67) resulting from abrasion by strong winds. Many small stones that occur somewhat randomly in loess on the upper slopes were probably blown from the ridges. Larger stones (Fig. 68) also occur randomly within the loess and have probably been deposited by solifluction, a process whereby thawing material slides down-slope on a firm or frozen surface. The fragic horizon probably represents an interval of severe cold with soil freezing, as is suggested by the vesicular structure that is present, the small voids being left after ice crystals in the soil have thawed. It is also possible that during this period of extreme cold and loess deposition, soluble salts accumulated in the soils, perhaps even forming a salt pan.

Figure 67. A boulder on a ridge with characteristic wind faceted shape (ventiforms) aligned in the prevailing wind direction.

Figure 68. A solitary boulder with the long axis aligned down-slope, deposited by solifluction.

7.13. Soil Susceptibility to Erosion

From historical records including photographs, it seems that the extensive tunnel-gully erosion of Wither and Vernon soils commenced in the late 1800's. The cause is generally attributed to vegetation depletion by overgrazing, burning, and rabbits, which allowed water infiltration through shrinkage cracks, and rabbit burrows. This explanation, while appearing plausible, may not however be the complete answer. The original pre-Polynesian vegetation was believed to be coastal forest that was replaced by tussock grassland as a result of Polynesian fires (Holloway 1959). If loss of vegetation cover was the primary cause of the Wither Hills erosion, then initiation of the tunnel gully erosion might reasonably have been expected to have taken place earlier at the time of this dramatic vegetation change in Polynesian times. There must have also been periods in the past when severe droughts would have caused subsoil shrinkage and facilitated the tunnel-gully erosion process.

It is possible that a major contributing cause may have been the Marlborough earthquake of October 1848 (estimated magnitude 7.5) and the Wairarapa earthquake of January 1855 (magnitude 8.2). According to Manson *et al*. (2006), the Marlborough earthquake earthquake was a movement on the Awatere Fault and the lower Wairau Plain bore the brunt of the force. They reported that the earthquake greatly disturbed the surrounding landscape triggering numerous landslides in the hills. The greater magnitude Wairarapa earthquake was reported to have caused slips in hills as far away as Kaikoura. It seems likely that the fragipan in Wither soils, a more or less continuous horizon that impedes the downward movement of water, would have been subject to some fracturing during the violent earth movements and if so, would have then easily allowed the entry of large amounts of water to the deeper horizons in later heavy rainfall events. This may have been a more effective mechanism for the initiation of the erosion than the postulated subsoil shrinking due to soil drying.

Increased soil pH, consequent on the conversion of the pre-European vegetation to introduced grasses for grazing, may also have contributed to the soil erodability, as Laffan (1973) found that some soils with low pH had lower dispersive values and some with high pH had high dispersive values.

As outlined above, Waihopai steepland soils are moderately susceptible to slip erosion with both old and fresh slip scars indicating that slip erosion is an ongoing process but which is probably accentuated during major seismic events. The lower steep slopes towards the heads of the valleys and gullies are more especially susceptible to slip erosion while sheet erosion is also active on dry sunny faces. Easier slopes on ridges and spurs show little sign of slip erosion. Surface boulders are common on many of the steep faces and their occurrence suggests that there may be an ongoing loss of fine soil material, perhaps by slow sheet erosion. Bouldery ridges are probably a relict of former times when wind erosion was severe. The most serious erosion in Waihopai soils is on the lowermost surfaces in some gullies and valleys where active slip and deep gully erosion is occurring.

The widespread erosion in Wither soils is largely historic in that it was initiated in the late 1800's and continued into the early 1900's but as reported by Laffan (1973) may have stabilised by the 1940's as comparison of 1949 aerial photographs with 1969 photos showed no measurable differences in its aerial extent. Erosion however, is clearly continuing with gully widening and deepening, headward extensions, formation of new tunnels, roof collapses and obvious evidence of sediment discharges. The widespread fragmentation of the land surface caused by the extensive gullying that has already occurred, in some respects may restrict the capacity for new gully formation, since large areas of undisturbed ground which could collect water that might be channelled down a soil crack, no longer exist. Since no significant areas of uneroded Wither soils were identified, it is unlikely that there would be any significant future expansion of Wither soils erosion, apart from on-going gully widening and headward retreat.

Vernon soils have a similar susceptibility to erosion as Wither soils in that tunnel gullies have readily formed, but there are differences that relate to their parent materials. The absence of thick underlying deposits of dispersible silty gravel means that deep gullies seldom develop. Vernon soils appear more susceptible to sheet erosion, which is best seen on numerous upper slopes in valley heads.

Sedgemere soils on gentle slopes show little sign of tunnel gully erosion but some gullying does occur as both the slope and the capacity for lateral down-slope transmission of water increases. Tahunanui soils are formed in unconsolidated dune sands where there is a high risk of erosion through sand blow out.

7.14. Off-site Consequences of Erosion

The principle off-site consequences of the erosional instability in the Wither Hills and Redwood Hill area are the removal of soil materials with their re-deposition on the adjacent lower lying surfaces, along with serious loss of water quality in drainage waters on the plains. There is ample evidence for the redistribution and deposition of materials from the valley sides to the floors of the gullies and the plains (Figs. 69-73). Fine sediments may accumulate on the floor of a gully, being trapped by grasses, if the flow rate is slow (Fig. 69). However, considering the large volumes of loessial materials that have been lost, it is likely that much of this material has been removed into the waterways of the plains and carried away as suspended sediment (Fig. 70). Even during times of low flow, waterways adjacent to the hills commonly are yellow coloured. Coarse sediments also end up on the gully and valley floors (Figs. 71 & 72). The deposition of sediments downstream is clearly episodic and related to major storm events as is illustrated by the presence of flood layers with buried topsoils in sediments adjacent to streams (Fig. 73).

With the increasing uncertainties associated with global climate change, climatic extremes may result in increased storm frequency and catastrophic storms, in which large amounts of soil material are removed from the hillsides and mobilised in down-valley flash floods as large scale debris flows. Such events are often reported from overseas and periodically occur in New Zealand. Fallen tree vegetation on lower surfaces can exacerbate flooding by forming temporary dams that release large amounts of water when burst. There is ample evidence from the distribution of various soil types on flat lands in the valleys outside the survey area that large scale movements of sediments have occurred in our recent geological past, most likely climate driven.

In the past, some sediment retention dams were built as part of the soil conservation work in the Wither Hills and have successfully retained large amounts of coarse sediment (Fig. 72). It is suggested that new dams be constructed on top of the existing accumulated sediments, as flattening the valley floor profile would be expected to impede the down-valley movement of a debris flow, as well as retaining the sediments that result from erosion within the catchments.

Figure 69. A thick deposit of predominantly fine silty sediment (colluvium) on the floor of a gully accumulating by sheet flow. The sediment is built up by runoff during rain events with coarser material added in heavier storms.

Figure 70. This runoff diversion barrier has trapped a small amount of silt and emphasises the ongoing loss of fine soil material from adjacent hill and steep slopes. Without the barrier, the silt would have ended up in the waterways of the Wairau Plain.

Figure 71. Coarse sediment accumulating at the foot of a small gully from an eroding catchment above. The size of the clasts is indicative of the high volume and velocity of the runoff waters.

Figure 72. A sediment retention dam built by the Marlborough Catchment Board as part of erosion control measures. Impounded sediments are periodically removed to maintain the sediment retention function, but a better alternative might be to build a new structure on top of the retained sediments.

Figure 73. Buried soils are marked by the old dark coloured A horizons in sediments on a gully floor. The sequence indicates episodic erosion and sedimentation with periods of stability over an unknown length of time.

Figure 74. Saturated soil on a hill slope showing the effects of stock on topsoils with both pugging and down-slope foot sliding. This leads to decreased pasture cover and exposes the soil to accelerated sheet erosion. Stock tracks also accumulate water, which may be channelled through a crack and into an under-runner.

7.15. Erosion Mitigation and Management

It is not clear what part a more intensive vegetation cover of pasture grasses has, or might have in preventing or minimising further ongoing erosion in Wither and Vernon soils. During the present field investigation, which was carried out over a season of higher than normal rainfall, it was observed that for much of the time, the soils were saturated. Water was seen flowing down-slope on the pan surface and was also observed ponding in hollows, in stock tracks and in stock footprints. Flows that were occurring in under-runners, indicated that infiltration into the subsoil is still taking place under an improved grassland cover. Attritional erosion of Wither and Vernon soils is likely to continue, perhaps punctuated by increased losses in severe rainfall events. The complex topography and deep eroded gullies makes physical treatment of the erosion impractical and planting with appropriate vegetation may be the only remedial action possible. Waihopai steepland soils are likely to continue to erode through shallow slipping with no practical means to prevent this and extensive slipping may occur in a significant local seismic event.

Soil loess however, is not confined solely to natural erosion processes but is exacerbated by stock. It was observed in many places during the survey that stock were causing down-slope movement of topsoil due to animals feet sliding on the saturated soil, with the bared soil then being subject to sheet erosion (Fig.74). Appropriate stock management is clearly an important part of minimising the soil losses.

7.16. Suitability for Urban Use

Because of steepness of the slopes and soil instability, most of the area within the survey area is unsuitable for urban use. Some areas of moderately sloping land at lower elevation around the margin of the hills with Waihopai soils are suitable for urban use, but the extremely patchy distribution of the erodable loessial cover materials makes specific site suitability difficult to predict without detailed site assessments. Building platforms that are excavated into the Marlborough Conglomerate are unlikely to pose a stability risk but building on any erodable or dispersible loessial material should be avoided unless they are removed.

Building on lower elevation moderately sloping land with a loessial cover is possible, provided the structure is on the underlying conglomerate and there is adequate distance between the batter and the structure to allow for the movement of soil on the slopes above (Fig. 75). Care should also be taken with the disposal of runoff water.

On gently undulating loess covered land, the risk for urban use is minimal. However, it is recommended that detailed soil/geotechnical site reports should be made for all building proposals in this region.

Urban development on the easy sloping land surfaces at the mouths of valleys or gullies adjacent to the Wither Hills/Redwood Pass (land that was not surveyed) should be treated with caution because of the potential for extensive sediment discharges in extreme events. Enhanced sediment retention measures in the gully floors should reduce the risk of possible large-scale debris flows.

Figure 75. The building platform at this site is on stable underlying gravels. The layered dispersible loessial materials have scattered piping channels that will have originated somewhere up-slope. Rill erosion is taking place on the face of the cutting and dispersed soil sediment is accumulating at the foot of the cutting and being removed in suspension. The erosion will continue but is unlikely to pose a serious risk to the building structure. There is no evidence of mass movement (slumps) occurring in these materials.

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