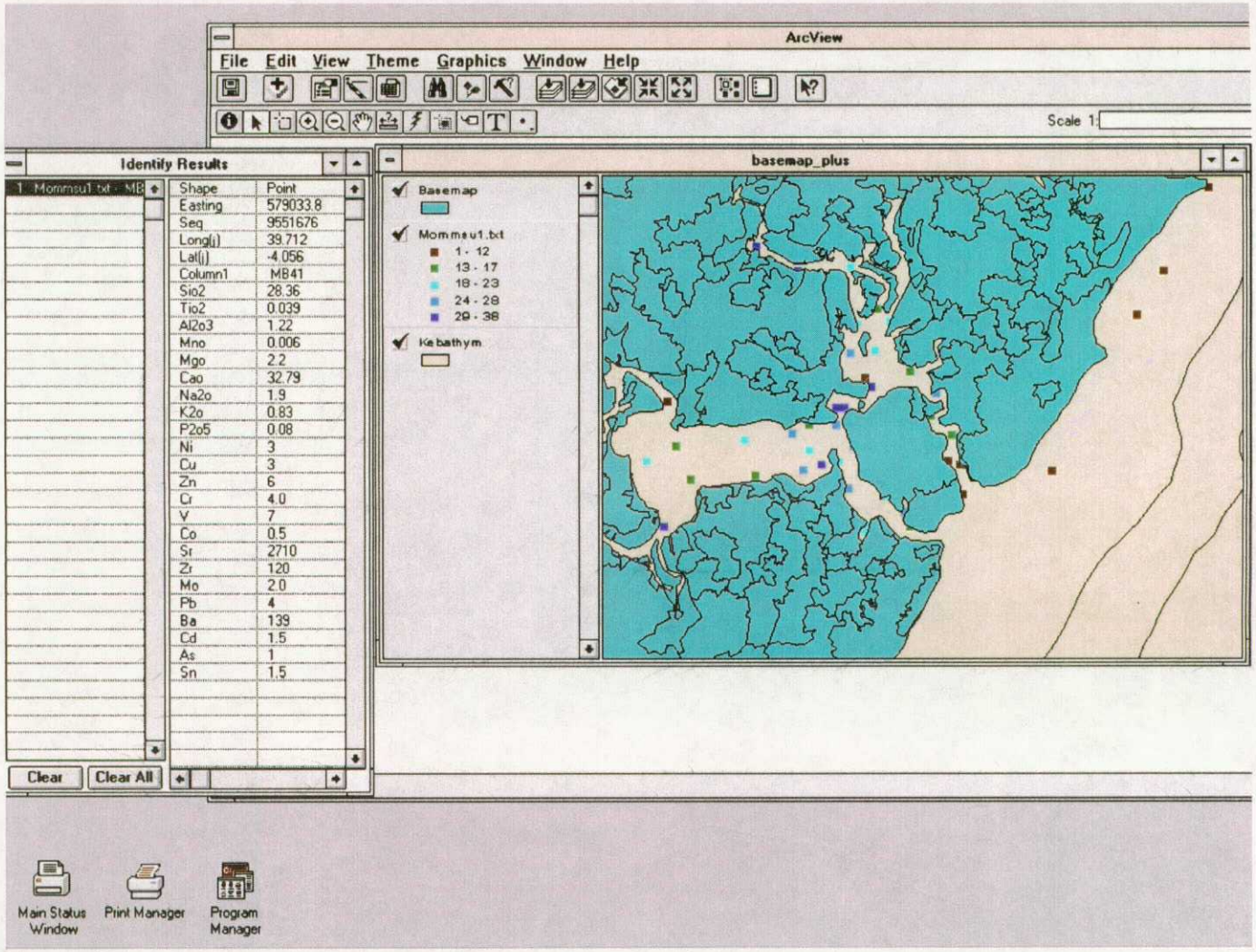

Figure 5: View of inshore sampling sites (colour classified to show Ni concentrations in interfacial sediment), with interactively highlighted multi-element attribute table for site MB41.

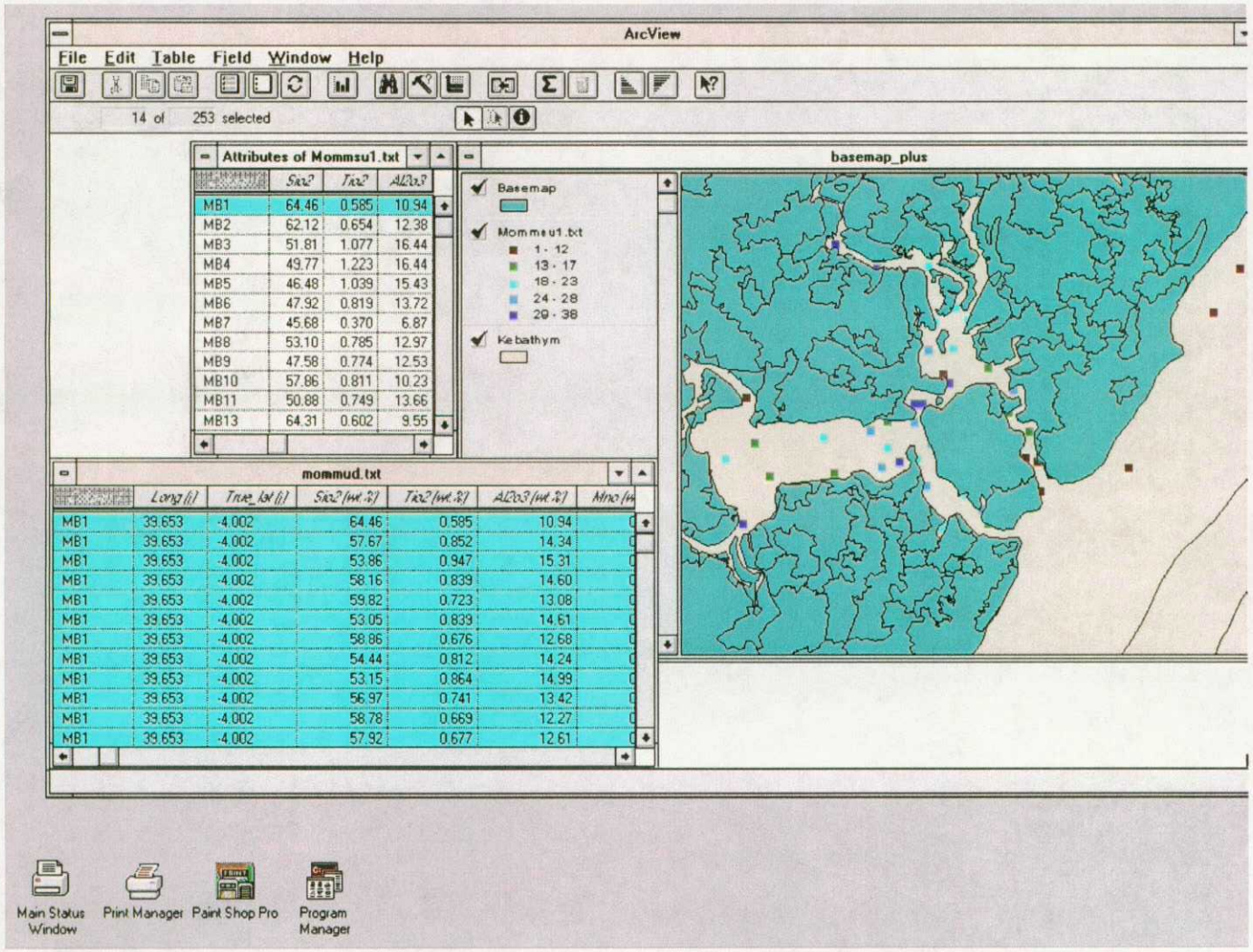

Figure 6: Retrieval of downcore multi-element attribute table for site MB1.

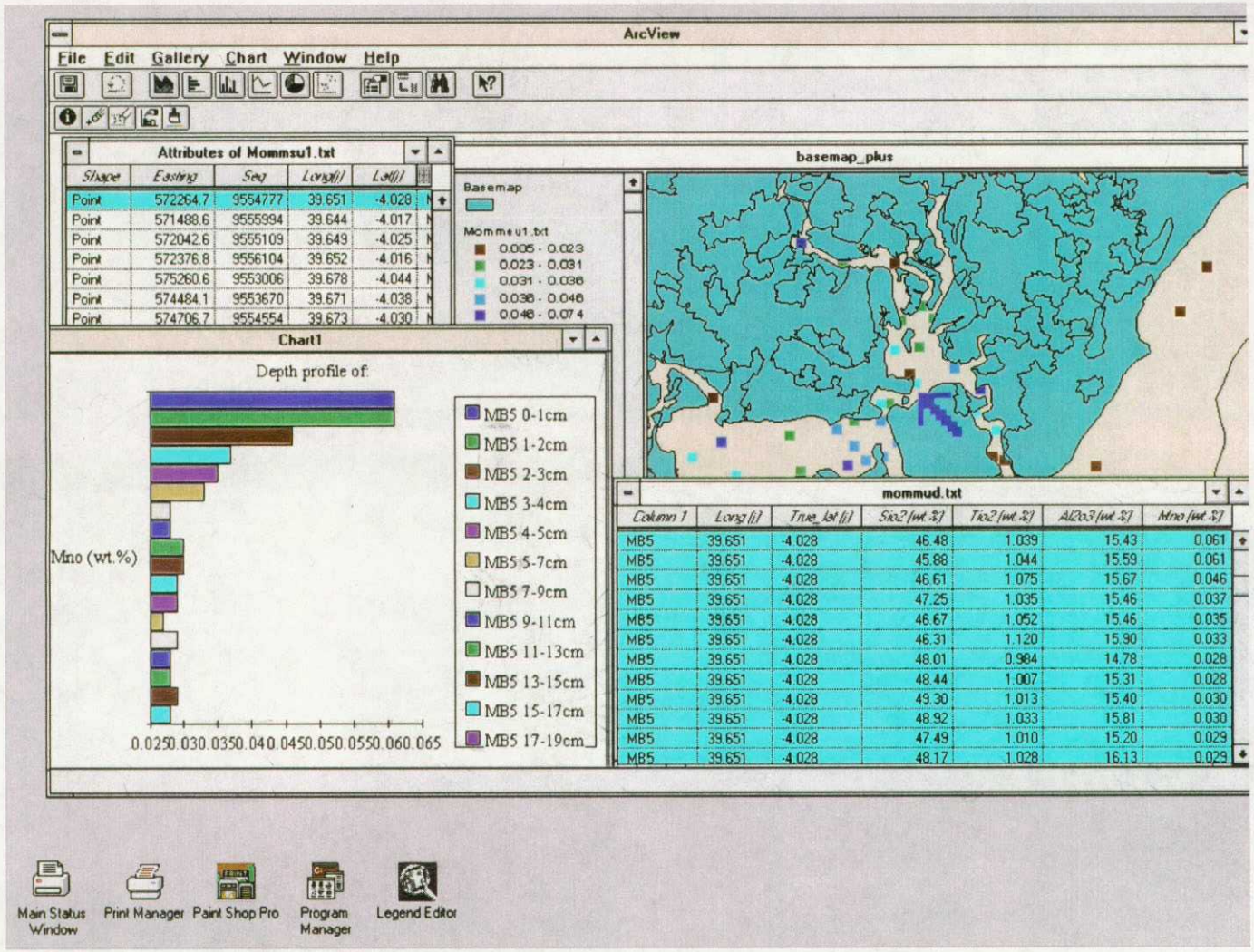

Figure 7: Graphic downcore profile for Mn in sediment at site MB5 (arrowed), generated interactively from the down-core multi-element attribute table.

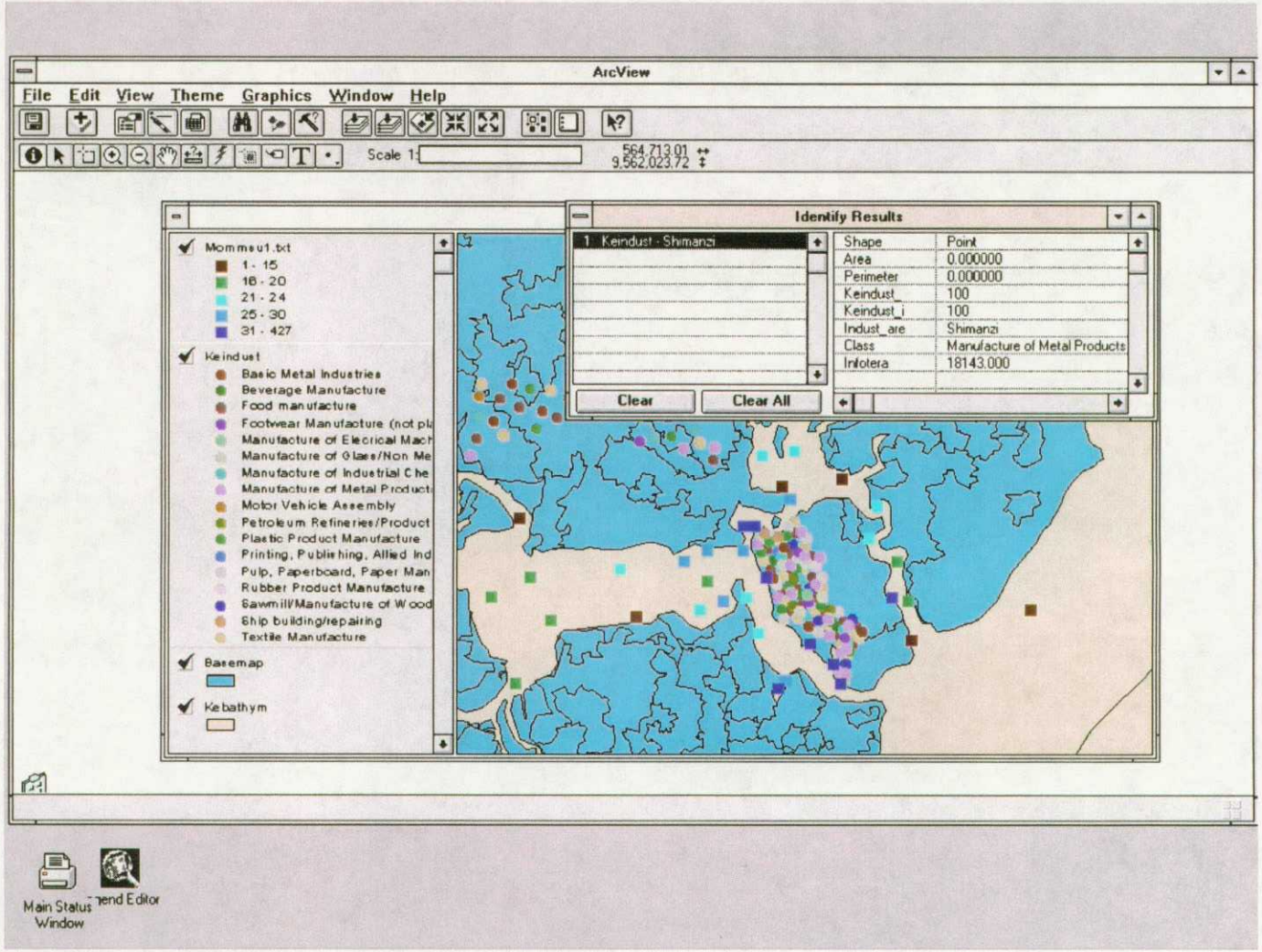

Figure 8: Multiple theme view showing LOCS sampling sites and classified industrial installations within Mombasa municipality (data imported from EAF/14 database).