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# Microtopographic Analysis of Cobalt-Rich Manganese Deposits on a Mid-Pacific Seamount

TETSUO YAMAZAKI  
RAHUL SHARMA  
KATSUYA TSURUSAKI

National Institute for Resources and Environment  
Onogawa, Tsukuba, Japan

*Evaluation of stereo photographs and video data shows a variety of surface features associated with the crusts and nodules across a mid-Pacific seamount. The differences in the coverage, distribution, and relief are used to classify the surface features. The crust outcrops have large coverage (up to 100%), and their surface features vary from step-like to lined and from cobble-type to nodular, giving rise to variable relief (from few centimeters to several meters). The relief is relatively low (10–20 centimeters) around the locations with crust outcrops along with nodules, and much less (~10 cm) in the areas of nodule fields. The microtopography (and relief) also varies between locations depending on the association of sediments with crusts and nodules, as well as their respective coverages. The occurrence of different types of surface features on the Co-rich manganese deposits and the resulting microtopography can have significant implications not only in the design of the mining system but also in planning the mining operation. The design of the miner head should be such that it can scrape the oxide layers along the microtopographic undulations on the crust surfaces as well as pick up the nodules in the vicinity. At the same time, it must also be designed to penetrate the sediment layer to collect shallow buried deposits and to separate the associated sediments before lifting the deposits to the surface.*

**Keywords** Co-rich manganese deposits, microtopography, miner design, seafloor observation, stereo photographs, surface features

Co-rich manganese deposits are gaining considerable significance due to their higher content of strategic metals such as cobalt, nickel, and platinum and to their occurrence at shallow depth from the sea surface as compared to the other deep-sea manganese deposits. Although their detailed resource assessment has not been done, and the commercial minability is not yet established, several studies have been carried out by different research groups, mainly in the Pacific (Cronan, 1984; Halbach, 1982; Hein et al., 1985a, 1985b; Manheim, 1986; Pichocki and

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The permanent address for Rahul Sharma is National Institute of Oceanography, Dona Paula, Goa 403004, India.

Address correspondence to Dr. Tetsuo Yamazaki, National Institute for Resources, 16-3 Onogawa, Tsukuba 305, Japan.

Hoffert, 1987). Some attempts have been made to quantify the deposits (Clark et al., 1984; Cronan et al., 1991; Yamazaki et al., 1992b) and to discuss the mining technology for these deposits (Hawaii Department of Planning and Economic Development, 1987).

Japanese research groups have been studying these Co-rich manganese deposits around the mid-Pacific seamounts (Figure 1) (Misawa et al., 1987; Ishikawa et al., 1989; Rokukawa, 1992; Yamazaki et al., 1992a). This study aims at classifying the microtopographic surface features on these deposits along an observation line extending from the edge of the top to the flank of a seamount. Such data are useful for understanding the distribution of the deposits with respect to the microtopographic variations on the seafloor, which is an important factor for planning detailed mining activities in the future.

## Methods

Stereo seabed photographs and video records taken across the seamount were analyzed for understanding the surface features and the distribution of the deposits in the area. Figure 2 shows the observation line on the seamount called Maloney in Smoot (1989), and the cross-section along the line is shown in Figure 3. The data was collected using cameras on a deep-tow frame, towed at 1 to 2 knots, at 3 to 5 m altitude during the cruise of Research Vessel Hakurui-maru No. 2 in 1992. The area of the seabed photographed varies from 3m × 5m to 4m × 6m, depending on the height of the towbody. The photographs were digitized by using a stereophotogrammetric digitization software on NEC 9801 personal computer. The features observed at various locations were classified into different designated types, and the microtopography in each photographic area was studied. The relief (in centimeters) on these features was plotted from the digitized elevation data in the form of three-dimensional (3-D) block diagrams to evaluate the elevation differences on the seafloor.

The video data were analyzed and compared with the photographic observations. The interpretation of video data included the identification of features on the seafloor and their types; relative quantitative distribution of crusts, nodules, and sediments; as well as the microtopographic changes on the seafloor.

The methods used for photographic survey and digitization of data have been described by Yamazaki et al. (1992b). The coverage of the crusts, nodules, and sediments is defined as the percent area covered by each of them in the photograph or video frame. The photos, which are fully covered with nodules, show some sediment substrate between the nodules; hence, the nodule coverages are always less than 100%. But the locations with large crust outcrops, with a thin film or small patches of sediment, are considered as 100% coverage for crusts.

## Results

The surface features observed around the Co-rich manganese deposits are classified and the resulting microtopography is described in the following paragraphs.

### *Crusts*

*Surface Features.* The crusts can be classified on the basis of their surface features as follows:

*Step.* Most of the crust exposures have a steplike surface at two, three, or more

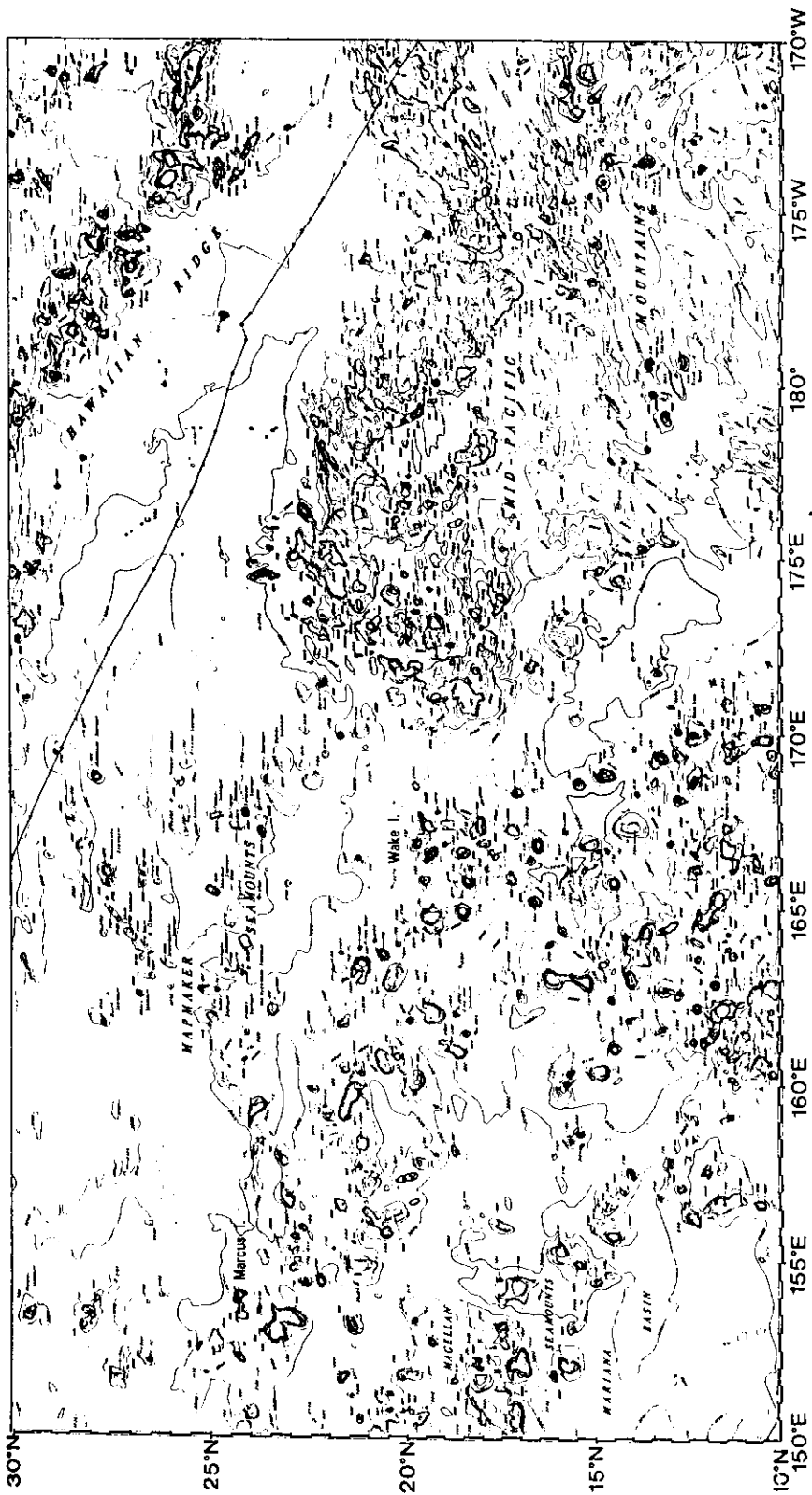
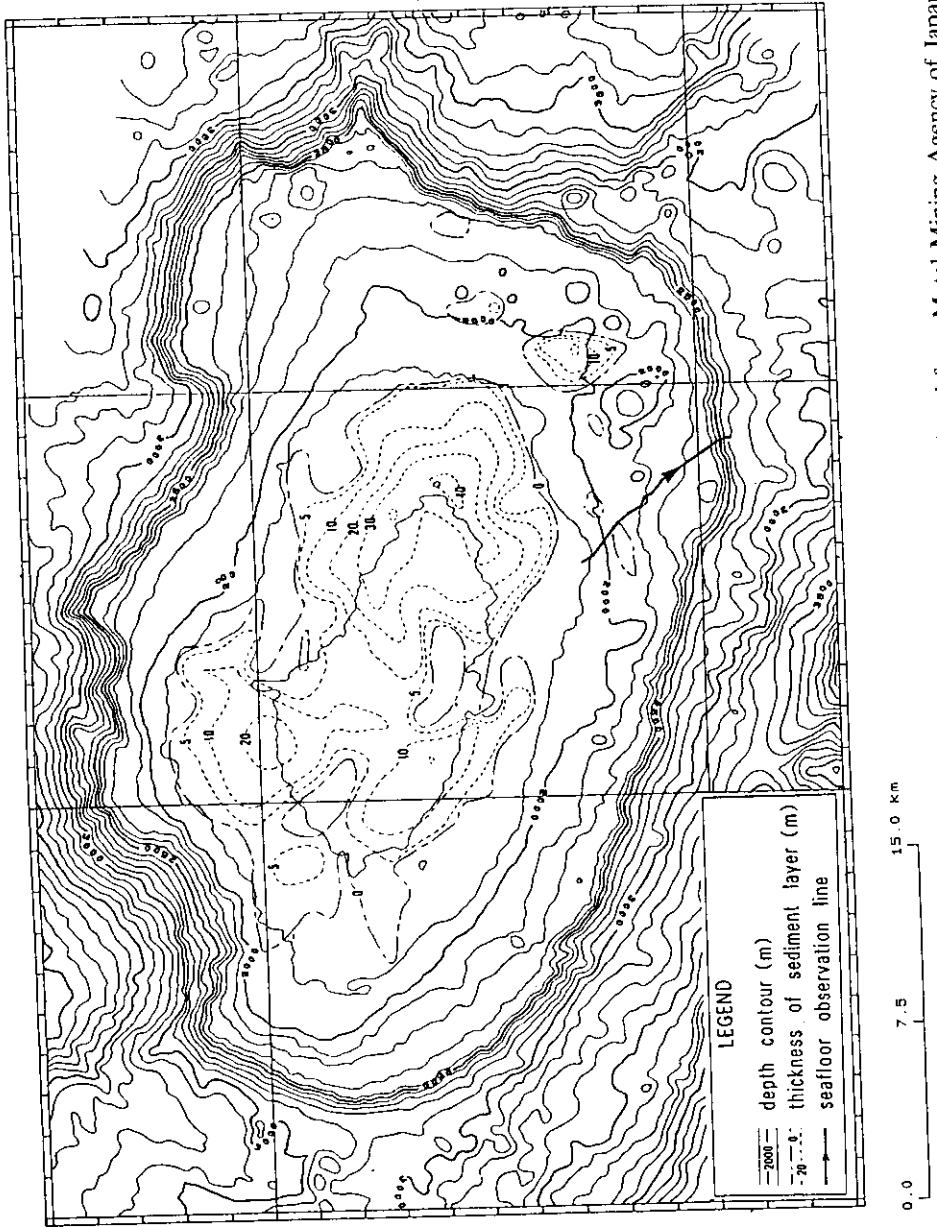


Figure 1. Bathymetry of central Pacific seamounts. Reprinted from Chase, T. E., H. W. Menard, and J. Mammarrickx. 1971. *Topography of the North Pacific*. Institute of Marine Resources, San Diego, USA.



**Figure 2.** Deepsea camera observation line across the seamount. Reproduced from Metal Mining Agency of Japan. 1993. *Survey report of deep-sea mineral resources—cobalt-rich crusts—for F. Y. 1992.* (unpublished report).

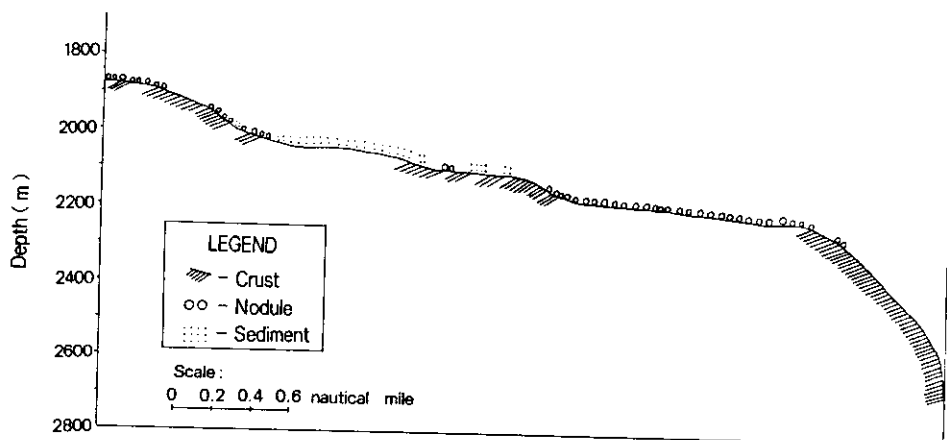


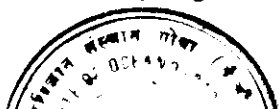
Figure 3. Cross-section of the seafloor and the distribution of Co-rich manganese crusts and nodules.

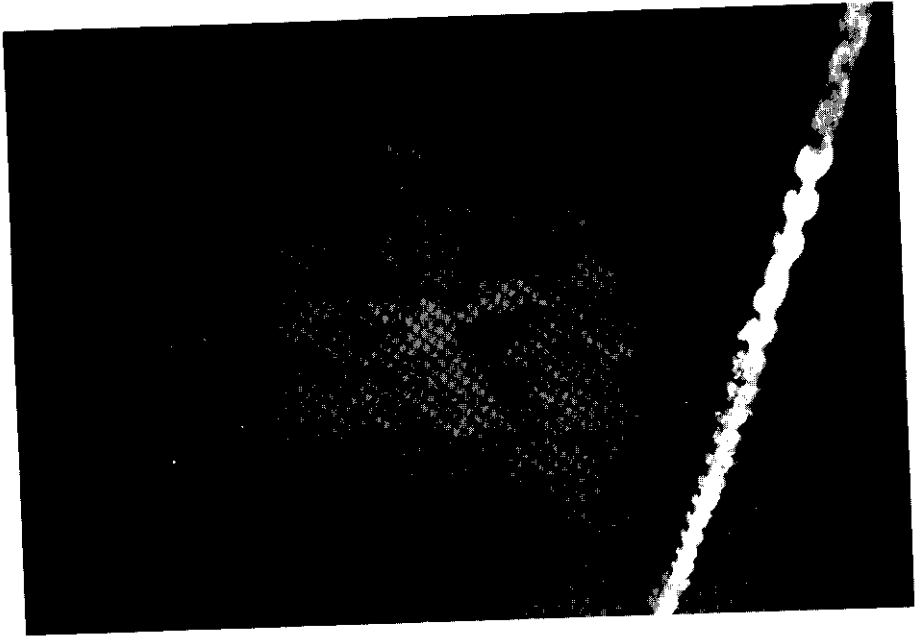
levels and vertical scarps between them (Figure 4a). This feature may be occurring on the upper slope of the seamount and generated due to the shape and surface of the host-substrate (usually rock outcrop), which has been encrusted with the oxide layers. Sediment patches are usually at the lowest step and are also sometimes on the intermediate steps; their width and thickness depend on the area and slope of each step. The elevation difference between the lowest and the highest step can be as much as 10 m or more (Figure 4b), with several intermediate steps at intervals of 0.5 to a few meters. The sediment accumulation occurs more on those steps that have wider surface area.

*Nodular.* The crust surface appears like a cluster of nodules, joined together as a pavement over hard substrate (Figure 5a). Sometimes, it looks like a carpet of nodules with a large coverage (sometimes more than 50%). This feature looks like a dense nodule field, but a closer examination of the video and photography data reveals that they are not only joined together but also attached to the substrate. The 3-D diagram of such an area (Figure 5b) shows that the nodular features occur on flat crust surfaces at relatively higher elevation 10–30 centimeters as compared with the nodules, which occur on the flat sediment surface.

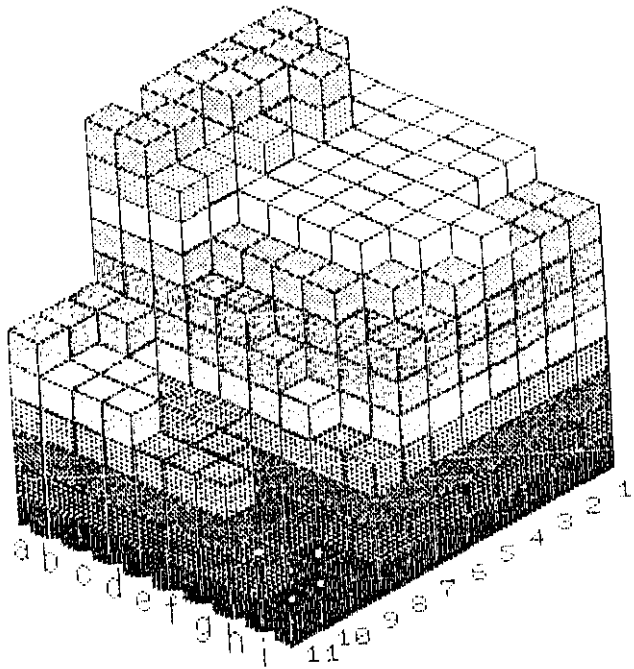
*Cobble type.* Large rounded to subrounded outcrops are observed on or around the crust exposures; 10–30 centimeters in size (Figure 5a). Usually observed on uneven topography, these cobbles and sometimes boulders are surrounded by sediments as well as nodules at many locations. The 3-D diagram (Figure 5b) shows that these have a higher elevation (> 10 cm) than the surrounding sediments and nodules. They appear to be projections of buried crusts exposed through the sediments.

*Lineated.* The crust surface appears lineated (with nodule-like surface) gradually sloping in one direction, and the regions in between the lineations are filled with sediment (Figure 6a). This feature may be occurring on the lower slopes of the seamount, as usually a small part of the crust is exposed, whereas the sediment coverage is very large. The elevation difference between the two ends of the crust outcrop is quite large (about 80 cm in this photo; Figure 6b), and the crust is exposed in the direction of the slope, giving a lineated appearance.





(a)

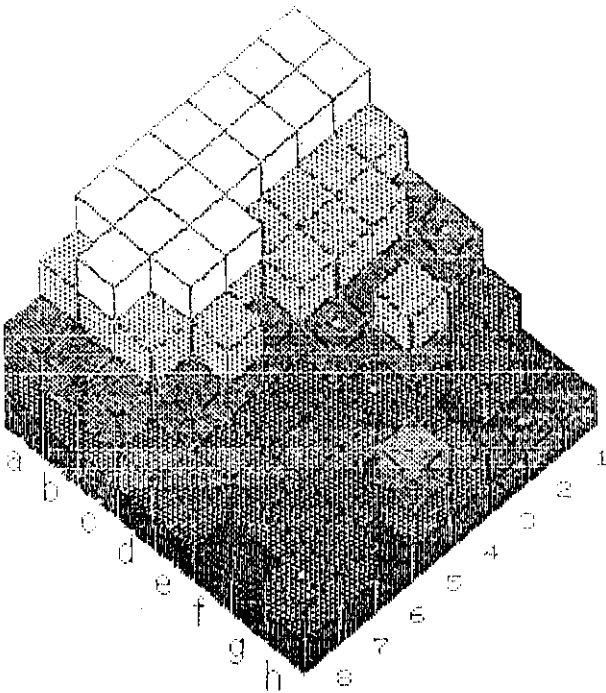


(b)

**Figure 4.** (a) Crust exposure with steplike feature. Photo no. = 53303. (b) Three-dimensional block diagram of the photo. Block size =  $80 \times 80 \times 100$ cm; view angle =  $30^\circ$ ; view direction =  $135^\circ$ .

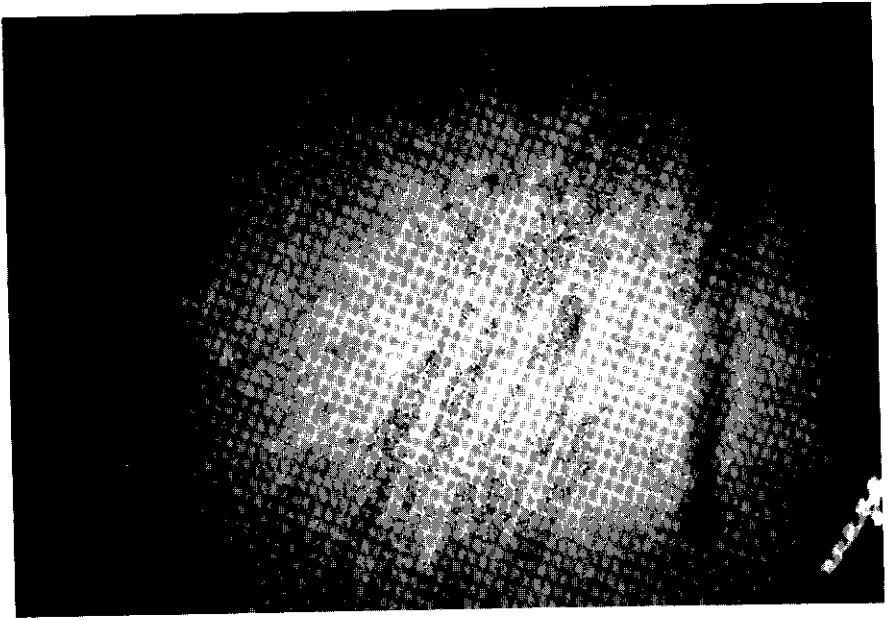


(a)

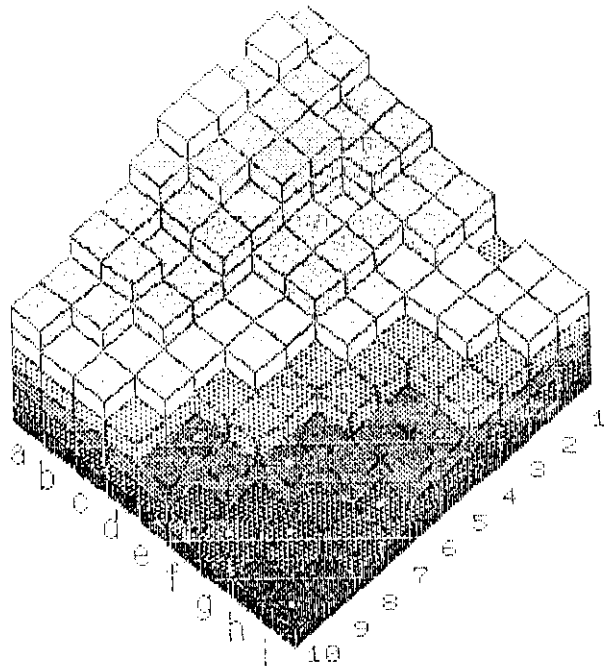


(b)

**Figure 5.** (a) Crust surface with nodular feature. Photo no. = 5348. (b) Three-dimensional block diagram of the photo. Block size =  $20 \times 20 \times 5$ cm; view angle =  $60^\circ$ ; view direction =  $135^\circ$ .



(a)



(b)

**Figure 6.** (a) Crust surface with linedated feature. Photo no. = 5366. (b) Three-dimensional block diagram of the photo. Block size =  $30 \times 30 \times 10$ cm; view angle =  $60^\circ$ ; view direction =  $135^\circ$ .



*Coverage.* The crusts can also be classified on the basis of their coverage as follows:

*Large.* Many crust exposures occur with an extensive coverage (more than 50%) over a large area on the seafloor with very less sediment cover (Figure 7a). Such exposures may be occurring along the steep slopes (mainly near the edge of the seamount top) where the accumulation of sediments and nodules is much less. These crusts also have a variety of surface features, such as a steplike or nodular appearance depending upon the microrelief and the slope on their surface. The elevation difference between the steps of the outcrop (in Figure 7a) is about 30 cm (Figure 7b). Whereas a sediment patch can be seen on the deepest level, the nodular feature is on the highest level on the crust surface.

*Few.* Very few rounded to subrounded exposures on the seafloor, with a coverage usually less than 15%, are observed, with a large coverage of sediment around these exposures.

*Scattered.* Rounded, spherical exposures on the seafloor occur isolated from one another. Larger in size than nodules (but not as spherical as nodules) and with a coverage usually more than 15%, they appear like scattered crust exposures.

### ***Nodules***

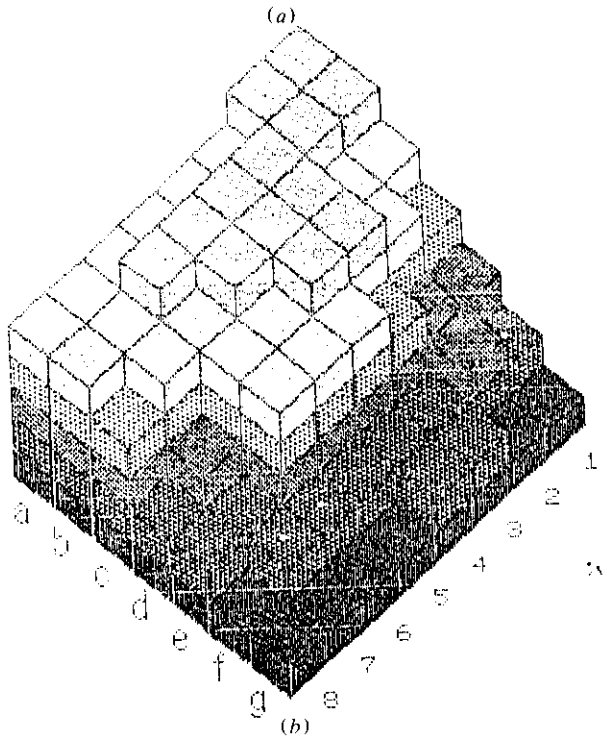
The occurrence of nodules on the seafloor can be divided on the basis of their coverage and sizes as follows:

*Coverage.* The coverage of nodules in the vicinity of the crust exposures varies from much less (5 to 10%) to moderate (40 to 50%), and the nodules in their vicinity occur on relatively flat areas (Figure 5a), although the seafloor topography is uneven due to the crust exposures (Figure 5b). The nodule coverage is usually quite high (60 to 70%) at most of the locations without any crust exposures (Figure 8a), and the seafloor in these areas is generally flat, with small elevation differences (5 to 10 cm) (Figure 8b).

*Sizes.* Nodules can also be classified on the basis of their sizes. They are usually small (less than 4 cm in diameter), but sometimes are medium (4 to 6 cm), large (6 to 8 cm), or very large (8 to 10 cm). They are usually uniform in size at a given location (Figure 8a), with very small elevation differences (Figure 8b). However, at some locations, the nodule size varies from small to large at the same location (Figure 9a). The elevation differences on the seafloor in such areas is small (10–20 centimeters; Figure 9b). At some locations nodules are also surrounded by isolated cobbles and boulders encrusted with oxide layers.

### ***Sediments***

The sediments are usually observed at the foot of the crusts (Figure 5a) and as substrate for nodules (Figure 8a). Much less sediment occurs on the surface of crusts, except in their microrelief. However, sometimes the sediments have a much higher coverage than the crusts and nodules, which is common in areas such as valleys where the nodules and the crusts get buried under thick sediment cover. The microtopographic features and the relief around the sediments depend on the occurrence of crusts, outcrops, nodules, etc. At some locations, current generated ripple marks are also observed at sediment dominant locations, as well as on the sediments between the crevices of the crust exposures.



**Figure 7.** (a) Large crust outcrop with very less sediment. Photo no. = 5373. (b) Three-dimensional block diagram of the photo. Block size =  $20 \times 20 \times 10$ cm; view angle =  $60^\circ$ ; view direction =  $135^\circ$ .

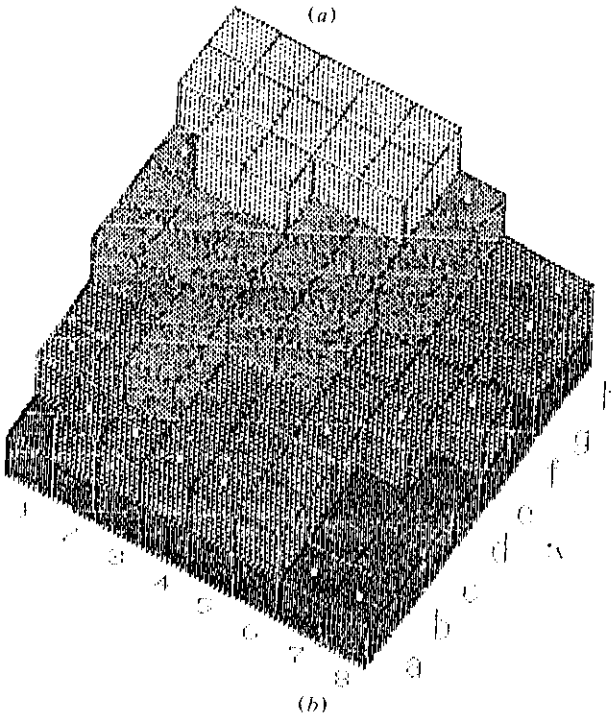
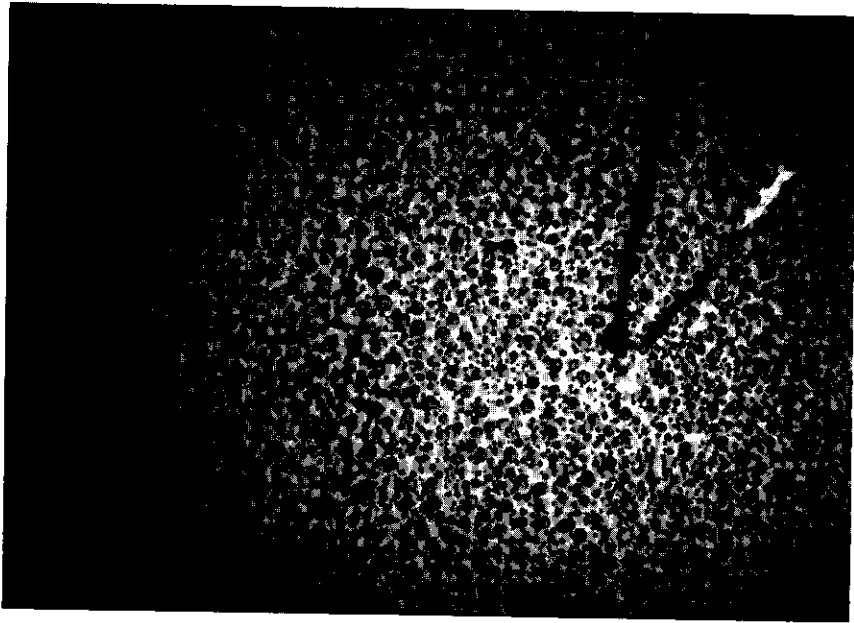
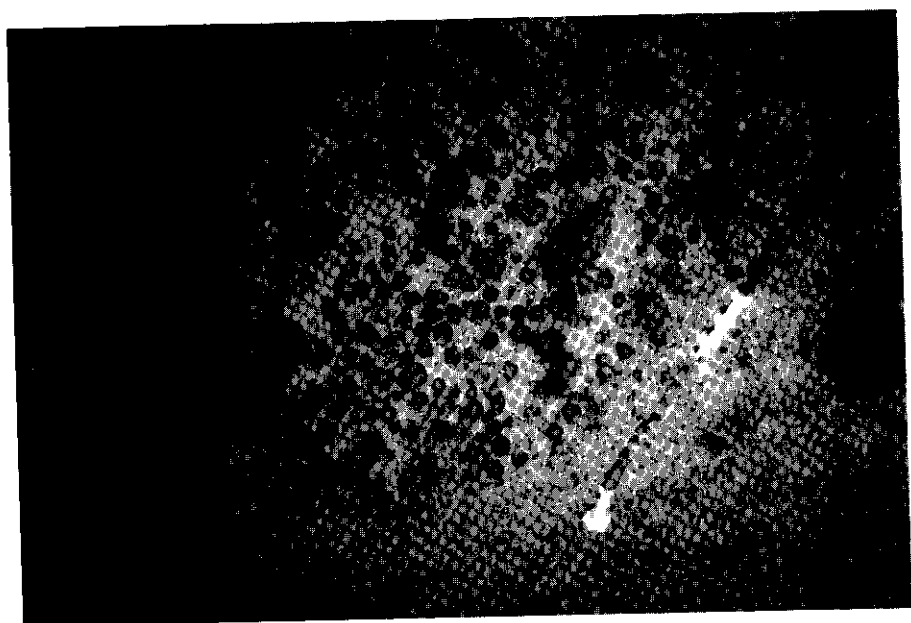
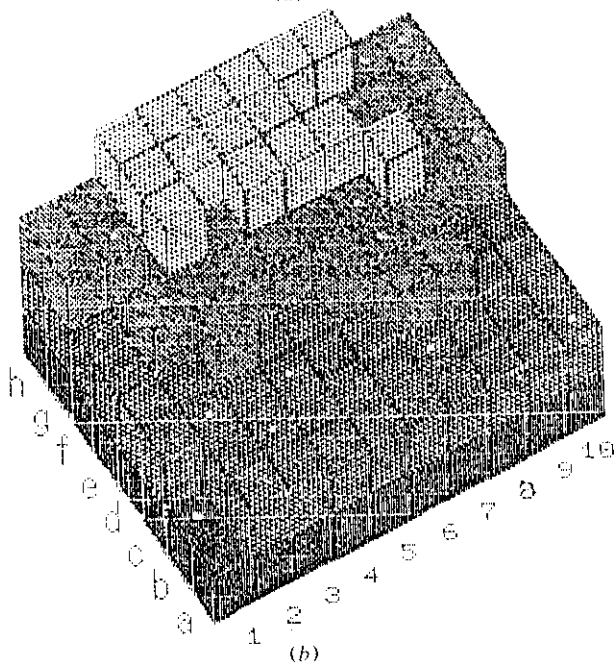


Figure 8. (a) Nodule field (60 to 70% coverage) on sediment substrate. Photo no. = 5318. (b) Three-dimensional block diagram of the photo. Block size =  $30 \times 30 \times 5$  cm; view angle =  $60^\circ$ ; view direction =  $30^\circ$ .



(a)



(b)

**Figure 9.** (a) Nodules of different sizes at a location. Photo no. = 5380. (b) Three-dimensional block diagram of the photo. Block size =  $30 \times 30 \times 10$ cm; view angle =  $60^\circ$ ; view direction =  $330^\circ$ .

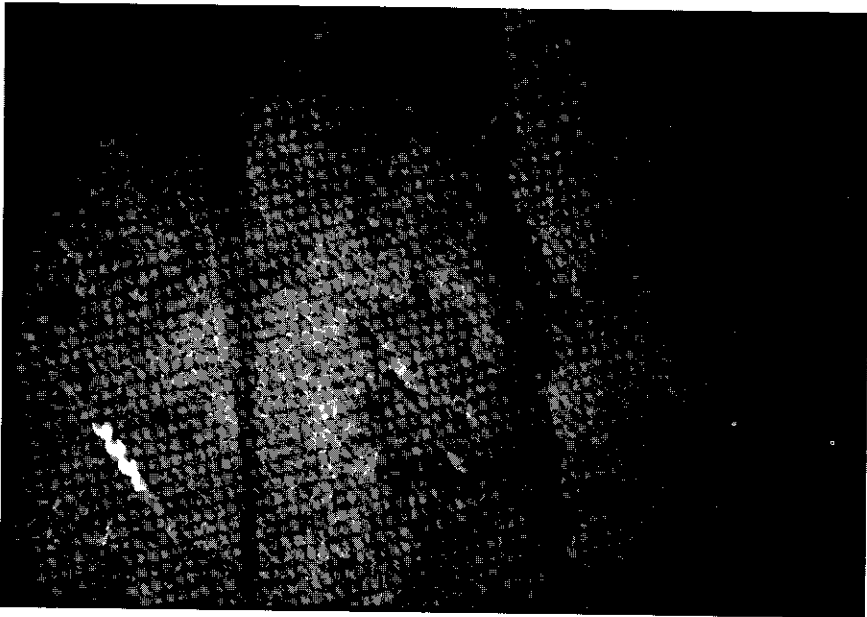
### *Benthic Activity*

The benthic activity is observed in the form of organisms and their lebensspuren (or traces), as follows:

*Organisms.* A variety of organisms such as fishes, shrimps, sea anemones, and sponges are observed in a number of photographs as well as on the video record. Sponges are usually attached to the hard (crust) substrate (Figure 10), whereas the fishes and the sea anemones are usually observed in the nodule and sediment areas. However, the presence of these organisms does not alter the microtopography significantly due to their sparse distribution in these areas.

*Traces.* In contrast to the organisms, their traces (lebensspuren) do change the seabed microtopography at some locations due to the concentration of casts and tracks on the seafloor. Elongated, tubular structures are commonly observed on the sediment around the crusts (Figure 11). These are probably the body casts of some of the organisms living on the seafloor. They appear to be fragile and to disintegrate in short period of time. These are more recent (or present) formations as no coating of oxide layers is usually found on them. The thickness of these features is a few centimeters, and they usually taper off at one end.

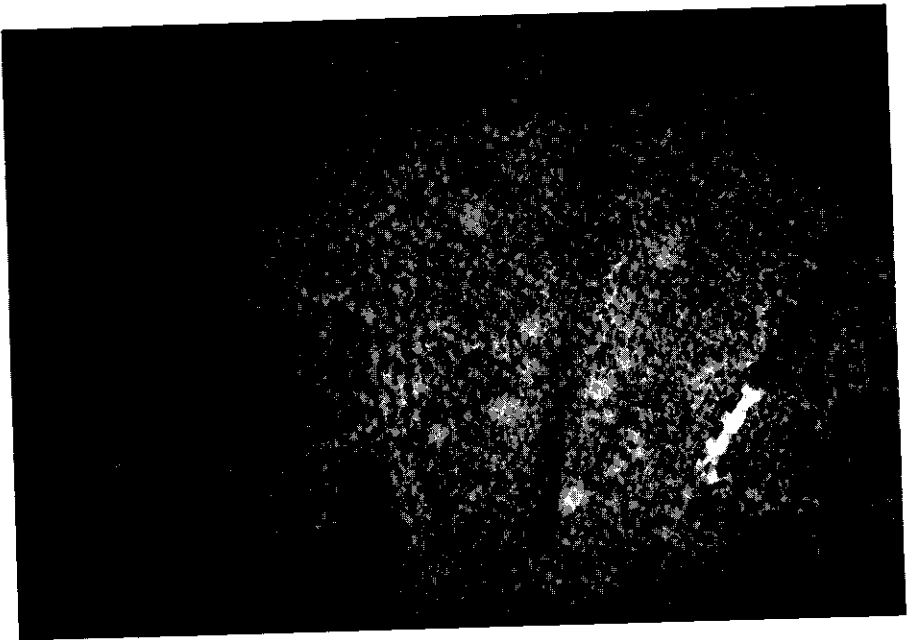
The tracks and trails of the organisms are seen on the sediment and nodule surfaces (Figure 12). The elevation difference of the seafloor in such areas is much less (5 to 10 cm), and the tracks do not seem to follow the microbathymetric contours.



**Figure 10.** A sponge attached to the crust outcrop.



**Figure 11.** Elongated tubular structures (probably casts of benthic organisms) on the sediments.



**Figure 12.** Track of a benthic organism on the nodule surface.

## Discussion

### *Microtopographic Variations Around the Co-Rich Manganese Deposits*

In general, the microtopographic variations range from a few centimeters to several meters at different locations. The average relief of the seafloor within a photographic area is about 10 to 50 cm. However, the relief on these deposits is highly variable, depending on the distribution of the crusts, nodules, and sediments as well as the associated surface features.

The large crust exposures have irregular surfaces, an overall relief of 30–50 centimeters (or sometimes meters), small vertical drops on their surface (about 10 cm), and troughlike regions that have sediments and sometimes cobbles between them. The surface of the crust can be smooth, nodular, or botryoidal; sometimes lineated; and at times steplike, giving rise to a variety of microtopographic features. On the crust surface, the hollow places in the microtopography act as zones of accumulation of sediments.

Also, boulders and cobbles encrusted with oxide layers are sometimes observed on or around the crust outcrops as well as over a matrix of nodules and sediments, with a relief of about 10 to 20 cm.

Certain crust surfaces are relatively flat (like pavements) with nodular appearance on their surface, and the relief of such surfaces is only a few centimeters. These are oxide coverings on basalts or hyaloclastic material and can occur over large areas (Hawaii Department of Planning and Economic Development, 1987). The surface is botryoidal, but shows only minor undulations due to sediment deposition between them and relatively flat topography.

Different microtopographic features are generated due to the association of nodules with different types of crusts. They occur between troughs on the seamounts and at the base of the crusts, the relief of such areas being 10–30 centimeters. Vast nodule fields occur on relatively flat seabed, and the nodule sizes range up to 4 cm, the relief of such areas being very small (< 10 cm). Many of these areas have densely packed nodules over large areas.

Sediments are usually observed at the foot of the crusts or as substrate of nodules. Large sediment coverage areas have small nodule populations and usually no crusts, but numerous worm tracks, tubes, and casts. The other microtopographic features observed on the sediments are the current generated ripple marks. Such features are observed in the sediment that has accumulated at the foot (base) of the crusts or in the crevices between large crust exposures where the current velocities are relatively higher.

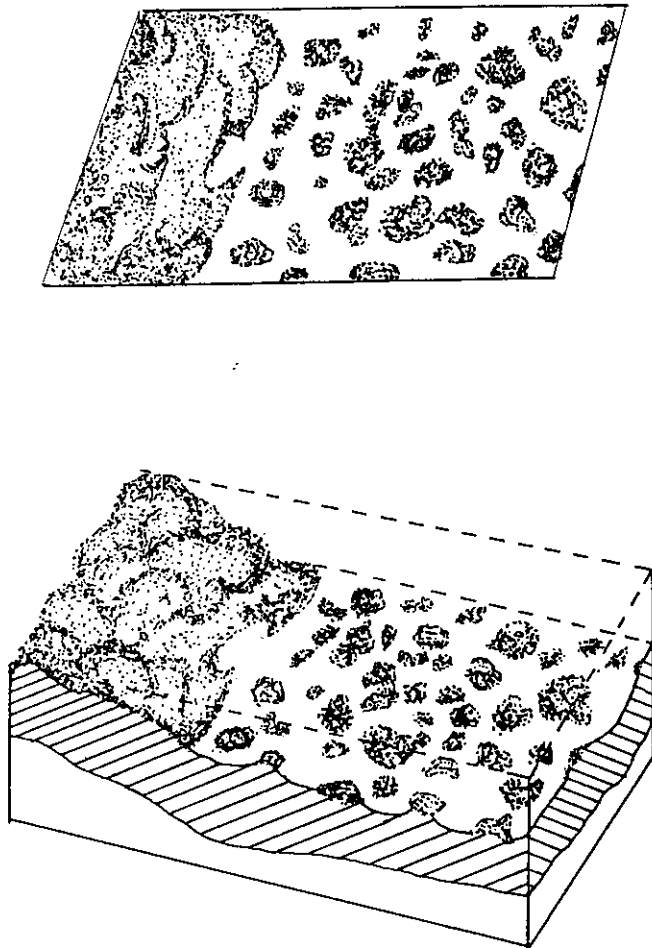
Many of these features have been observed by other researchers in different areas as well. Occurrence of large crusts, pavements, nodule fields along with manganese-encrusted cobbles, large boulders surrounded by sediments, trough between crusts filled with sediments, and current induced ripple marks have been reported in Co-rich manganese crust areas in the EEZ of the Hawaiian Archipelago. The seafloor has been classified on the basis of the crust micromorphology (Hawaii Department of Planning and Economic Development, 1987) Le Sauve et al. (1986) also reported the presence of current marks on the sediment along the axis of a channel between crusts.

### Role of Microtopography in Generating Certain Features

Whereas the distribution of crusts, nodules, and sediments depends upon the seafloor topography, the microtopography is responsible for generating certain features on the seafloor.

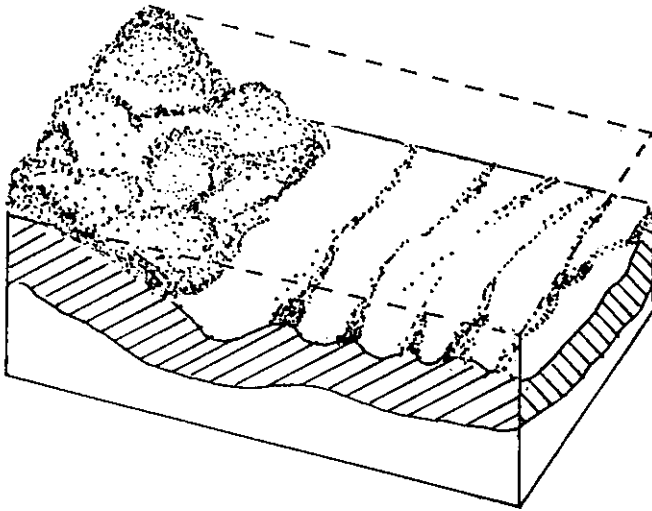
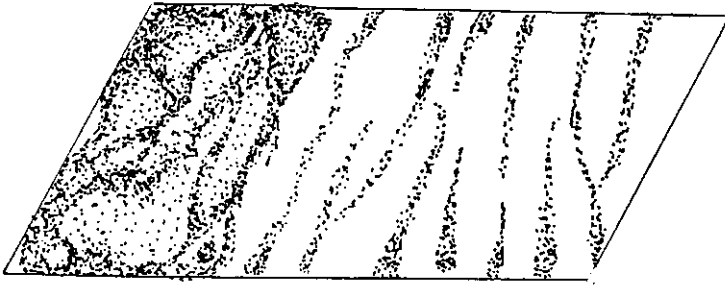
The crust surface may look like abundant nodules in the first observation, but a closer examination of the photos as well as the video record reveals that these are botryoidal features on a flat crust surface that are joined together and have a thin layer (or filling) of sediment in the microtopography between them (Figure 13). Such a nodular surface can also occur on pavements on flat terraces on the flanks of the seamounts.

A linedated pattern on crust surfaces appears as if many nodules are arranged in a line. These features are caused due to the microterraces or microsteps, with alternating bands or rows of sediments between the nodular surfaces of the crust, giving it a linedated appearance (Figure 14).



**Figure 13.** Schematic diagram showing nodular feature on crust surface.



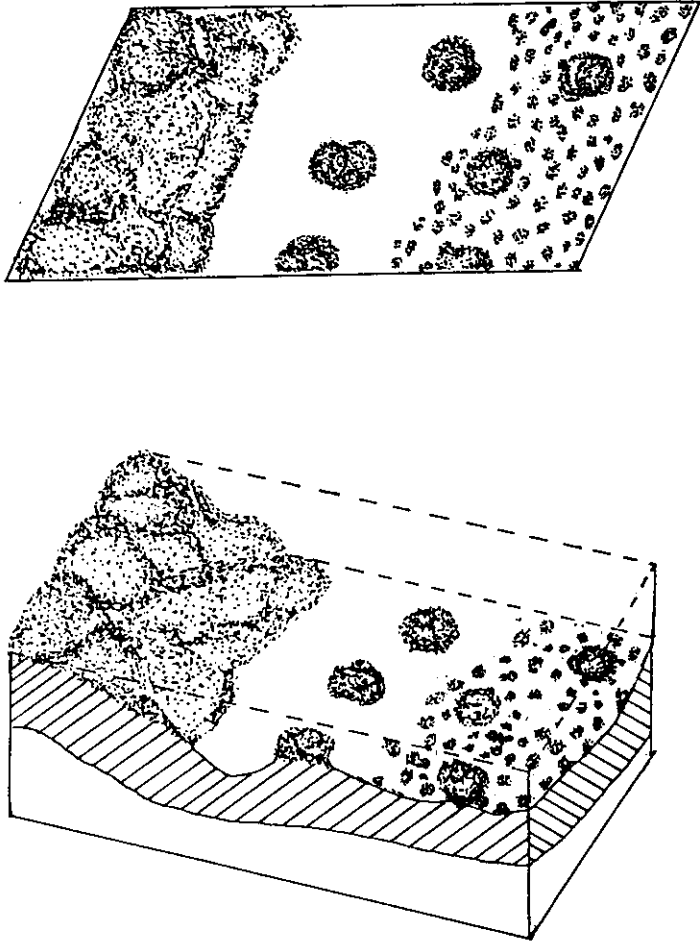


**Figure 14.** Schematic diagram showing lined pattern on crust surface.

Many cobblylike features are observed on the crust surfaces as well as on the sediment substrate. These appear to be projections on the crust surfaces, which are fully exposed at some locations and partially buried under sediments at other locations. Because of submarine erosion, they may also be broken out, detached from the crust surface, and deposited on the sediment in some cases. (Figure 15).

### **Implications of Microtopography on Exploitation of Crusts and Nodules**

The distribution of crusts, nodules, and sediments is the major factor that will influence the exploitation of these deposits. The percentage of occurrence of these on the seafloor will determine the commercial viability of the deposit, and the microtopographic undulations will influence the minability of the deposit during a mining operation. Mining of the crusts will require some mechanism of cutting (or scraping) of the surface, and the fragmented crust as well as the nodules can be



**Figure 15.** Schematic diagram showing cobblelike projections on crust surface.

picked by hydraulic suction mechanism (Hawaii Department of Planning and Economic Development, 1987).

By considering the shallow buried crusts, the resource potential can be increased by about 150 to 400% (1.5 to 4 times) depending upon different locations on the seamounts, and up to 800% (or 8 times) in specific areas, as compared with the resource potential calculated from the exposed crusts only (Yamazaki et al., 1992a). The type and quantity of the associated sediment will affect both the cutting and the suction mechanism of the mining system. Hence, the thickness and the geotechnical properties of the overlying sediment will also have to be considered while designing the recovery mechanism (Richards and Chaney, 1981). The characteristics of the associated sediments will also influence the generation of plume and suspension and the redistribution of particles in the near-bottom waters.

The undulating surface and the variable thickness of the crust outcrops may pose some problem for uniform removal of the ore (Morgan et al., 1988). Similarly,

the exploitation of the isolated crust fragments, as well as cobbles and pebbles, may also need a special device. However, the crust pavements may be the most favorable minesites due to their low microtopographic variations, in addition to the vast nodule fields, which also usually occur on flat seabed. The efficiency of the miner will depend upon its maneuverability through such microtopographic variations and the ability to recover the ore and screen out the unwanted debris or the sediment particles.

## Conclusions

The microtopographic undulations on the seafloor result from the distribution of the crusts, nodules, and sediments, as well as the surface features associated with them. At times certain features are generated as a result of a combination of different features at a given location. The microtopographic undulations have a variable magnitude, ranging from a few centimeters to several meters depending on the occurrence of different surface features. Hence, the microtopography of the potential minesites can be a critical factor not only in assessing the minability of the deposits but also in designing the mining system. Thus, knowledge of such microtopographic variations on the seafloor and the resulting features associated with the Co-rich manganese deposits are important factors to consider when designing the future mining system for this mineral resource and when planning a detailed mining activity in these regions.

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