Geomorphologic observations of rivers in the Oregon Coast Range from a regional reconnaissance perspective

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ABSTRACT


Changes in long profile, gradient, gradient index, pseudo-hypsometric integral, valley incision, and sinuosity fractional dimension for rivers in western Oregon were studied to determine their usefulness in assessing an hypothesis of differential uplift within the Coast Range. All data were gathered from topographic quadrangles and geologic maps, and so the results of this paper are limited to the description of river forms with only limited interpretations. Rivers were naturally divided into three groups, those in the western Coast Range, the eastern Coast Range, and the Klamath and Cascade Ranges, and differences in river morphometry were generalized. Rivers in the western Coast Range had more divergent characteristics, whereas those in the other groups were more similar within each group. For example, long profiles of western Coast Range rivers had diverse forms, but in the other groups, long profiles were similar within the group. Pseudo-hypsometric integrals had a wide scatter in the western Coast Range, but in the other ranges, the pseudo-hypsometric integral was more narrowly defined. Valley entrenchment and high sinuosity were common in the western Coast Range, and were less visible in the eastern Coast Range.

These regional generalizations do not hold for the central Coast Range near 44.5°N where the Yaquina and Marys Rivers are located. In the eastern Coast Range, the Marys River is unique in that it has a convex bulge in its long profile, does not have an increasing valley-floor width to valley height ratio downstream, and has a high sinuosity fractal dimension. In the western Coast Range, the Yaquina River is unique in that it has a smoothly decreasing long profile, has a very low pseudo-hypsometric integral, and does not have a decreasing valley-floor width to valley height ratio downstream. There may be many explanations for these observations, but these observations are also consistent with tectonic interpretations that the central western Coast Range is the locus of synclinal tilting and that the entire Oregon coast is experiencing landward tilting and uplift.

Introduction

A question of fundamental importance to earthquake hazards research in the Pacific northwest is whether the currently active subduction of the Pacific plate beneath the North American plate can produce great earthquakes (Adams, 1984; Heaton and Kanamori, 1984; Riddihough, 1984; Weaver and Michaelson, 1985; Atwater, 1987; Spence, 1988) (Fig. 1).

Many methods for investigating the present amount of subduction are being used, for example, geodetic surveys along coastal Oregon, correlation of river-terrace sequences, and stratigraphic analyses of cores from salt-marsh estuaries (see Hays, 1988, 1989). This paper presents the results of examining some aspects of river morphometry in western Oregon to better understand the geologically recent history of Pacific-plate subduction (Fig. 2).

Regional analyses of drainage-basin and river-valley morphology have helped define differential uplift in many tectonically active
regions. For example, Bull and McFadden (1977) showed that differences in amount of river entrenchment north and south of the Garlock Fault in southern California reflected differences in uplift. Seeber and Gornitz (1982) used differences in stream profiles to identify regions in the Himalayas that had different rates of uplift. Maclean (1985) and Mayer (1985) used differences in valley morphology and river long profiles to help identify segmentation of the Wasatch fault zone. More recently, McKeown et al. (1988) interpreted varying amounts of regional uplift in northeast Arkansas from variations in the pseudo-hypsometric integral. Wells et al. (1988) applied methods of geomorphic analysis developed in arid and semi-arid regions to a humid tropical region and were able to identify spatially varying uplift in a region of plate convergence. Most recently, Merritts and Vincent (1989) showed that relative rates of uplift could be determined from analysis of river gradients in the vicinity of Cape Mendicino, California.

This paper presents the analyses of river longitudinal profiles, river gradient changes, val-
Geomorphic Observations of Rivers in the Oregon Coast Range

Ley morphology, and spatial sinuosity in western Oregon toward a goal of identifying areas of differential uplift in the Oregon Coast Range. All the data presented come from examination of topographic quadrangles and geologic maps. Consideration of other hydrologic variables was not feasible, nor was additional field work. These restrictions limit the interpretations of the data. The size, geology, and climate in the area under study vary more than in many other studies, including those cited previously. Rivers examined in this study are third- or higher-order and typically over 100 km long, whereas most other researchers studied first- or second-order streams or sections of rivers less than 25 km long. No active surface faults are known in the Oregon Coast Range because vegetation is dense and few studies have been done, whereas other investigations typically have been in areas of known tectonic activity. Two relatively new geomorphic parameters, the pseudo-hypsometric integral (McKeown et al., 1988) and sinuosity fractal dimension (Snow, 1989) were examined in this study, in addition to the longitudinal profile and stream gradient.

Geology of study area

The interpretation of the river morphology in western Oregon is assisted by an awareness of the distribution of rock types in the region. A sharp change in river gradient can be important because it may occur over a region of uplift, but it could also result from flow across a lithologic boundary or an inactive fault.

Plate convergence over the last 10 m.y. between the Juan de Fuca and North American plates (Magill and Cox, 1980; Riddihough, 1984; Spence, 1988) has left a complex sequence of overlapping rocks in western Oregon (Neim and Neim, 1984). These rocks differ greatly in erodibility. The Klamath Range consists of accreted marine sediments and volcanic rocks of Mesozoic age, whereas the Coast Range consists of accreted oceanic crust, marine basin deposits, and volcanics, all of Tertiary age. The Cascade Range is covered almost exclusively by Quaternary volcanics, and the Willamette Valley includes Tertiary marine sediments and volcanics, deposited both in subaerial and subaqueous environments. The degree of resistance to erosion varies among and between the volcanic and sedimentary rocks, partially depending on the amount of interbedding between them. Throughout the whole western region, mafic intrusions of varying sizes are common.

The only consistent morphological response to lithology was that river gradients steepen across the mafic rocks. The region of the high gradient was coincident with the region of exposed mafic rocks whether the exposure was 300 or 3000 m across. No other consistent association between river behavior and lithology was found (see discussion in “Long Profiles” section).

Geomorphic indicators of uplift

By far the most commonly used technique to identify river response to tectonics is analysis of the longitudinal profile, which is a graph of the relationship between river elevation and river length (Fig. 3). Leopold and Langbein (1962) discuss the theoretical end members of profile evolution, from least-work to equally distributed work. On the theoretical river with the steeply concave least-work profile, energy loss is exactly proportional to elevation loss, and other factors that influence slope, such as

* A note about scale: Many authors have decided to normalize long profiles by graphing vertical and horizontal scales at 100% elevation versus 100% length, omitting size of the river, as represented by length, from consideration. I do not agree with this practice, and yet I also recognize its merits—scale independent patterns are further evidence of the ongoing process. I have, instead, chosen a large enough vertical exaggeration to emulate the normalized profile but have retained the actual elevation and length scales to demonstrate relative size of the rivers studied.
discharge, rock type, grain size, bedload, etc., are not considered. On the theoretical river with the almost linear equally distributed work profile, energy loss is exactly uniform downstream, because increasing discharge (energy) is exactly proportional to increasing surface area (work). Theory being what it is, the authors admit that most rivers fall between these extremes, and Snow and Slingerland (1987) have theoretically shown that perturbations in
the long profile are expected as a result of discontinuities in discharge and sediment load, for example. The least-work profile is thought to be more common in humid regions (Bloom, 1978), and from this investigation, appears to be common in areas that have experienced high uplift and tilting.

Analysis of the long profile leads to other calculations, including gradient, gradient index, and the pseudo-hypsometric integral (PHI) (Fig. 4). Gradient and gradient index are most commonly used to measure river slope, and can be used to define relative differences in uplift (Merritts and Vincent, 1989) and erosion (Hack, 1973). River slopes used here are obtained from measurements on topographic maps and are, therefore, greater than true (thalweg) slope. (Sinuosity is generalized on topographic maps and therefore map length will always be less than true length. Since slope is proportional to 1/length, slopes determined from topographic maps will be greater than true slopes.) Gradient, or slope, is the elevation change over a distance and is useful for comparing slope changes over similar nearby lengths. Gradient index is the elevation change over a logarithmically normalized distance and is more useful for comparing slopes over greater distances and on different rivers. It is also more useful for highlighting gradient changes. PHI is a numerical means to describe the overall shape of the long profile. PHI reflects the relative amount of deformation and/or degradation that has occurred on each river. Comparisons between long profiles are more easily made using PHI because bias introduced by scale and vertical exaggeration in figures is removed.

Valley incision is another measure that can be used to define relative uplift (Bull and McFadden, 1977; Ouchi, 1985). Cross-valley profiles were constructed from topographic maps. Valley-floor width was estimated from the distance between abrupt slope increases adjacent to the river and valley height was estimated from the elevation between the river and the average elevation of the most pronounced slope decreases (ridge top) on either side of the river. A high valley-floor width to valley-height ratio (seen in a broad valley) is associated with a tectonic quiescence because lateral erosion has had time to occur. Conversely, a low valley-floor width to valley-height ratio (seen in a steep, narrow valley) is associated with recent tectonic movement (Maclean, 1985; Mayer, 1985). A steep and narrow valley profile may have many generative causes, but could be an indication of recent uplift.

Along with downcutting or deposition, a river may respond to uplift by changing channel patterns, such as by increasing sinuosity, or by changing channel pattern to straight or braided (Schumm, 1963; Burnett and Schumm, 1983; Ouchi, 1985). Spatially increased meandering on western Coast Range rivers can be seen on topographic maps, but sinuosity cannot be calculated because the rivers are entrenched and it is not possible to measure the "valley" length without bias (Schumm, 1963). In Schumm's (1963) pa-

![Fig. 4. Equations used to calculate pseudo-hypsometric integral (PHI), gradient (grad.), and gradient index (index). PHI is calculated for the whole river from the area under the profile (Ap) and the area of the rectangle defined by height and length (Ar). Gradient and gradient index are calculated for each elevation change, \( h_1 - h_2 \), over the corresponding change in length, \( l_1 - l_2 \). An average gradient and gradient index are also calculated for the whole river.](image-url)
per, the river "valley" is defined as a broad plain through which the river course varies over time. A river meandering through its floodplain is a typical example. A different parameter, sinuosity fractal dimension, can be used to numerically characterize the amount of river meandering when no floodplain is evident: a higher fractal dimension indicates a more sinuous course and a lower fractal dimension indicates a less sinuous course (Snow, 1989). Fractal sinuosity can be thought of as a measurement of the degree of river curvature, which is independent of "valley" length.

Sinuosity fractal dimension was calculated for western Oregon rivers by computerized calculation of length using progressively increasing "ruler" length, in this case from 500 to 10,000 m (see Snow, 1989, for a complete description of this method). Using a short ruler generates a more precise, and therefore longer calculation of length, whereas using a long ruler generates a more general, and therefore shorter calculation of length. Limiting values for the short and long ruler lengths exist (see Fig. 5), but between these a linear relationship exists between the calculated lengths and the ruler lengths. The slope of the linear relationship is mathematically related to fractal dimension. On the average, ruler lengths smaller than 500 m did not change the measure of river length; similarly ruler lengths greater than 10,000 m did not change the measure of river length (Fig. 5). Sinuosity fractal dimensions were calculated from the slope of linear regressions, which mostly had $R^2$ values between 90 and 98%.

Other morphological parameters, used in other investigations of Quaternary uplift, were considered in this study. Maclean (1985) found drainage density and drainage area only minimally useful toward identifying differential uplift in the Wasatch Fault Zone. Merritts and Vincent (1989) also found that drainage density and area, as well as river length and river relief, were less useful in identifying uplift rates near Cape Mendocino. Therefore, some

![Graph](image)

**Fig. 5.** Sample of calculation for the sinuosity fractal dimension. Length of the ruler used to measure river length is plotted on the vertical scale and the corresponding river length is plotted on the horizontal scale. Asymptotic values at the low and high ends of the graph show the limits of short ruler and long ruler measurements. The slope of the intermediate values is related to fractal sinuosity by $1 - (1/slope)$.

of these measurements are reported for descriptive purposes only (Table 1).

**Long profiles and related variables**

Long profiles of the main tributaries of western Oregon rivers are typically steeply concave, approaching Leopold and Langbein's (1962) least-work profile. The regional reconnaissance nature of this study requires that I ignore the influences of localized variations in a bedrock formation, grain size, and bedload, which significantly influence the local river slope (less than 25 km) and concentrate on differences observed over 50 to 100 km. Since my goal is to make regional comparisons of river shapes, I must presume that at the scale of my perspective (1,500,000 and smaller), the local variations are invisible. However, significant differences between bedrock lithologies must still be considered.

Although there is a general similarity in river
<table>
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<th>Slope (m/km)</th>
<th>Gradient index</th>
<th>PHI² (%)</th>
<th>SFD³</th>
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¹Highest elevation.
²Pseudo-Hypsometric Integral.
³Sinuosity Fractal Dimensions.
long profile shape, there are differences among profiles within the different mountain ranges. These differences may reflect differences in tectonic geomorphology that were previously unnoticed. Four regions in western Oregon were initially outlined based on drainage direction and area. These were the western Coast Range, the eastern Coast Range, the Klamath Range, and the Cascade Range (Fig. 1). The last two regions were combined because of similar patterns in long profiles, sinuosity fractal dimension, gradient index, and valley shape.

Separating the rivers into their naturally defined geographical groups revealed differences in several parameters, PHI for one (Table 1, Fig. 6). Ranges of PHI overlap for each of the three regional groups, but the mean for the eastern Coast Range is distinct from the mean for the Klamath and Cascade Ranges at a significance level less than 0.01% using the two-sample t-test. Observation of the eastern Coast Range river profiles confirms that they have greater concavity than the Klamath and Cascade Range river profiles (Fig. 3). There is no statistical difference in PHI between rivers in the western Coast Range and any other region mostly because, unlike other regions, the PHI mean in the western Coast Range has a large standard deviation.

Lithologic differences between the western Coast Range and the other areas do not explain the differences in PHI. PHI for rivers in

![Graph](image_url)

Fig. 6. Comparison of pseudo-hypsometric integral (PHI), sinuosity fractal dimension (SFD), and average gradient index by region. The mean and standard deviation of each group are plotted by a circle with a vertical bar showing the limits of one standard deviation. The scatter in PHI for WCR is clearly shown, as are the small standard deviations for ECR and KCR. For SFD, the bar on one point (marked by an X) in WCR shows the range of SFD for Siuslaw. Again, the scatter of SFD for the WCR is observed, but also there is slightly higher SFD for the WCR than for ECR or KCR. Gradient index is generally higher in the KCR.
the Cascade Ranges and the Klamath Ranges are very similar although the Cascade Ranges consist of primarily late Cenozoic and Quaternary volcanic rocks and the Klamath Range is a complex of Mesozoic sedimentary and volcanic rocks. Even though the Coast Range is the most lithologically variable region consisting of sediments, volcanics, and accreted oceanic crust, the PHI for the eastern Coast Range has the smallest standard deviation and the PHI for the western Coast Range has the largest.

The observed differences in the range of PHI on either side of the Coast Range could be related to complex tilting in the Coast Range. Reillinger and Adams (1982), and more recently, Yeats (1989), have found evidence from repeated leveling surveys of eastward tilting and uplift of the Coast Range. Yeats (1989) also interprets northward tilting of the southern coast and southward tilting of the north coast. In the eastern Coast Range, general eastward tilting could have the effect of steepening the upper reaches of rivers while lowering their base levels downstream (Fig. 7). If aggradation in the lower reaches occurs more rapidly than incision in the upper reaches, the PHI would be lowered. In the western Coast Range, general eastward tilting combined with synclinal tilting on the coast could have a highly variable effect: variable gradients are observed for all but two rivers in the western Coast Range. These two rivers, the Yaquina and the Siletz, have the minimum PHI’s for the western Coast Range, and are located where the proposed northward and southward tilting converge.

Highly variable gradient index is typical of the western Coast Range rivers (Fig. 8), a pattern Merritts and Vincent (1989) found to occur in areas experiencing an intermediate rate of uplift near Cape Mendicino, California. Highly variable gradient indices could also be caused by changes in lithology or bedload. Since this is a regional reconnaissance study, consideration of bedload changes caused by something other than lithology will have to be deferred to another study. However, in this study, several observations discount the role lithology has on the gradient index:

1) Nehalem River’s (western Coast Range) gradient index oscillates from 38 to 142 near the headwaters and from 56 to 340 toward the mouth (Fig. 8a). These changes occur in conjunction with major changes in bedrock: the lower range correlates with highly erodable marine sediments and the higher range correlates with highly resistant volcanics (Beaulieu, 1973; Neim and Neim, 1985). In this case, changes in lithology correlate with gradient index changes.

2) West Fork Dairy River’s (eastern Coast Range) gradient index smoothly declines from over 200 near the source to less than 20 near its junction with the Willamette River (Fig. 8b), even though the bedrock ranges from marine sediments to resistant volcanics to Quaternary alluvium. In the same highly erodable marine sedimentary bedrock where the Nehalem River has a low gradient index, the West Fork Dairy has its highest gradient index (Wells and Peck, 1961). In this case, even though the same lithologic changes occur in the vicinity of the West Fork Dairy River that were

![Fig. 7. Cartoon exaggerating the proposed eastward tilting of the Coast Range. Arrows indicate changes in ground elevation relative to the untilted terrain. After tilting, west flowing rivers would have lower gradient and, therefore, incision would be expected. Elevated river terraces might also be observed on west flowing rivers. After tilting, east flowing rivers would have higher gradient and, therefore, river aggradation would be expected. Flooded, submerged river mouths might also be observed on east flowing rivers.](image-url)
Fig. 8. Gradient indices for sampled rivers. Gradient indices were calculated for all river data, but only samples are shown here. “Smooth” profiles have generally declining gradient indices while profiles with convex regions have variable gradient indices. Because gradient index is calculated at every topographic contour and is sensitive to small changes, extremes in single values must be downweighted. The single-value pulses in the Yaquina and Coos Rivers' profiles are not strong evidence for highly variable gradient index as are the broad zones of high and fluctuating gradient indices for the Nehalem, Smith, Siuslaw, and Marys Rivers.
observed near the Nehalem River, the same correlation between lithology and gradient index is not evident.

(3) The Siuslaw and Smith Rivers (western Coast Range) have highly variable gradient indices (Fig. 8c), and the bedrock in both river valleys is almost entirely Tertiary marine sediments (Baldwin, 1956; Ramp, 1972). Both rivers have broad convex slopes in their middle reaches, and, as will be discussed later, both rivers are entrenched and have a high fractal sinuosity in the middle reach. In this case, there is no variance in lithology, from the regional perspective, to explain the variations in gradient index.

From these examples, the relevance of lithologic control on the highly variable gradient indices in the western Coast Range is questionable at best.

The patterns in the river profile and gradient index for the Siletz and Yaquina Rivers in the western Coast Range, and the Marys and Luckiamute Rivers in the eastern Coast Range, are opposite to the patterns previously described for each of those ranges (Figs. 8d and 8e). The western Coast Range rivers were typified by variable PHI's, variable gradient index, and variable long profiles while the eastern Coast Range rivers were typified by smoothly declining profiles and gradient indices and low PHI's. However in this case, the Siletz and Yaquina Rivers have the lowest PHI's in the western Coast Range—similar to ones in the eastern Coast Range—and the Marys and Luckiamute Rivers have medium-high PHI's. The Siletz and Yaquina Rivers have generally declining gradient indices while the Marys and Luckiamute Rivers have variable gradient indices, marked by convex zones in their long profiles (Fig. 3). The area defined by these rivers coincides with the area where Yeats (1989) postulates the convergence of northward and southward tilting in the also eastward tilting Coast Range and also where the Coast Range drainage divide is the lowest and narrowest. This complex tilting may be the source of deformation that has produced the complex shape of these rivers. Snavely et al. (1976b) also reported a series of northwest-oriented faults near the Yaquina, with motion up to the northeast, that may be related to the concentration of deformation there.

The Alsea River, also between the Nehalem and Siuslaw Rivers, has a slightly irregular long profile. The short-length convexities in its long profile coincide very closely with exposure of mafic intrusives (Wells and Peck, 1961; Snavely et al., 1976c).

Profiles for rivers in the Klamath Mountains are generally smooth, even though knickpoints and convex reaches are present. The convex reaches observable on the profiles of the Umpqua and Rogue Rivers are due to dams and edges of volcanic flows. These rivers are the only ones studied with lengths greater than 200 km and have the largest watersheds in western Oregon (excluding the Willamette River). Their profiles do not show evidence supporting or contradicting the possibility of uplift in southern Oregon. This observation supports Merritts' and Vincent's (1989) conclusion that the gradients of higher order streams are not generally useful for illustrating recent tectonic movement.

Profiles for several smaller rivers in the Klamath Range are not distinctive enough to allow speculation about possible tectonic control (Fig. 3). All approximate the least-work profile (Leopold and Langbein, 1962) and flow on similar bedrock (Baldwin, 1974; Beaulieu, 1973; Wells and Peck, 1961). A step in the South Fork Coquille River's profile near the source is coincident with an abrupt change in river course, and with the crossing of a large syncline (Baldwin and Beaulieu, 1973; Wells and Peck, 1961). A similar step in the Coquille River's profile is coincident with the same syncline (Baldwin and Beaulieu, 1973; Wells and Peck, 1961). Whether these steps indicate active motion on the syncline is unknown, and they may deserve further investigation. Pro-
files of the other small rivers examined, the Coos, Elk, Illinois, and South Fork Illinois Rivers, do not contain any slope or gradient index anomalies.

Comparing long profiles and gradient indices for the the eastern Coast Range and Cascade Range shows that rivers in both ranges, except the Marys River, have generally smooth profiles although the Cascade Range rivers are more steep overall than eastern Coast Range rivers (Fig. 3). The greater steepness in the Cascade Range shows up in higher values for the gradient index there (Table 1, Fig. 6).

Valley development and sinuosity fractal dimension

River valley development in the western Coast Range is different from that in either the eastern Coast Range or the Klamath and Cascade Ranges (Fig. 9). Valley heads in the eastern Coast Range and the Klamath and Cascade Ranges are narrow and deep, and have low valley-floor width ($V_{fw}$) to valley height ($V_{ht}$) ratios that progress to wide and shallow valleys downstream (higher $V_{fw}/V_{ht}$ ratios; for examples see Figs. 9e and 9f). This downstream valley widening (increasing $V_{fw}/V_{ht}$ downstream) is common for mountain streams. However, in the western Coast Range, decreasing $V_{fw}/V_{ht}$ ratios are observed in a downstream direction: valley heads are wider and shallower than valleys downstream, which are narrower and deeper (Figs. 9a–c). The only western Coast Range river that does not have

Fig. 9. Valley cross-sections at elevations indicated for some rivers in the western Coast Range (a–d), the eastern Coast Range (e), and the Klamath and Cascade Ranges (f). Note that valley-floor width is smaller and valley height greater for areas close to the source in the eastern Coast Range and Klamath and Cascade Ranges than they are for areas close to the source in the western Coast Range. Also, valleys broaden and shallow downstream for rivers in the eastern Coast Range and Klamath and Cascade Ranges, but this is not consistent for rivers in the western Coast Range. The exception to this observation is the Yaquina River, which has already been shown to have a form different from other western Coast Range rivers.
a decreasing $V_{rw}/V_{sh}$ ratio downstream is the Yaquina (Fig. 9d), which has also been shown to have a long profile, PHI, and gradient index that differ from other western Coast Range rivers. Maclean (1985) and Mayer (1985) demonstrated that the shape of river valleys can be related to uplift history, at least along a mountain front defined by a fault. They showed that mountainous valleys intersecting the Wasatch Fault in central Utah in regions that had more recent uplift also had lower $V_{rw}/V_{sh}$ ratios. The lower $V_{rw}/V_{sh}$ ratios observed in the western Coast Range may be indicative of more recent uplift and may also indicate that eastward tilting has occurred (see discussion of pseudo-hypsometric integral and Fig. 7).

Although significant lithologic differences exist in western Oregon and could be part of the explanation for different valley development, there are many contradictions. For example, the Nehalem River is entrenched where bedrock is basalt, but the West Fork Dairy River is not entrenched where the bedrock is basalt. The Nehalem River is not entrenched where bedrock is highly weathered sedimentary rock, but the Siuslaw and Smith are entrenched in sedimentary rock, even though the gradients are low in these places. The Yaquina River in the western Coast Range and several rivers in the eastern Coast Range are not entrenched even though they flow on the same sedimentary rock unit that the entrenched Siuslaw and Smith Rivers flow on. The Siletz River has a reach in sedimentary bedrock that is not entrenched, and another reach in sediments further downstream that is entrenched. These variations in valley development demonstrate that the lithologic control on the development of entrenched valleys is ambiguous at best, and therefore the variable valley development may be more directly related to variable uplift in western Oregon.

As many studies have shown, river responses to uplift includes both entrenching and increases in sinuosity, among other responses (Shepherd and Schumm, 1974; Bull and McFadden, 1977; Burnett and Schumm, 1983; Ouchi, 1985). Since spatial sinuosity cannot be unambiguously measured for entrenched rivers (see discussion in section on Geomorphic Indicators of Uplift, and Schumm, 1963), sinuosity fractal dimension (SFD) (Snow, 1989) was computed for rivers more than 50 km long. SFD was highest in the western Coast Range and re-emphasized differences between the western Coast Range rivers and the Marys River (in the eastern Coast Range) on the one hand and the eastern Coast Range, Klamath, and Cascade Range rivers on the other hand (Table 1, Fig. 5). In the central part of the western Coast Range, the Siletz, Yaquina, Alsea, Siuslaw, and Smith Rivers have the highest SFD’s of all rivers studied and are adjacent to one another. This coincidence may be related to the fact that all these rivers flow on the middle Eocene Tyee Formation, which consists of rhythmically bedded siltstone and sandstone (Baldwin, 1956; Wells and Peck, 1961; Snavely et al., 1976b, c). This formation may have greater susceptibility to erosion than other formations in the western Coast Range but, as demonstrated for valley development and for the shape of long profiles, lithologic control of river form is ambiguous. For example, on the Siuslaw River, sinuosity is observably different on three reaches and the SFD in these reaches varies from 1.22 in the first 50 km, to 1.38 in the next 70 km, to 1.19 in the last 45 km; bedrock for all three reaches is the Tyee Formation. Also, the Marys River in the eastern Coast Range has higher SFD than other rivers in the eastern Coast Range, even though its bedrock is not unique in the eastern Coast Range. Once again, there is no consistent relationship between lithology and the development of river form and other sources that shape river form must be considered.

Structural control on river development cannot be adequately investigated in a regional reconnaissance study, but some observations can be made. There are synclines mapped north and south of the Siuslaw River at the down-
stream end of the highly sinuous reach (Walker and Duncan, 1989; Wells and Peck, 1961; Baldwin, 1956) which may be related to the extreme measurements in SFD, gradient, and $V_{tw}/V_{ht}$ ratio that are observed in the middle reach of the Siuslaw River. However, on many other rivers changes in sinuosity are not observed even though synclines are close to or cross the river. Higher SFD's for the Siletz, Yaquina, and Smith Rivers also do not appear related to structural control (Snively et al., 1976a, b; Baldwin, 1956). Combined with the entrenching, gradient index, and long profile patterns, the high values for SFD in the western coast range point to an interpretation that more recent uplift has occurred in the western coast range than elsewhere in western Oregon.

Conclusions

This investigation of the river morphometry in western Oregon demonstrates that many ambiguities exist in the lithologic, structural, and tectonic control of river morphology and these ambiguities cannot be resolved in a regional reconnaissance study. Even so, observations from this study are relevant to interpretations of previous investigators that eastward tilting of the Coast Range is combined with southward tilting of the coast north of 44.5°N and northward tilting south of 44.5°N (e.g., Reilinger and Adams, 1982; Yeats, 1989). Differences in long profiles, gradient indices, sinuosities, and valley heights relative to valley widths, are consistent with an interpretation of differential uplift within the western Coast Range and between the western Coast Range and the rest of western Oregon.

Summarizing the observations: The western Coast Range rivers have a wide scatter in their pseudo-hypsometric integrals, which is consistent with variable conditions of uplift and erosion in the western Coast Range. The eastern Coast Range, and Klamath and Cascade Range Rivers have a narrow range in pseudo-hypsometric integrals, which is consistent with similar conditions of uplift and erosion in each area. Except for the Yaquina and Siletz Rivers, western Coast Range rivers have highly variable gradient indices, and except for the Marys and Luckiamute Rivers, eastern Coast Range rivers have steadily decreasing gradient indices in the downstream direction. Merritts and Vincent (1989) observed, on lower order streams than any I have studied, that variable gradient indices occurred in areas experiencing intermediate uplift rates and steadily declining gradient indices occurred in areas experiencing low uplift rates. Perhaps in the future, a similar conclusion will be drawn for western Oregon. Valley entrenchment is common in the western Coast Range, and is not common in the eastern Coast Range, which is consistent with an interpretation of greater uplift in the west than in the east. High gradients from headwaters to middle reaches of rivers and the lack of entrenchment in the eastern Coast Range is unusual and may be consistent with an interpretation that landward tilting and oversteepening of eastern Coast Range rivers has very recently occurred. The predominance of a high sinuosity fractal dimension for western Coast Range rivers, except for the Yaquina, and a low sinuosity fractal dimension for eastern Coast Range rivers, except for the Marys, is consistent with an interpretation that greater uplift has occurred in the west than in the east and that north–south coastal tilting is occurring along with landward tilting (Yeats, 1989).

Acknowledgements

“One consistent axiom associated with rivers is that what initially appears complex is even more so under further investigation” (Rosgen, 1989; p. 4).

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