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Geomorphic Mapping from Landsat-3 Return Beam Vidicon (RBV) Imagery

Three broad tectono-physiographic regions in eastern North Island, New Zealand were recognized and ten geomorphic categories were successfully mapped.

Abstract: *Landsat-3 Return Beam Vidicon (RBV) imagery of eastern North Island of New Zealand is useful for regional geomorphic mapping. Three broad tectono-physiographic regions—Western Taupo volcanic plateau zone, Central blockfaulted Mesozoic greywacke zone, and Eastern Inland Hawke Bay zone of dissected Tertiary hill country—are recognized and their features discussed. Some previously unmapped lineaments are noted. Ten geomorphic categories—coastal dunes, raised marine terraces, alluvial terraces, volcanic cones, dip slopes, large landslides, undissected plateau, dissected plateau, undulating hill country, and steep hill country—have been successfully mapped from the RBV data. The principal advantages of RBV images for geomorphic mapping are their improved geometric accuracy and their relatively high spatial resolution (40 m). Limitations in differentiating land-water interfaces are present. Landsat RBV imagery can be used to supplement future studies in the earth sciences, especially in remote or poorly mapped areas.*

Introduction

The Earth Resources Technology Satelite (ERTS) program had planned to use Return Beam Vidicon (RBV) cameras as major sensors in conjunction with a four-band Multispectral scanner (MSS) system in the 1972 Landsat-1 program. However, due to early technical difficulties and the highly successful results from MSS data, RBV data were not widely used nor widely available. The MSS was the prime sensor on Landsat-2. A modified, higher resolution RBV camera system was included on Landsat-3, launched on 5 March 1978. As with other Landsat missions, Landsat-3 follows a sun-synchronous, near polar orbit at an altitude of 914 km, passing over any one point on the Earth's surface once every 18 days. The RBV camera views the surface of the Earth vertically beneath the satellite and records images, each covering an area of 98 by 98 kilometres. The coverage of four RBV scenes corresponds approximately with that of a single Landsat MSS scene (185 by 185 km).

The Landsat-3 RBV system senses in the visible and near infrared region of the electromagnetic spectrum (0.5 to 0.75 μm). It is a modified television camera tube or vidicon in which the signal is derived from the depleted electron beam that is reflected from the ground target to the sensor. The

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return beams are recorded and stored on a photosensitive surface which is electronically scanned to provide a video signal, and subsequently transmitted to ground receiving stations where hard copy reproductions are produced.

It had been planned that both RBV and MSS sensors would record in similar spectral ranges, each using a number of sensing bands. However, it was found that duplication in spectral bands was unnecessary (Slater, 1975). Modifications of format and sensing band widths, together with resolution improvements in the RBV system, were incorporated into the most recent Landsat-3 program. The purpose of the RBV system, therefore, is now to provide high resolution (40 m) panchromatic images that supplement information obtainable from the more conventional MSS imagery.

Mapping of Earth science data from orbital altitudes has recently shown considerable potential, and the diverse range of possible applications has included physiographic mapping (Ulaby and McNaughton, 1975), fault pattern recognition (Iranpanah, 1977), and the identification of economic deposits (Smith *et al.*, 1978). Sauchyn and Trench (1978) studies of slope stability concluded that Landsat data were only marginally useful.

In May 1978, the first RBV images of New Zealand were taken from Landsat-3; this study attempts to evaluate their potential use for geomorphic mapping.

Study Area

This study examines an area of approximately 26,000 km^2 in the eastern North Island from Whakatane in the north to Hawke Bay in the south. The Landsat RBV imagery consists of four subscenes A through D, three of which have been used in the analysis (Figure 1). At the time of the satellite overpass on 31 May 1978, the area was covered in varying amounts of cloud, which posed limitations to mapping; i.e.,

- Subscene A was 56 percent cloud covered,
- Subscene B was 26 percent cloud covered and is shown as Figure 2,
- Subscene C was 100 percent cloud covered and was not used, and
- Subscene D was 62 percent cloud covered.

The present study affords the first example of New Zealand applications of Landsat-3 RBV imagery to a specific mapping project, namely geomorphic mapping. The Whakatane/Hawke Bay area is particularly suited to this type of analysis. The area constitutes part of the East Coast Mobile Belt and is characterized by active transcurrent faulting and volcanism associated with a westerly dipping subduction zone (Ballance, 1976).

Three tectono-physiographic regions are present in the study area:

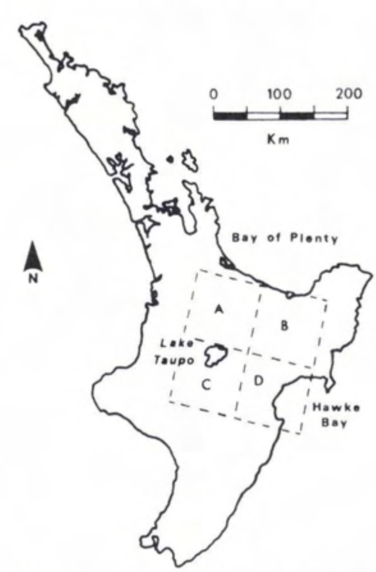

Fig. 1. Location map of the North Island, New Zealand, with the boundaries of the Landsat RBV image scenes E-30087-21141-A, B, C, and D shown.

- Taupo Volcanic Zone to the west, consisting of acidic and andesitic volcanic rocks associated with subcrustal melting of lithospheric material of the underthrust Pacific plate. It is predominantly a plateau area of massive ignimbrite sheets overlain with rhylotic pumice with some higher ranges largely of angular rhyolite rocks.
- A Central Zone consisting of indurated metasedimentary (greywackes) and minor volcanic lithologies forming upstanding blocks of the Urewera massifs of Raukumara Peninsula. It is characterized by coarse textured angular dissection (Figures 2 and 5).
- Inland Northern Hawke Bay, consisting of a variable sedimentary cover (limestone, sandstone, mudstone, and siltstone) which has been finely dissected by fluvial erosion. Most of this area is hill country with complex fine textured dissection.

Methods

A test site of approximately 250 km^2 in the Whakatane/Taneatua area of the Bay of Plenty was used for a pilot study to identify geomorphic features on the RBV image. This area was chosen because of its varied geologic, tectonic, and topographic nature (Figures 2 and 3). The area consists of indurated 'greywacke' type rocks of Mesozoic age (Torlesse Terrane), as well as less indurated marine Pleistocene sandstones and siltstones (Ohope Formation), unconsolidated alluvial sediments of Pleistocene age (Taneatua Formation), and Holocene dunes.

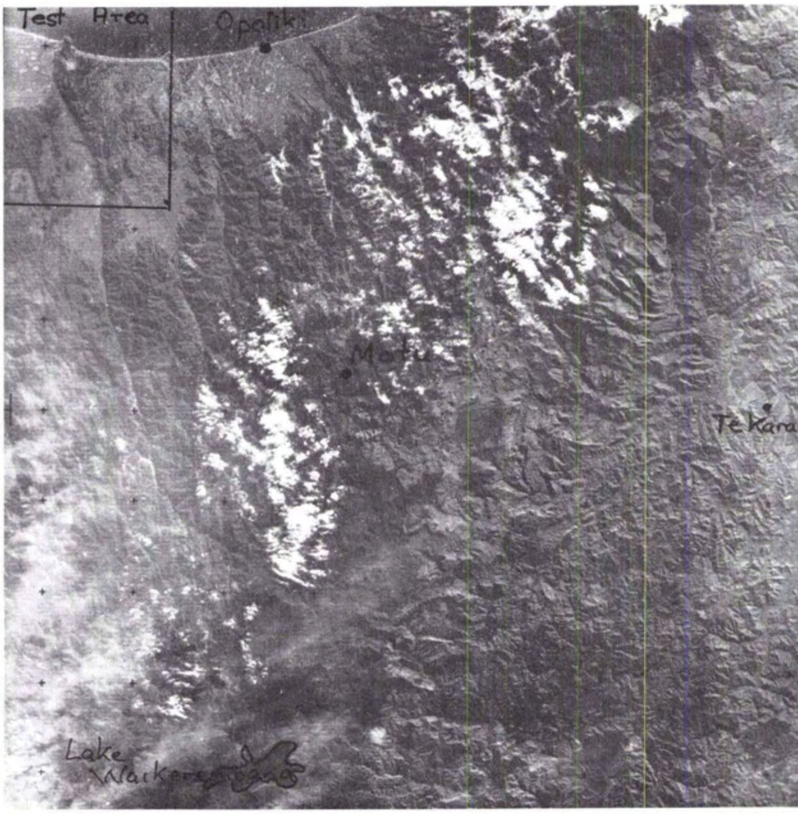

FIG. 2. Landsat-3 RBV scene (E-30087-21141-B) of the Whakatane-Lake Waikaremoana area. Note the conspicuous Whakatane Fault near the western (left) margin, Lake Waikaremoana in the south, the extensive landslide area of the Upper Waipaoa River in the northeast, and the distinctive structural boundary running diagonally through the center of the image separating the northwestern and southeastern halves of this area.

Topographically the area ranges in elevation from sea level to over 400 metres.

Mapping techniques involved five steps:

- Photo analysis of tone, texture, and lineaments on the RBV images, reproduced at a scale of 1:500,000, initially using only subscene B (E-30087-21141/B). In addition, the 10 percent sidelap on RBV images A and B allowed stereo-viewing of a portion of the area. Recognition of tonal patterns from the RBV images, based on known features in the test site, have been extrapolated to other areas by visual photo recognition on the RBV images.
- Comparison of these RBV data with topographic and geologic maps. The RBV images of the test area show both large and small faults mapped by Peltridge (1958) and Healy *et al.* (1964).
- Photogeological mapping from conventional, low altitude, vertical panchromatic aerial photography taken in 1974 was carried out to augment these maps.
- Field analysis of selected areas.
- Finally, comparisons were also made between the RBV images and Landsat MSS images enlarged to 1:1,000,000, 1:500,000, and 1:250,000 scales in order to evaluate the role of RBV images in geomorphic mapping.

The geologic features of the Whakatane-Taneatua test area are shown in Figure 3. Three normal faults with eastern uplifted slabs—the Whakatane Fault in the west, the central Maraetotara Fault, and the Tarepe Fault in the east—are especially prominent (Figures 2 and 3).

RESULTS

GEOMORPHIC LINEAMENTS

Geomorphic Lineaments mapped from the three Landsat-3 RBV images are presented in Figure 4. As used here, a lineament refers to any mappable simple or composite linear feature at the surface, which differs distinctly from the patterns of adjacent features, and presumably reflects a subsurface phenomenon (O'Leary *et al.*, 1976).

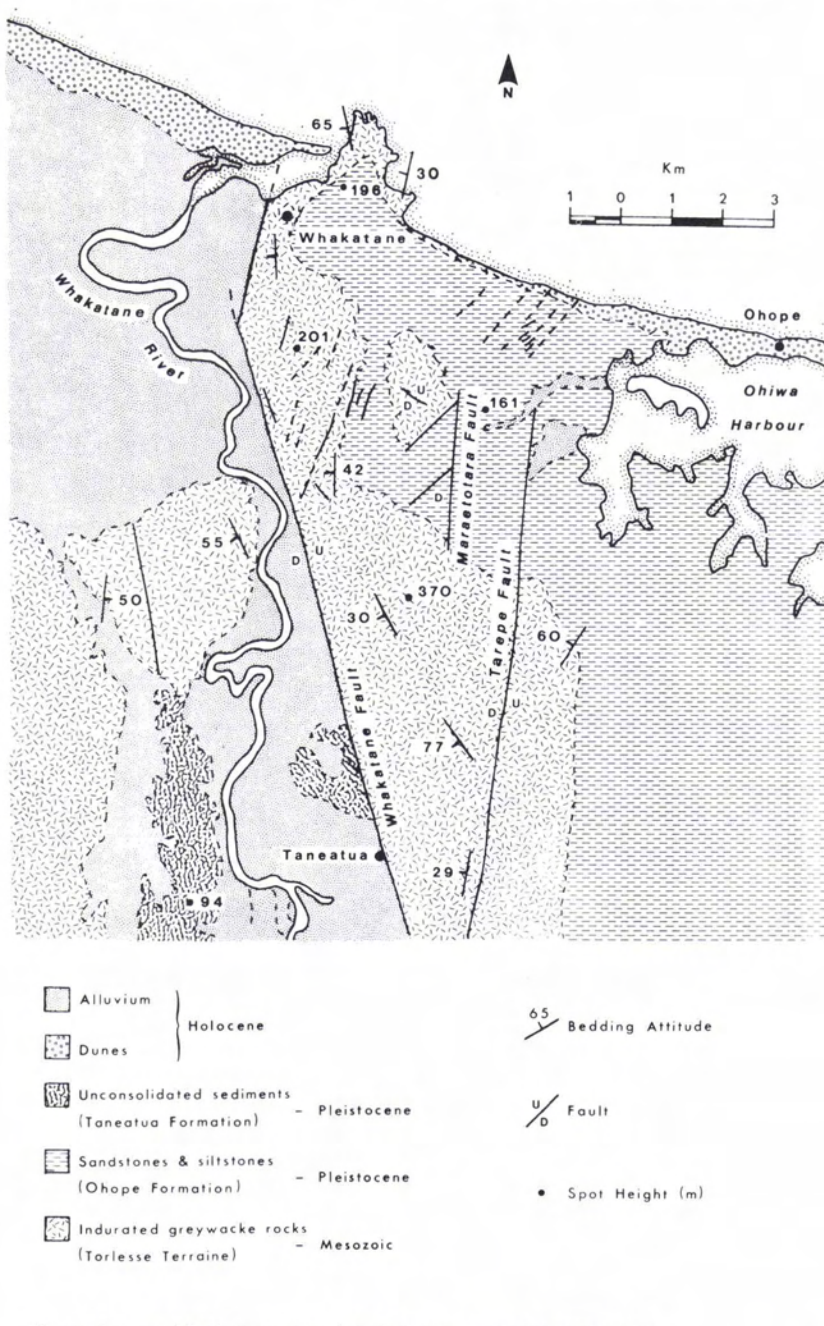

FIG. 3. Geologic map of the Whakatane/Taneatua test area showing major rock types, faults, bedding attitudes, upthrust and downthrow, and spotheights. (Test area outlined in northwest corner of Figure 2).

The dominant trends in the geomorphic lineaments are different in the three geologic (tectono-physiographic) regions mentioned above. To the west of Whakatane and partially obscured by cloud, a small part of the Taupo Volcanic Zone is represented by a pattern of closely spaced northeast trending lineaments.

In the Central Zone, northern trends of greywacke areas are dominant. In particular, in the Whakatane/Taneatua test area, large faults are recognizable from the RBV images, although the smaller faults are not. In addition, the relative topographic contrast between river valley and hill country facilitates identification. These tend to suggest uplift along many of these faults (such as the Whakatane Fault) or faultline traces due to erosion.

Toward the east, the Inland Northern Hawke Bay tectonic belt is dominated by northeasterly trending lineaments which are markedly contrasted to the trends of the Central Zone.

Several interesting lineaments have been mapped from the RBV images. (1) At Motu (Figure 4), there is a prominent change in lineament orientation, from the north-northeast to the east. This change represents the contact between the Lower Cretaceous Taitai Series and the Upper Cretaceous Clarence Series, both being similar 'greywacke' type lithology. The contact was mapped by Kingma (1965) as faulted and is clearly visible on the RBV imagery. (2) Fault traces of probable Holocene age, and not previously map-

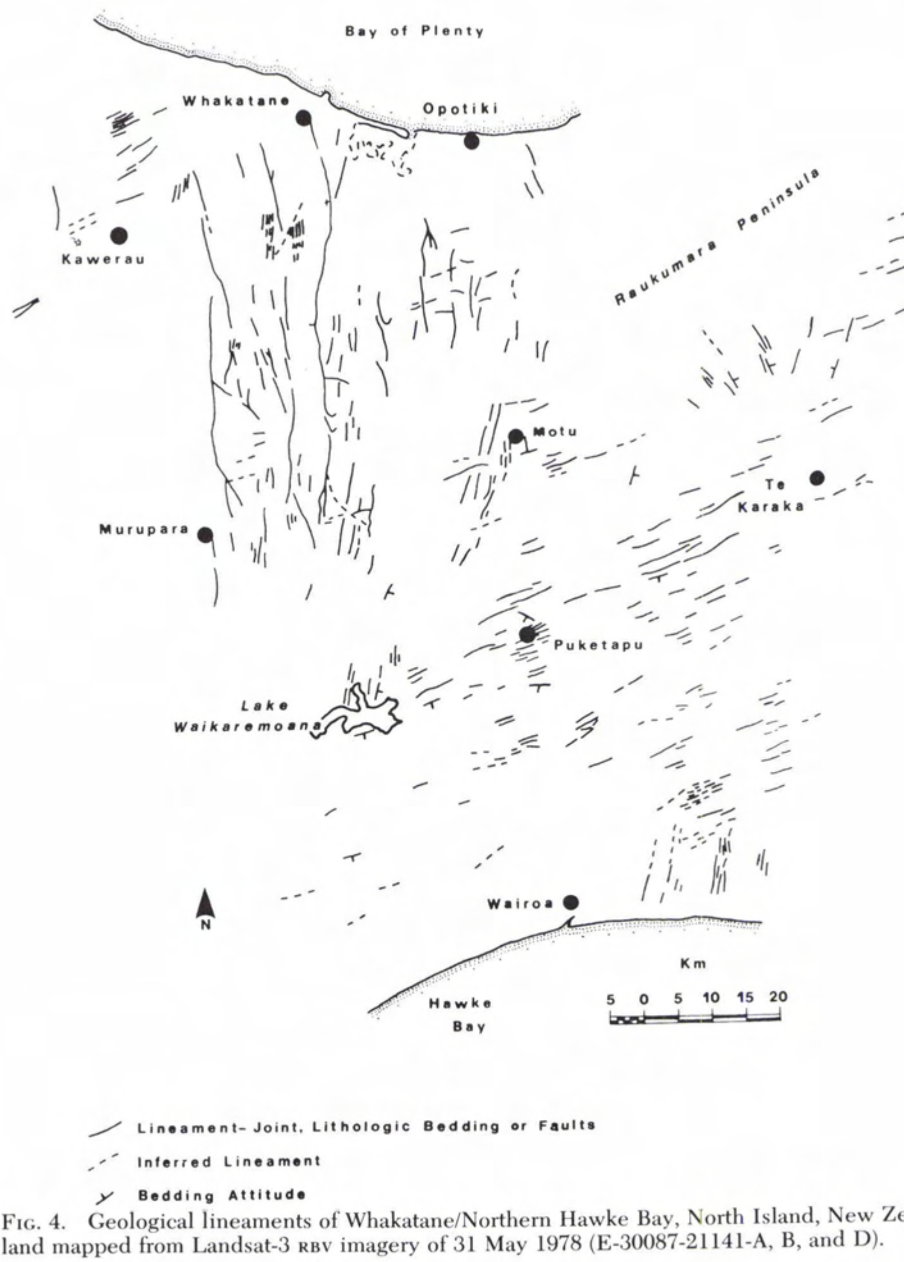

FIG. 4. Geological lineaments of Whakatane/Northern Hawke Bay, North Island, New Zealand mapped from Landsat-3 RBV imagery of 31 May 1978 (E-30087-21141-A, B, and D).

ped by Grindley (1960), have been recognized at Puketapu (Figure 4), northeast of Lake Waikaremoana. These traces occur on flat alluvial terraces some two kilometres wide, and are spaced at closer intervals. These features are clearly visible on the 1:500,000-scale RBV imagery. (3) Along the Whakatane Fault, northeast of Murupara, unusual curved terminae are evident on the RBV images (see Figure 2). These curved sections, interpreted as fault zones, follow major streams such as the Ohane and Otaipouri (between Murupara and Motu, Figure 4). Healy *et al.* (1964) had mapped this part of the Whakatane Fault as a continuous linear belt, but this information from Landsat-3 from RBV imagery suggests otherwise and would at least warrant field investigation. (4) Just to the south in the Waikare River, a small tributary to the Whakatane River, a criss-cross lineament pattern on the RBV images are not mapped by earlier workers (Healy *et al.*, 1964; Grindley, 1960) may also warrant field investigation.

Augmenting the mapping of lineaments, it has been possible in some cases to plot the attitude of the strata from the Rule of V's (Ragan, 1968), as commonly used in photogeologic mapping, provided the drainage flow direction can be ascertained from topographic maps.

Geomorphic Landform Types

In addition to the mapping of lineaments from the Landsat-3 RBV images, and the recognition of the patterns of major structural zones, geomorphic mapping on a broad scale was also attempted. Following photo analysis of tonal-textural patterns on images corresponding to geomorphic classes, ten geomorphic types were recognized (Figure 5).

- *Coastal dunes* were difficult to distinguish from raised marine terraces, except where geometric configuration was an obvious indicator (such as the spit at Ohope, or the river mouth at Wairoa). Elsewhere, such as in the Whakatane/Taneatua test area, raised marine terraces and coastal dunes are juxtaposed (Figure 3). However, with little topographic and textural contrast, these two categories have not been differentiated and are classed as raised marine terraces in this survey.
- *Raised marine terraces* were recognized by a continuity of slope from coastal to inland areas.
- *Alluvial terraces* were differentiated from raised marine terraces by their obvious intermontane nature.
- *Volcanic cones*. The volcanic centers around Lake Rotoma and Kawerau Mountain (off Figure 2, see Figures 4 and 5) were clearly indicated by their topographic protuberance or from their radial drainage patterns.
- *Dip slopes* were recognized where large flatish areas were exposed that corresponded to the altitude of the strata (as determined by the Rule of V's pattern or from early geologic maps). These dip slopes were recognized in inland Hawke Bay, and may represent hard sandstone beds.
- *Landslides*. In some areas recognition of large landslides has been facilitated by their mottled image tonal characteristics. The over 12 km stretch of severe landslides flanking the upper Waipaoa River is especially prominent (right side of Figure 2).
- *Undissected plateau*, and
- *Fluvially* incised or dissected uplands. They are separated from other flat geomorphic surfaces by their elevated topography and distinctive slope-break relationships. Both are formed on massive ignimbrite sheets.
- *Undulating hill country*. It has not been feasible to map various types of Tertiary lithology as sandstone, mudstone, and so forth, but rather these units constitute a more or less homogeneous textural type, consisting of undulating dissected hill country. Recognition of this zone is difficult from the RBV imagery alone, as it is very similar in appearance to the dentritic drainage pattern of the dissected ignimbrite category mentioned above. Discrimination, to a large extent, has been based upon correlation with the textural signature of the Whakatane/Taneatua test area, augmented by inspection of existing topographic maps.
- *Steep hill country* is suggested by deeply incised streams, steep slopes, and elevated topography.

The frequent (though not universal) occurrence of a continuous forest cover (native bush) was found useful as a crude first approximation in the identification of this geomorphic category.

Discussion and Conclusions

Wherever possible, mapping procedures from remotely sensed data should utilize all available imagery, including active and passive multiband sensors, of varying scales. Mapping should also be based on time-sequential imagery although this is less useful for geomorphic mapping than for land-use studies. Although training and experience of interpreters are probably the main cause, these procedures would reduce some of the recent criticism of the variability in mapping techniques between different observers (Cochrane, 1977; Hajic and Simonett, 1976; Huntington and Raiche, 1978).

All available satellite data of the area surveyed were analyzed. This was limited, however, to a Skylab IV handheld 70 mm near vertical color photo and two earlier Landsat MSS scenes.

Visual comparisons were made of tone, textural patterns, and lineaments with earlier Landsat-2 MSS scenes (E-2281-21182) of 30 October 1975 and (E-2334-21123) of 22 December 1975. Single band images as well as color composites were compared. Band 7 (0.8 to 1.1 μm) was found to be the single most useful spectral band for geomorphic mapping, confirming earlier work in different areas by Siegal and Abrams (1976) and Kayan and Klemas (1978). Most of the geomorphic categories recognized from the RBV image can also be seen,

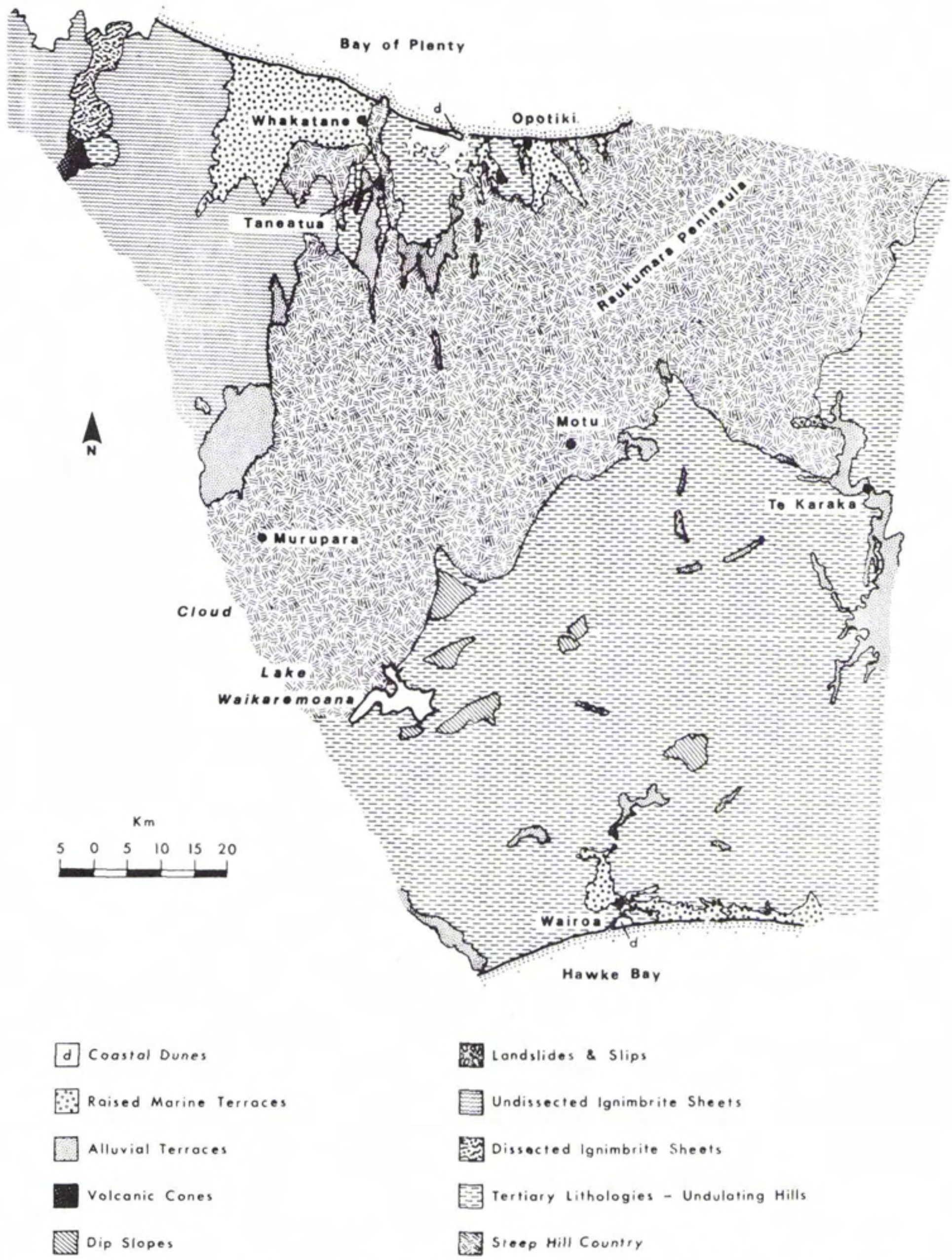

FIG. 5. Map of geomorphic units of Whakatane/Hawke Bay area North Island, New Zealand, mapped from Landsat-3 RBV imagery (E-30087-21141-A, B, and D).

though less obviously, on the MSS Band 7 image. If the MSS data had been used first before analyzing the RBV images, it is doubtful that some of the landform categories would have been recorded. The higher spatial resolution of the RBV MSS imagery compared with the MSS imagery, even when the latter was enlarged to 1:500,000, aided significantly in lineament detection, especially in the Northern Hawke Bay region (i.e., within the Tertiary sedimentary lithologies characterized by complex fine-textured dissection).

For the recognition of the regional pattern of geomorphic units, both RBV and MSS imagery were superior to conventional low altitude (ca. 1:25,000 scale) panchromatic photography. The broad synoptic view, the smaller scale, and the homogeneous spectral response (tonal patterns) of distinctive areas over a large area facilitated regional analysis. However, low altitude panchromatic aerial photography was valuable in specific mapping projects such as detailed mapping of landslide areas. These could only be broadly demarcated on RBV imagery and less clearly still on the coarser resolution MSS imagery.

The stereo viewing capabilities of adjacent RBV images, albeit a small strip only, aids in slope and height analysis. Although not tested in this study, it may facilitate quantitative estimates of bedding plane dip angles from Landsat RBV data.

The strongly northeastern trending lineaments of the Hawke Bay tectonic zone contrast markedly with the northern trend of the Central zone. They may well reflect greater transcurrent faulting closer to the subduction axis.

The RBV imagery analyzed does not sharply delineate land/water interfaces. This poses a limitation to its application to coastal zone studies. Problems were encountered in mapping the boundary between the Ohiwa Harbour at Ohope on the Bay of Plenty, and the adjacent land area. The shallow Whakaki Lagoon (some 4 km long) east of Wairoa in Hawke Bay, was not indicated on the RBV images. This problem is spectral and not due to the RBV imaging technique. Used in conjunction with enlarged MSS Band 7 data, this problem can be overcome.

Scan-line traces (noise) running ESE-WNW across the images could pose a limitation in detecting lineaments that are parallel to this trajectory when using the photographic products. Inspection of vertical aerial photographs and topographic maps showed that the Whakatane/northern Hawke Bay area has lineaments primarily orientated north or northeast, so that this was not a major problem in this study area.

Because distinctive tonal relationships on RBV images frequently correspond with landform type, the analysis of RBV film transparencies by color isodensitometry could prove a useful correlative analytical mapping technique. It is planned to use this method in conjunction with visual photo analysis.

It may be concluded, therefore, that Landsat-3 RBV imagery provides valuable additional information not provided in New Zealand. The higher resolution and improved geometric accuracy have proved particularly suitable to regional geomorphic mapping. As is true of *any* application of remote sensing data, RBV data should be used in conjunction with other data sources. Landsat RBV imagery may be of particular benefit in as yet little known or inaccessible areas for recognition of broad geomorphic units and lineaments.

Although detailed geomorphic mapping is probably not possible from existing satellite data (other than Skylab S-190 B photos), this study suggests that, with the improved spectral and spatial resolution of the Landsat-D Thematic Mapper (TM), both regional and detailed geomorphic mapping should be possible without recourse to needing intermediate scale vertical aerial photography.

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