Landform Development of the Central Coastal Bay of Plenty Region: An Integrated Study

J H Rae
MSc (Hons)
Network Control Planner, Transfield Services (New Zealand) Ltd.

Abstract: The Central Bay of Plenty contains numerous widespread, lithologically variable geological deposits that have been formed by a dynamic system of volcanic, geomorphic and tectonic processes. The landscape is characterised by alluvial plains and dissected ignimbrite plateaux. Tectonism and processes of deposition and erosion have resulted in a distinctive terraced morphology. Regional morphology is controlled primarily by both lithological and structural attributes, while selected studies show that localised development results from a combination of slope failure mechanisms and surface processes, related to differences in geotechnical properties, lithology and drainage. Recent reworking and re-sedimentation is evident across the region, as indicated by the presence of numerous volcaniclastic units and alluvial terraces. This is indicative of a landform development cycle which is can be summarised by both depositional (constructive) and erosional (destructive) phases.

INTRODUCTION

Volcanoes, particularly when associated with silicic volcanism, are often known for large scale, cataclysmic episodes, resulting in distinctive primary products and features (e.g. pyroclastic flows, caldera formation, ring faulting, cone collapse). The hazards, which result from such eruptive processes and products, vary enormously during the event and the immediate, resultant effect on the community and infrastructure can be devastating. In addition to the initial impact of a volcanic event, secondary processes and effects can continue to affect the surrounding environment as the local system adapts to new materials and alteration. Effects are widespread and can occur hundreds of kilometres from the source. The landform development of such areas can be attributed to primary (syn-eruptive) processes and materials and in addition, secondary (post-eruptive) events where both deposition and erosion are responsible for morphological development. Physical features include: Coastal cliffs; fault scarps; alluvial valleys and terraces; coastal plains and dune formations. The central coastal Bay of Plenty is a region defined by such distinct geological and geomorphic features.

In order to further an understanding of regional history and landform development an integrated study involving stratigraphic, lithological and geomorphic analysis was performed. This study was conducted for a thesis at the University of Waikato and incorporated description of both regional and localised processes. Initial field work and mapping was conducted in conjunction with Environment Bay of Plenty Regional Council. The study involved detailed analysis of a field area located within the central, coastal Bay of Plenty region (Figure 1.), extending from Matata in the east and to Pukehina in the west, and inland to Pongakawa and Manawahe. Detailed mapping was undertaken within this 250 km^2 area and landform development processes interpreted as a result of this field study.

REGIONAL GEOLOGY

The geology of the central coastal Bay of Plenty is dominated by a variable series of deposits, representing the products of a dynamic system of volcanic, geomorphic and tectonic processes. These deposits vary in source, lithology, thickness and distribution. Located on the edge of the Whakatane Graben, west of the Taupo Volcanic Zone (TVZ), the area contains evidence of numerous past volcanic and sedimentary processes and products. Volcanism however forms the dominant control on regional development. Localised tectonic instability and climatic factors also influence geomorphic and geological development.

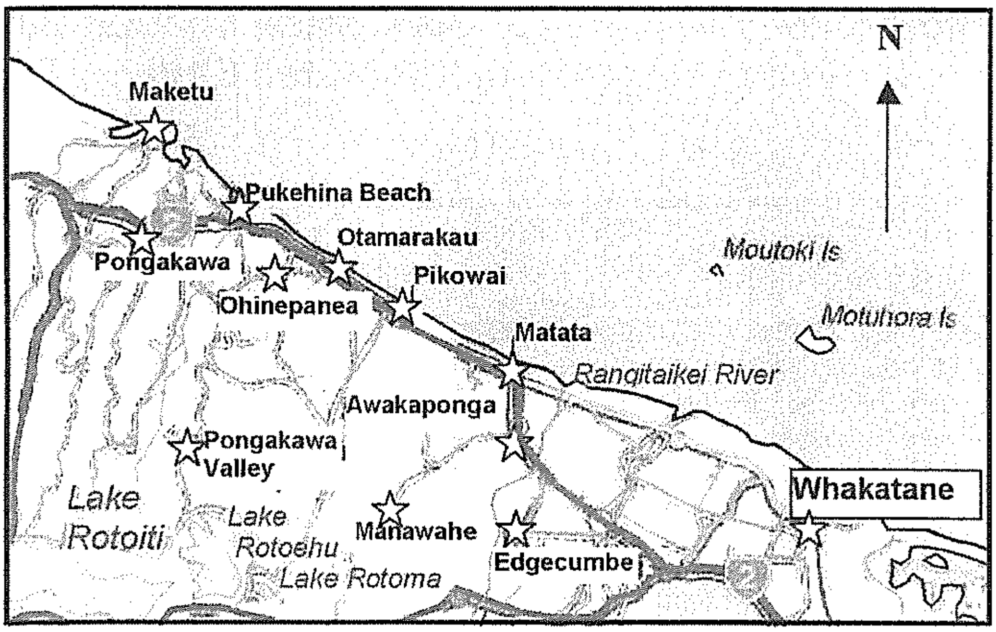


Figure 1. Location Map of Study Area.

The Okataina Volcanic Centre (OVC) is located directly south of the study area and forms the principal source of materials. Deposits are also found originating from several smaller vents located to the south-east of the study area (i.e. Manawahe, Putauaki/Mount Edgecumbe). These deposits are localised, of intermediate (dacitic and andesitic) composition, and where preserved, record early development prior to the increased dominance of Okataina volcanism, now evident across the field area. Uplift has also resulted in the exposure of various sedimentary materials and basement rock. Lithology is therefore variable with the majority of sections formed primarily of rhyolitic/silicic materials. Less silicic rock (i.e. andesite), basement and extensive, reworked deposits are also present.

Development can be summarised by the following:

- Erosion of basement and sedimentary deposition i.e. marine deposits. This stage is constructional and destructional.
- Initial and on-going eruption of local vents i.e. Manawahe Andesite extrusion. This stage is constructional.
- Caldera forming pyroclastic phase. Deposition of with large volume, welded and non-welded pyroclastic density current (PDC) materials i.e. Mamaku and Matahina Ignimbrites. This stage is constructional and destructional.
- Caldera alteration/ infilling events with smaller, lower volume PDC events i.e. Rotoiti Ignimbrite. This stage is constructional.
- Dome building phase with lava extrusion and eruption of, minor pyroclastics i.e. Rotorua Subgroup. This stage is constructional.

The study area is dissected by numerous NE-striking faults, closely mimicking structural trends that are consistent with its position in the northern Taupo Fault Belt. As a consequence the field area is tectonically active, with an extensive history of subsidence and uplift which began around 2 Ma with formation of the Whakatane Graben (eastern boundary of the study area). The Matata fault forms a prominent fault scarp dividing the Kaharoa Plateau from the Rangitaiki alluvial plains. Uplift along this fault has exposed greywacke gravels, evidence of past flooding events on the Rangitaiki Plains. Subsidence still occurs to the west, while uplift occurs in the east, resulting in a gradual tilting of the study area. Western subsidence has formed a distinct low-lying block faulted topography with local exposures of basement. Several large greywacke outliers are present, formed through the uplift of the Mesozoic basement, along a series of buried faults. Remnant greywacke is massive, extensively fractured, and shows signs alteration. Localised faulting has also resulted in the weakening of materials and provides a structural control for streams across the study area.

REGIONAL GEOMORPHOLOGY

The study area is a geographic rise between two lowlands. The eastern boundary of the study area is defined by the Rangitaiki Plains and Matata fault zone. The Pukehina Plains define the western extent. The Kaharoa Plateau dominates the central study area. The upper surface of this dissected ignimbrite plateau is comprised of moderately steep-low rolling hills (35-45°). Lithology is controlled by strongly welded ignimbrite and andesitic lava flows in the east and unconsolidated, non-welded flow and fall deposits in the west.

West of Matata, coastal sections show rapid termination of the upper surface of the Kaharoa Plateau and unconsolidated, non-welded materials form steep coastal cliffs (45-85°). Along this eastern section of study area the upper surface of the plateau is dissected by streams, forming narrow, convoluted escarpments that become deeper towards the coastline. Stream patterns follow the regional faulting trend where stream channels are narrow and steep, caused by water incising along fault scarps, cutting down through welded materials and consolidated deposits (Matata Cliffs). Stream channels are filled with coarse gravel and boulders (welded Matahina Ignimbrite and Manawahe Andesite) and small volumes of fine pumiceous silt. Groundwater is impeded in many areas, often caused by an impervious tephric, fine silty, clay surface that exists below the Matahina Ignimbrite. Along this contact zone seepage is heavy, and thick, altered, clayey layers may be found where seepage has weathered the underlying marine materials and surface colluvium.

Further south-east the Matahina Ignimbrite is down-faulted and only weak, unconsolidated pyroclastic deposits are exposed (Mangaone and Rotorua subgroups). Moderately thick loess deposits may also be found overlying the Matahina Ignimbrite. This material is soft, unconsolidated and subject to rilling.

The western side of the study area marks the termination of the Kaharoa Plateau and is characterised by lowland plains and broad alluvial valleys with low hills to the south. Figure 2. shows the Rotoehu valley which is typically bounded by a terrace of volcanic materials and infilled by gentling sloping alluvial fans (0-5°). The terraces are described as flat topped with moderately steep (26-35°), convex profile slopes. The Matahina Ignimbrite is absent from the western half of the study area, and stratigraphy is dominated by the non-welded Rotoiti Eruptives (e.g. Matahi Scoria, Rotoehu Tephra Rotoiti Ignimbrite, and reworked unit). The Rotoiti Ignimbrite is widespread. formed of several thick units, and provides a major geomorphic control. The ignimbrite overlies and mimics a gently dipping surface formed from older ignimbrites. The upper surface of this unit is truncated, showing evidence for post depositional erosion and stream channels are frequently infilled with reworked Rotoiti sourced pyroclastic materials.

Figure 2. Rotoehu Valley Morphology.

South of the coastal lowlands the western extent of the Kaharoa Plateau thins and terminates. The plateau surface (formed of Rotoiti Ignimbrite) is gently dipping, moderately elevated, and stream incised. The ignimbrite surface has been eroded to form a stream-incised landscape with low rolling 'beehive' shaped hills. Tectonism has formed a terraced morphology. These terraces represent distinct periods within the geological development of the study area, where down-faulting and erosion have lowered the surface of the ignimbrite. Surface geology is permeable, consisting of a low density, highly vesicular, highly porous substrate, with low impedance therefore reducing surface flow and runoff and largely increasing groundwater recharge rates. Alluvial sediment is thick and extensive across the valley floors and subject to reworking during high intensity rainfall events. Hummocks are found at the base of steep sided terrace slopes and form through riverbank failure and aggradation. Streambeds have a clayey-fine sand base and contain dominantly fine-grained sediment with channels of low angles, bounded by a thick alluvial terrace, formed from reworked volcaniclastic deposits and representing a depositional regime.

Lithology and Failure Types

A number of failure types are seen across the field area; these are controlled by lithology, faulting and climatic conditions (i.e. frictional resistance, permeability, water volume and flow rate. There are two distinct trends:

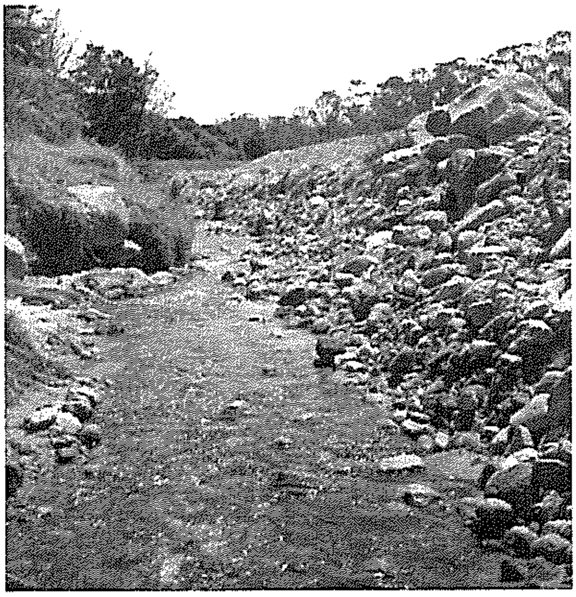
- Rock fall and debris flow failures where welded and indurated materials are prone to large-scale mass movement processes. This is a dominant feature of stream valleys within the eastern study area, in the vicinity of Matata.
- Translational movement and soil failures are a dominant feature of the western study area.

The majority of reworked deposits across the field area can be described as soft, dominantly granular with a silty glass rich matrix. Deposits are both grain and clast supported. Tephric loess and sandy, fine-grained reworked deposits are common. Poorly sorted, frequently bedded deposits of indurated rock are also found to the east of the study area, indicative of numerous small debris flows. Debris flows are common within the eastern study area, where welded ignimbrite materials overlie impervious marine sands. The Matahina Ignimbrite displays thin, discontinuous jointing with a hexagonal and columnar pattern often common to welded ignimbrites. Slab failure is common along these joint planes, where joint propagation has occurred and is associated with high seepage and pore water pressure. Failure susceptibility is increased due to high intensity rain storms and the presence of a clay-rich drainage impeding surface beneath coherent ignimbrite materials.

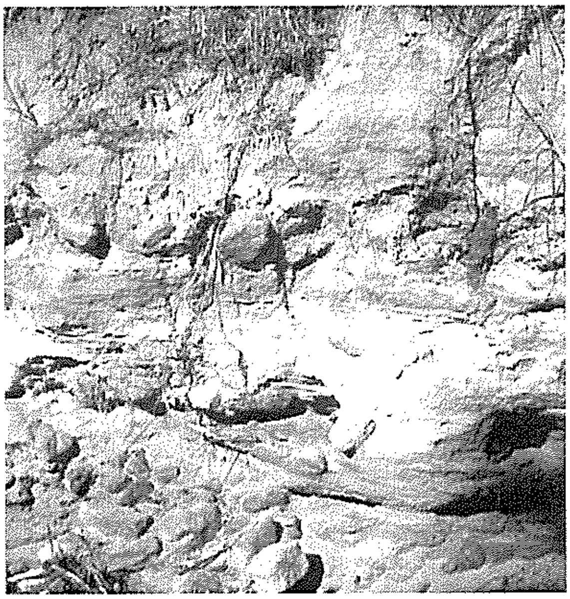
Debris flows initiate in the headlands of local streams and exhibit run out distances of 2-3 km. Dispersal occurs as flows reach the cliff base and form wide depositional lobes. Such flows damage engineering structures (culverts, drains) and create a hazard to local roading systems (i.e. SH 2). These minor events occur frequently i.e. several times a year (based on field observations). Deposits described in the field suggest that the study area has in the past seen numerous erosional and mass movement events and been inherently unstable, particularly within zones defined by steep slopes and unconsolidated deposits. As Figure 3. shows, many stream beds, poorly sorted, poorly graded deposits are found, formed from reworked, welded ignimbrite and rhyolite lavas (e.g. upper Mimiha Rd, NZMS 260 V15 346 616). Debris deposits are also evident in geological history. Thick (2-6 m) layers are found within marine sands, where streams have now incised into the Matata cliffs (e.g. western Herepuru Rd, NZMS 260 V15 374 626). Paleo-flows form deposits similar to recent debris flow deposits, with coarse ignimbrite boulders and cobbles, dispersed with a fine sand and silt matrix. Recent failures (i.e. recent slips at Pikowai) also highlight this instability.

Smaller slumping events and subsurface failure (rills, gullying, sheet wash) features occur in low lying, rolling hill country, constructed of unconsolidated pyroclastic deposits to the west and south of the study areas, these events however, form low-risk events due to the unpopulated nature of the field area. Soil failures are common particularly in low angle, reworked volcaniclastic materials. Soil failure may occur due to increased load or pore water pressure and is common in clay rich soils. These clay rich layers have low frictional resistance and impeded drainage, resulting in high pore water pressure along the failure plane, and subsequent failure. Translational failures also occur frequently in low foothills, with low slope angles (5-30°), these are however of minor size (25 m length maximum). Recently deforested areas are prone to translational slides particularly during high rainfall events (e.g.

Manawahe Rd, NZMS 260 V15 378 563; Otamarakau Valley Rd, NZMS 260 V15 265 650). Failures occur easily within the soft granular substrate and include minor rills and gullying. Translational failure is common, particularly along alluvial flats and on interfluves where rich clay accumulation has occurred. Foot-slopes are particularly prone to gullying and slide failure. Roading systems are easily undermined as grain transport carries away sediment from beneath the surface.



[Debris Alongside SH2, Ohinekoao]



[Relict Debris Flow Upper Mimiha Road (NZMS 260 V15 346 616]

Figure 3. Reworked Volcaniclastic Deposits

In low lying areas (i.e. western section and south-eastern areas) high-volume surface water flows across soils and recently exposed unconsolidated substrate resulting in grain by grain transport. Slight depressions in topography result in concentration of flow and preferential incision into the ground surface i.e. formation of distinctive gullying along Manawahe Rd. Gullies exist on low angle slopes and range in size from 1-3 m diameter, and 5-7 m length. Rills are widespread across freshly exposed primary and reworked pyroclastic materials and form on low-steeply dipping slopes (3-60°). Size ranges between 5-20 cm. Sheet wash occurs across flat, low-sloped valley floors with low-density vegetation. Bedload transport is also unusually high considering low water volumes present within the streams and occurs as a direct result of preferential elutriation and transportation of fine, low density pumiceous materials. Coarse material is very rare, and larger clasts where present are pumiceous.

DEVELOPMENT

Initial investigation reveals that primary volcanic processes were vital in landscape modification in the area. In addition to this, field study shows that secondary processes have the potential to have a continued effect on the local environment, both disrupting infrastructure and creating a disturbance to human behaviour and developments, the most noticeable effect being on local waterways and road systems.

Landform development has been accentuated by erosional and depositional events throughout the Quaternary. Terrace formation is dominantly degradational, where reworking and erosion have changed the surface morphology of pyroclastic deposits (i.e. reworking of Rotoiti and Mangaone Tephra formations). Terrace construction also occurs where re-deposition has resulted in the formation of thick alluvial terraces (i.e. Pongakawa and Rotoehu valleys). Terraces are constructed with a flat upper surface and steep slopes, separated by alluvial valleys. At a closer scale, large gorges and fluvial reaches are often found within these valleys, with inner channels and low alluvial terraces. Migrating sand dunes are common towards the coast. Also minor north-south trending faults and jointing are common particularly along the coastline (Otamarakau Quarry) and are responsible for minor colluvium and talus deposits. Units are highly distorted around fault systems.

Primary Depositional Processes

Volcanism provides a large and instantaneous source of sediment and is responsible for the destruction of vegetation and hydrological systems. Primary volcanic deposits provide the principal source of detritus for resedimented volcaniclastics in the study area. Boundaries are defined through weathering and erosional contacts, i.e. paleosols, fluvial/aeolian deposits. Truncation and debris deposits provide evidence of erosion following the deposition of the Matahina and Rotoiti Ignimbrites. Volcanic deposition provides the foundation for morphological change. Geomorphic features relate directly with primary materials i.e. fine grained crystal rich deposits are prone to erosion. Thick non-welded pyroclastic fall deposits (i.e. Maketu and Hauparu Tephras) form the dominant lithology of low terraces to the west. These pumiceous deposits contain low density, coarse, highly vesicular clasts, which have extremely high friction values, enabling pumiceous deposits to form vertical faces as seen in Figure 4.

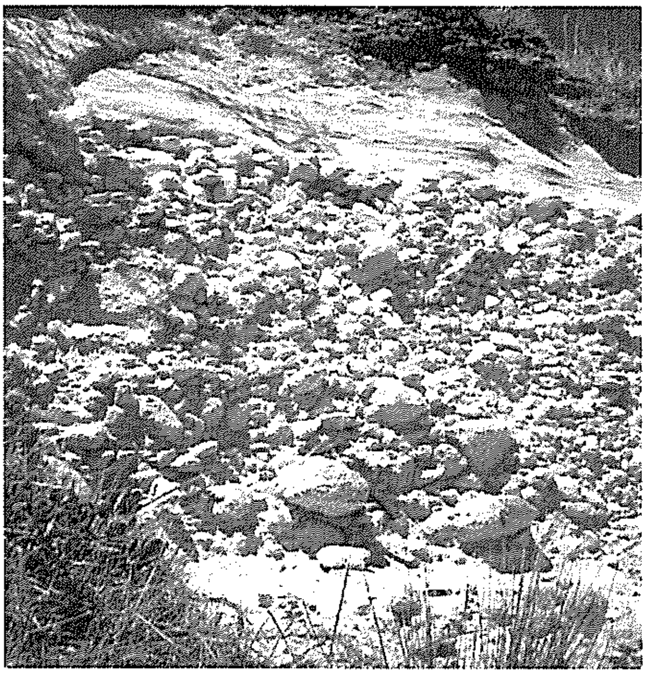


Figure 4. Hauparu Tephra as Seen at Otamarakau Marae (NZMS 260 V15 271 684).

Hydrological Processes

Large, gently sloping, low angle watersheds tend to have a large proportion of infiltration, with lower overland flow, compared to high angle, small catchments with quick surface runoff. Major floods will change stream bed geomorphology as the fluvial system adjusts to new conditions. Adjustment occurs when a stream exceeds the limiting threshold and new equilibrium conditions are required to account for increased bed load and water volume (Inbar, 2000). Gravel and boulders have a high shear threshold and require a higher flow regime to allow bed transport. Rivers with frequent flooding and riverbank failure events are found with a thin veneer of coarse alluvium over bedrock e.g. Ohinekoao Stream (NZMS 260 V15 375 627). Within the field area streams with a low flow regime (e.g. Hauone Stream) contain fine silts and sands and stream banks show fine sedimentary structures.

Dense vegetation along SH2 generally stabilises slopes, however with heavy rainfall events, load is increased on the substrate due to saturation and wet vegetation. A large section of vegetation was removed from the cliff face during a recent, localised failure event, and the exposed surface has been subject to extensive rilling. Within a recently felled forestry block (Manawahe Rd, NZMS 260 V15 387577) sheet wash and rill formation are clearly seen. Gullies with widths measuring up to 1 m and depths of 0.75 m, have formed rapidly in the newly exposed, silty, tephra rich substrate. The majority of damage in such an altered landscape is caused by concentrated flow erosion and winnowing of low density, porous materials.

Weathering and Alteration

The degree of alteration and weathering is also important. Devitrified pumice is soft, with low tensile strength, is easily deformed and is highly sensitive. Alteration weakens clasts (thermal oxidisation), however minor clay formation increases cohesion. Non-welded ignimbrites (i.e. lower Rotoiti Ignimbrite) and pyroclastic fall deposits essentially act as a large mass of individual grains.

Sea water reacts quickly with tephritic deposits, forming thick, well-indurated iron pans and lithified deposits resistant to erosion (Figure 5.).

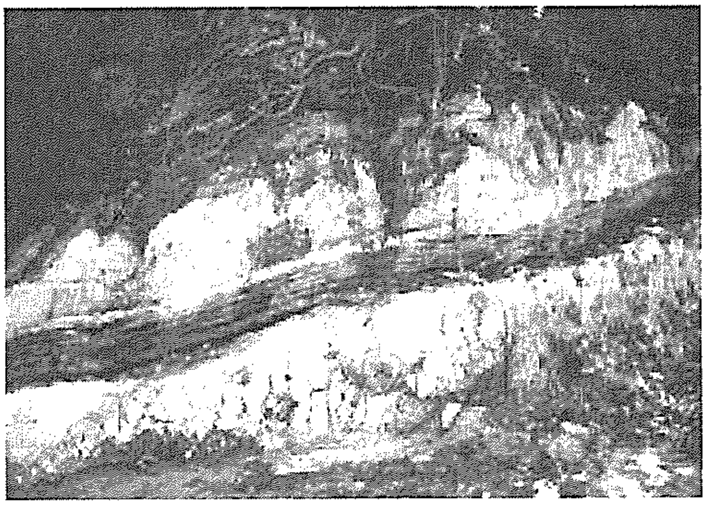


Figure 5. Well Indurated Iron Pan, Pukehina Beach (NZMS 260 V16 214 727).

Soil type also influences shear strength and hydraulic conductivity. Clay type is variable and dependant on climatic conditions. A temperate climate with frequent intense rainfall events has contributed to a variety of weathering and transportation processes responsible for the formation of extensive terraces, mass movement features and reworking processes and deposits. Limonite staining and leaching are also both common where there is impeded drainage and high rainfall. Thick (4-5 m) reworked deposits are found in the Pongakawa and Rotoehu valleys. Significant reworking occurred after the deposition of the Rotoiti Ignimbrite and Mangaone Subgroup tephras, due to a colder climate with intensified erosion. These reworked deposits are soft and prone to failure.

During phases where eruption rates are rapid, paleosols are poorly developed (i.e. few paleosols are seen occurring within the Mangaone Subgroup Tephras. Paleosols develop most readily during warmer climatic periods, therefore extensive paleosol development has occurred during the Holocene. Enhanced weathering and paleosols development is evident after the deposition of the Rerewhakaaitu Tephra, marking the end of the last glacial and the beginning of climatic warming. Deposits above this tephra bed indicate a significant reduction in fluvial aggradation, down-cutting processes, loess accumulation and increased paleosol development (Newnham *et al.*, 2001). Materials are more weathered and frequently reworked through pedogenic processes and incorporated within paleosol layers (e.g. Taupo and Kaharoa tephras).

Erosional Processes, Reworking, and Re-Deposition

Numerous stream deposits and relict debris flows indicate how a post-eruption surface can been subject to large scale reworking. Thick, poorly sorted, heterolithological (greywacke and volcaniclastic) reworked fluvial and debris deposits are found along stream beds (e.g. Taupo and Kaharoa Flood deposits) and have helped to construct the modern environment (Nairn and Beanland, 1989).

In the centre of the field area, laharic deposits are found. These deposits incorporate Matahina Ignimbrite and are overlain by Rotoiti Tephra, indicating that deposition occurred during the extensive erosional break between units. Sections within the Herepuru and Ohinekoao Stream valleys display thick reworked fluvial and debris deposits, formed from weathered Matahina Ignimbrite. A number of sections also indicate large amounts of reworking, (i.e. Herepuru Valley, Mimiha Rd Pikowai Rd, and SH 2 Pikowai Pyroclastics sections) from a source outside the study area. These reworked deposits represent erosion and reworking of pyroclastic materials, no longer seen in their original state, within the field area. Faulting of these sediments has occurred since deposition and in the Pikowai Pyroclastics, is responsible for the formation of thick liquefaction structures within the deposit.

Deposits show a range of sorting classes, ranging from moderately well-sorted (moderately fine-grained traction current deposits, i.e. Mimiha Rd fluvial section) to very poorly sorted (fine to coarse-grained debris flow deposits, i.e. Pikowai Rd reworked section). A range of secondary transport processes is responsible for the formation of these deposits and these processes have resulted in significant alteration of primary source materials. In the western sector of the field area, preferential elutriation and transportation of fine pyroclastic materials, and high volumes of bedload within streams, has also caused major problems to drainage systems and land use (i.e. Hauone Stream). Gully and tunnel processes occur frequently causing slope failures and underslips, which undermine roads and fences (i.e. Pongakawa valley). Fine-grained reworked materials can be seen covering pastureland.

The Rotoiti eruptives have also been eroded and extensively reworked. The upper surface of the Rotoiti eruptives is truncated. In several sections a poorly sorted clay-rich unit overlies the eruptives and is interpreted to represent fluvially reworked welded Rotoiti Ignimbrite and incorporated Rotoehu Ash. Thick, coarse-grained loess deposits also overlie the Rotoehu Ash, i.e. at Cameron Quarry. Several sections along Manawahe Rd show truncation of both the Matahi Scoria and Rotoiti Ignimbrite caused through extensive erosion, most likely resulting from a cold climate and high rates of physical weathering and transport.

Colluvium and talus deposits are also common and susceptible to remobilisation due to low densities and high pore water pressures. Talus deposits can be rapidly destroyed by weathering, resulting in intensive surface erosion through rilling, gullying and sheet wash. Subsurface failure results in slumping. Erosion causes undermining at the base of the talus slope and results in shallow-seated slide failures.

A warmer wetter climate has also enhanced peat formation. Thick peat layers are found along the coastal plains in low lying areas, overlain and intercalated with Holocene tephras (Lowe *et al.,* 1992; Newnham *et al.,* 1995; Giles *et al.,* 1999). Scattered dune sands and blow-out dunes comprise areas of higher elevation (ridges and hummocks) and result from a migrating, prograding coastline and increased accretion (Nairn and Beanland, 1989). Voluminous tephra deposits have altered the coastline and been responsible for major progradational events.

Alluvial deposition and coastal progradation continues to occur along the Bay of Plenty coastline. Shoreline and longshore drift are influenced by northern storms and the predominant strong south-westerly winds. Frequent high intensity rain events and high rates of clay formation will cause the continued instability of coastal cliffs, therefore the probability of further debris flows along the coastal section is high. Aggradation is a common depositional processes, with streams displaying high bed load. Small debris flows and drainage channel infilling continue to occur along coastal sections. Impeded drainage and a clayey sub-surface also enhance mass movement processes (slumping and creep).

CONCLUSIONS

For simplification, landform development has been categorised into a series of stages based on major structural, depositional and erosional events, including:

- Deposition of Pre-Matahina materials (including reworked greywacke gravels, marine sands, intercalated tephras);

- Caldera formation south of the study area – with periodic ignimbrite deposition and reworking of post eruptive surfaces (Matahina Ignimbrite).
- Pre-Rotoiti erosion, reworking and transportation. (Upper Mimiha Rd Fluvial deposits, Pikowai Pyroclastics);
- Continuation of volcanic deposition (Rotoiti eruptives);
- Renewed erosion and reworking. Thick loess formation;
- Caldera modification and deposition of Mangaone and Rotorua Subgroup fall and flow deposits.
- Renewed erosion and reworking, with increased soil formation and alteration after the end of the last glacial period.

Study of geological history within the study area reveals periods of fluvial erosion, deposition of pyroclastic fall and flow materials, reworking and transportation, and this has resulted in a unique morphology. Landform development is summarised into cyclic phases of both constructive development (incorporating all depositional events), and destructive development (incorporating all erosional events).

Constructive (depositional) phases resulted in extensive terrace formation. This has occurred at several points in geological history (deposition of Matahina Ignimbrite, Rotoiti Eruptive and Mangaone Subgroup materials) and resulted in the formation of a stepped morphology. Erosional phases are responsible for truncation, surface alteration and failure events. Destructive phases have also caused formation of numerous heterolithological deposits (e.g. Pikowai Rd fluvial deposits, Pikowai Pyroclastics, assorted debris flow deposits and volcaniclastic fluviatile facies). A range of sedimentary facies is represented within these deposits, with a range of sorting and grainsize classes seen. These reworked deposits infill alluvial valleys and occur at several periods throughout the stratigraphic record. Erosion and reworking of the Rotoiti Ignimbrite also resulted in the deposition of extensive terraces. Reworked ignimbrite also forms low hummocks within alluvial valleys. Low (5 m thick) terraces are located in the north-west of the field area (Pukehina Plains) and are comprised of Mangaone Subgroup deposits.

Minor reworking and mass movement processes still operate within the study area. Debris flows are prevalent in the east (within jointed, hard rock substrate), while less prominent surfical erosion and subsurface failure (slumping, rill and gully formation, translational failure) occur in the west (soft, unconsolidated, granular pyroclastics). Such flows have a tendency to flow out over the road surface along the eastern, coastal cliff section causing minor damage to roadside structures and drainage systems.

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