ES322 Geomrophology Journal Article Review – Roering et al., 2005, Characterizing structural and lithologic controls on deep-seated landsliding: Implications for topographic relief and landscape evolution in the Oregon Coast Range, USA

Reading Summary Questions
Instructions. Read the Roering et al., 2005 paper, and answer the following summary questions. Questions are aligned with article organization from abstract to conclusion.

1. Using internet resources: draw a sketch showing the differences between deep-seated rock-block landslides, and shallow-failure debris flow. Write a brief description of each.

2. List the causal long-term and short-term factors that influence the occurrence of deep-seated landslides.

Answer: In general, deep-seated landslides result from a combination of long-term factors that condition slopes for failure (such as channel incision, slope morphology, geologic structure, shear strength loss due to weathering, and lithologic variation) and short-term processes that tend to trigger instability (such as hydrologic and seismic events).

3. Draw a sketch map showing the location of the Oregon Coast Range (OCR) and the occurrence of outcrop in the Eocene Tyee Formation that underlie the hillslopes.

4. True or False: the OCR was subject to Pleistocene glaciation. Explain your answer.

Oregon Coast Range (OCR) has proven to be a fruitful study area for analyzing sediment production and transport processes because rates of erosion and tectonic forcing are relatively well constrained and the region did not experience Pleistocene glaciation

5. True or False: landslide-dam lakes are an uncommon occurrence in the central OCR, explain your answer.

numerous landslide-dam lakes in the OCR suggest that deep-seated landslides may also play a role in shaping the region

6. List the three goals of the Roering et al., 2005 study.

The goals of this study are to: (1) formulate and test an automated algorithm that uses digital topographic data to identify the extent of terrain affected by deep-seated landsliding, (2) illustrate and quantify how geological structure and lithology control the spatial distribution of slope instability, and (3) use geologic constraints to interpret and predict how large landslides evolve in response to rock uplift and affect topographic relief over million-year.

7. Describe the physiographic and geologic setting of the central OCR and the landscape that is underlain by outcrops of the Tyee Formation.

The Oregon Coast Range is a humid, soil mantled landscape largely composed of Eocene sedimentary rocks that overlie volcanic basement accreted to the North American plate in the early Tertiary (Orr et al., 1992). Locally, basaltic dikes crop out within the Tyee Formation and tend to form prominent peaks (Walker and MacLeod, 1991). We developed our algorithm to identify deep-seated landslides occurring in Eocene sedimentary rocks, specifi cally the Tyee Formation, which is a sand-rich, delta-fed turbidite system (Heller and Dickinson, 1985) that covers a large portion of the central OCR (Fig. 1).

8. What is the age and depositional history / environment of the Tyee Formation. Describe the changes in sedimentary rock composition (facies) from north to south in the OCR outcrop belt.

Heller and Dickinson (1985) suggested that a sand-rich sequence of turbidite deposits that constitutes much of the Tyee Formation originated from a delta-fed submarine ramp depositional system. Sedimentologic properties within the early Eocene sedimentary system vary primarily with latitude, as the underlying crustal block has been rotated clockwise 40°–70° due to oblique subduction along the Pacifi c Northwest margin of North America (Heller and Ryberg, 1983).

North-south–oriented facies changes, which are characterized by depositional structures, bed thickness, and the sandstone:siltstone ratio, are the dominant source of lithologic variation within the Tyee Formation (Chan and Dott, 1986). In the south, deltaic and shallow continental shelf deposits have a high percentage of sandstone (>90%), cross-bedding, and thick (>3 m) beds. Moving north, bed thickness and the sandstone:siltstone ratio decrease as slope and proximal ramp sediments grade into distal ramp and ramp fringe sediments (Chan and Dott, 1983; Heller and Dickinson, 1985).

9. What is the tectonic and deformational history of the OCR. Cite the evidence that supports your answer.

Since the late Eocene, the Tyee Formation has been compressed into a series of low-amplitude, gently dipping folds (the maximum dip of bedding along the fl anks of folds rarely exceeds 15°–20°) oriented NNE (Fig. 2A) (Baldwin, 1956). Uplift of the OCR commenced in the Miocene (McNeill et al., 2000) and continues today as evidenced by abandoned wave-cut platforms along the Oregon coast (Kelsey et al.,

10. What are the ranges of rates of uplift in the OCR and coastal Oregon. Cite your sources of evidence.

Rates of rock uplift derived via dating of marine terraces adjacent to our study area (latitude ranging from 43°–45°) vary from 0.1–0.3 mm yr^{-1} (Kelsey et al., 1996) and are generally an order of magnitude lower than geodetic uplift rates derived from highway leveling and tide gauge data (Mitchell et al., 1994).

11. What are the measured short-term and long-term rates of erosion in the OCR. Cite your sources of evidence.

Erosion rates generated by short-term (~10 yr) and long-term (~5000 yr) analyses of sediment yield are commonly 0.05–0.3 mm yr^{-1} (Beschta, 1978; Reneau and Dietrich, 1991; Heimsath et al., 2001), consistent with rates of coastal uplift (Kelsey et al., 1996) and Holocene bedrock channel incision (Personius, 1995)

12. True of False: the rates of erosion greatly exceed the rate of uplift in the central OCR. Explain your answer.

These studies have been used to argue that an approximate balance exists between rock uplift and erosion in the OCR such that the topographic form may be relatively uniform with time.

13. What is the range of time that deep-seated landslide features persist on the landscape. How does this compare with shallow debris-flow features?

In contrast, deep-seated landslides produce topographic features that persist for 10–100 k.y., and temporal patterns of sediment production associated with these large failures are unconstrained.

14. What does radiocarbon age dating indicated about the timing of landslide events in the central Oregon Coast Range?

Based on radiocarbon data, the ages of two large lakes, Triangle and Loon, were estimated at >40,000 and 1400 yr, respectively (Baldwin, 1958; Worona and Whitlock, 1995).

15. List the data sources that were used by the authors to analyze the distribution and occurrence of landslide features in the OCR.

The topographic signature of deep-seated slope failure is immediately apparent via inspection of aerial photos and topographic maps. To streamline the mapping process, we formulated a quantitative method for delineating landslidedominated terrain from DEM data. For

16. What effects to igneous intrusive rocks have on landscape resistance to erosion and relief in the OCR?

Small voids in the clipped topography (shown with the letter "I" superimposed) represent igneous intrusive rocks that are more resistant to erosion than the Tyee Formation and tend to be associated with large knickpoints in river profiles. Although we removed topography associated with bedrock other than the Tyee Formation in our analyses,these highly resistant dikes appear to regulate valley incision within Tyee-underlain slopes that flank the intrusions. Adjacent channels are anomalously steep as they connect to headwaters atop the resistant dikes, and small-scale (and thus unmapped) features often form knickpoints and contribute to steepening of channel profiles

17. Using 3 to 4 sentences, briefly describe the methodology and analysis used by the authors to conduct their study.

We used spatial averaging in applying the topographic signature of deep-seated landslides to the DEM of our study area. First, we identified every grid node within the DEM having gradient and curvature values that fall within our deep-seated morphologic criteria. The resulting binary grid (values of either 0 or 1, with 1 indicating inclusion in the deep-seated topographic envelope) revealed a speckled pattern in some

18. Describe the results of the analysis in the context of landslide occurrence and character, in the northern vs. southern Tyee outcrop belt in the OCR. What are the primary geologic / bedrock factors that appear to control the distributions of landslides in the region.

Our analysis reveals systematic latitudinal variation in deep-seated landsliding, as ® values tend to be relatively low in the south and increase to the north (Fig. 8). This pattern may refl ect facies variability within the Tyee Formation (Chan and Dott, 1983; Heller and Dickinson, 1985). In the southern region, landslides comprise 5%–10% of the landscape, whereas for latitudes greater than 44°, the proportion of slide-prone terrain consistently exceeds 15%–20% (Fig. 8A). This relatively discrete transition corresponds with a significant change in the sandstone:siltstone ratio (from 9:1–6:4) and a shift from proximal to distal ramp facies. The overall pattern shown in Figure 8A does not result from variation in structural controls as the orientation of bedrock does not vary systematically with latitude (see below). Instead, the high proportion of slide-dominated slopes north of 44° latitude may reflect greater availability of low-shear-strength siltstone beds, which comprise 40%–50% of the bedrock and frequently exhibit thicknesses greater than 1 m (Heller and Dickinson, 1985).

19. Describe how fold deformation of strata and dip angle influences the occurrence of deep-seated landslides in the OCR.

Landsliding in sedimentary units is frequently controlled by bedrock orientation as depositional interfaces exhibit low shear strength that facilitates slope deformation. Considering the series of low-amplitude folds in the Tyee Formation, how does the deformation pattern influence the distribution of deep-seated landslides? One might expect landslide-prone terrain to be pervasive in zones with steeply dipping bedrock.

The distribution of landslides in the Tyee Formation is consistent with bedrock orientation. On the western part of the area depicted in Figure 7, landslides are predominantly directed to the southwest, coincident with the bedrock dip associated with the plunging anticline that trends SSE. On the eastern side of the anticline, the aspect of failure-dominated slopes is southeast, confi rming the correspondence between dip direction and landslide slope aspect (Fig. 7). Locally, bedrock dip and the downslope aspect of slide-prone slopes exhibit similar orientations

20. Discuss the potential significance of rainfall patterns and seismicity in controlling landslide occurrence in the OCR>

Historical rainfall events have occasionally been suffi cient to reactivate older slides, but the relative importance of valley incision, hydrologic events, or seismic activity in initiating new failures remains to be explored. The location of the OCR above an active subduction zone suggests that infrequent, large-magnitude earthquakes (Atwater et al., 1991; Nelson et al., 1995) may have contributed to landslide initiation, but the lack of historical observations makes this hypothesis difficult to test. Coseismic landslides of similar scale have been documented for recent seismic events (King et al., 1987; Martinez et al., 1995; Schuster et al., 1998; Guzzetti et al., 2002; Khazai et al., 2004). Establishment of a highresolution landslide chronology record via lake cores or internal slump ponds may reveal the synchronicity of failure events.

21. Using key figures provided in the article, draw a sketch from north to south in the OCR Tyee Formation outcrop belt, illustrating the effects of bedrock composition and lithofacies, on the style and occurrence of landslides in the Coast Range. Label your drawing and provide a brief explanation.

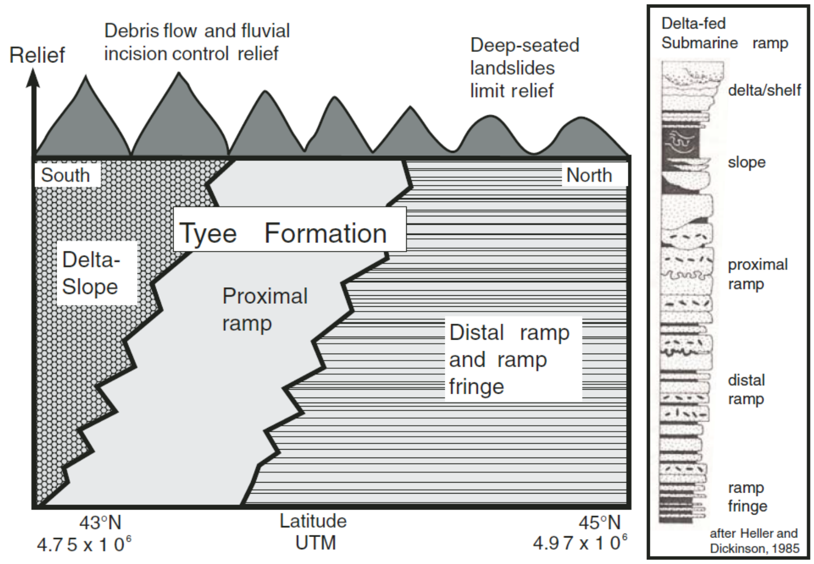

Figure 12. Schematic illustration of the topographic manifestation of sedimentary facies of

The fraction of terrain affected by deep-seated landsliding varies from 5%–25% as a function of bedrock structure and lithologic variations. The frequency and thickness of lowshear- strength siltstone beds in the sand-rich deltaic-turbidite deposits of the Tyee Formation increase to the north, coincident with a systematic increase in the fraction of terrain dominated by deep-seated landsliding. The fraction of slide-prone terrain increases proportionally with bedrock dip angle and in the northern region of our study area, where nearly 30% of the landscapes exhibit the signature of deep-seated landsliding. Local relief declines correspondingly, implying that deep-seated landsliding imparts a fi rst-order control on landscape development