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RESEARCH ARTICLE

Kev Points:

- Elevated, low-relief landscapes were formed in situ in the hinterland of Bhutan
- Landscape reconstructions suggest ~800 m of surface uplift in the hinterland
- Constraints from cosmogenic erosion rates show surface uplift started ~0.8-1 Ma

Supporting Information:

- Readme
- Table S1
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In situ development of high-elevation, low-relief landscapes via duplex deformation in the Eastern Himalayan hinterland, Bhutan

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Abstract Prior studies have proposed tectonic and climatic mechanisms to explain surface uplift throughout the Bhutan Himalaya. While the resulting enigmatic, low-relief landscapes, elevated above deeply incised canyons, are a popular setting to test ideas of interacting tectonic and climatic forces, when and why these landscapes formed is still debated. We test the idea that these landscapes were created by a spatially variable and recent increase in rock uplift rate associated with the formation of structural duplexes at depth. We utilize a new suite of erosion rates derived from detrital cosmogenic nuclide techniques, geomorphic observations, and a landscape evolution model to demonstrate the viability of this hypothesis. Low-relief landscapes in Bhutan are eroding at a rate of ~70 m/Ma, while basins from surrounding steep landscapes yield erosion rates of ~950 m/Ma, demonstrating that this portion of the range is in a transient period of increasing relief. Applying insights from our erosion rates, we explore the influence of an active duplex on overlying topography using a landscape evolution model by imposing a high rock uplift rate in the middle of a mountain range. Our simulations show that low-relief landscapes with thick alluvial fills form upstream of convex knickpoints as rivers adjust to higher uplift rates downstream, a pattern consistent with geologic, geomorphic, and thermochronometric data from Bhutan. With our new erosion rates, reconstructed paleo-river profiles, and landscape evolution simulations, we show that the low-relief landscapes were formed in situ as they were uplifted ~800 m in the past ~0.8-1 Ma.

1. Introduction

The pattern of mean elevation and local relief within a mountain belt is influenced by spatial and temporal changes in rock uplift rates, the length of transverse tributaries, changes in fluvial dynamics, glacial incision, and spatial patterns of precipitation and rock strength [Whipple et al., 1999; Whipple, 2004]. The profile of the eastern Himalaya in Bhutan deviates significantly from the classic profile of the central Himalaya in Nepal, where the lower Himalaya (or foothills) transition to the higher Himalaya (or hinterland) (Figure 1a). Bhutan is generally characterized by a steeply rising mountain front and no abrupt foothills-hinterland topographic transition; instead, isolated, low-relief, high-elevation landscapes in the hinterland interrupt the broader topographic taper (Figure 1a) [Duncan et al., 2003; Baillie and Norbu, 2004; Grujic et al., 2006; Adams et al., 2013, 2015]. Because the elevation drop on rivers sets most of the relief in mountain ranges [Whipple et al., 1999], the differences between the mean topography of the Nepal and Bhutan Himalaya are also clearly expressed in the longitudinal profiles of transverse rivers (Figure 1b).

Two primary hypotheses exist for the formation of the enigmatic topography of the Bhutan Himalaya. In the first, surface uplift of low-relief landscapes was caused by a reduction in erosivity, with no change in rock uplift rate, due to a reduction in precipitation rates [Grujic et al., 2006]. In the second, surface uplift of low-relief landscapes was triggered by an increase in rock uplift rate [e.g., Duncan et al., 2003; Baillie and Norbu, 2004]. In either case, the presence of high-elevation, low-relief landscapes suggests that landscape adjustment is still in progress, and as knickpoints migrate upstream, local relief will increase and thus eventually increase erosion rates and topographic relief. Interpretation of geochronometric and thermochronometric data suggests that long-term erosion rates and the topography in this portion of the range have been declining since the late Miocene, possibly due to the initiation of new shortening structures in the Shillong Plateau of India to the south that accommodate some of the still-continuing convergence between India and Eurasia [Coutand et al., 2014; Adams et al., 2015] or deformation of the Tibetan Plateau to the north [Long et al., 2012; McQuarrie et al., 2014].

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Figure 1. (a) Thirty kilometer wide swath profiles, perpendicular to the strike of the Himalayan range, from central Bhutan and central Nepal (see Figure 2 for locations). Thick lines denote mean elevations and surrounding gray envelopes represent 2 standard deviations about the mean. White dots mark the Physiographic Transition 2 in Nepal and Bhutan. (b) Longitudinal profiles of Himalayan river systems (exclusive of the Tibetan Plateau) within the swath profiles from Figure 1a. The solid black line shows the form of the Chamkhar Chu (CH; Figure 2b) and its tributaries that drain the Bumthang surface of central Bhutan (BS; Figure 2b). The dashed black line shows the form of Nepal. A black dot marks the major convex knickpoint in Bhutan. Note that high glacial peaks are roughly coincident with this knickpoint. White dots mark the concave knickpoints associated with Physiographic Transition 2 in Nepal and Bhutan.

These apparently contradictory hypotheses for the erosional evolution of the Bhutanese sector of the Himalayan orogenic wedge might be reconciled. For instance, if the chronometric data provide evidence for a late Miocene-Pliocene reduction in the thickening of the wedge [Adams et al., 2015], while the geomorphic data provide evidence for a more recent reinvigoration. Thus, geomorphic observation and theory can span the temporal gap between the thermochronometric data and modern day observations. Here we explore this possibility using a combination of methods that builds on thermochronometric constraints on Miocene-Pliocene wedge evolution.

We develop a new conceptual model for the formation of high-elevation, lowrelief surfaces in the hinterland of Bhutan from geologic observations, analysis of landforms, and a new detrital cosmogenic radionuclide (CRN) erosion rate data set. We test and illustrate the viability of this conceptual model in simulations using a landscape evolution model [Tucker et al., 2001]. These simulations allow us to develop a strategy to reconstruct paleo-river profiles to calculate the magnitude of surface uplift, which in combination with the detrital CRN erosion rate data allow us to constrain the timing of surface uplift. Given the diversity of approaches required, this paper is organized thematically rather than in a standard method-

result-discussion format. After outlining the tectonic setting and context of this study, methods, results and pertinent discussion are incorporated into each thematic section, organized into the following logical progression: (1) morphologic and geologic characterization of the enigmatic high-elevation, low-relief surfaces; (2) description of plausible tectonic models and their diagnostic differences; (3) determination of the spatial pattern of erosion rates (a key diagnostic); (4) hypothesis testing with landscape evolution modeling; (5) determination of the magnitude and timing of surface uplift; and (6) synthesis and discussion.

2. Tectonic Setting

The structural architecture of the Bhutan Himalaya is one of nested tectonostratigraphic packages separated by three major south vergent thrust systems [*Heim and Gansser*, 1939; *Gansser*, 1983]; from the south to north, these are the Main Frontal thrust (MFT), Main Boundary thrust (MBT), and Main Central thrust (MCT) systems (Figure 2a). The active MFT system, which places unmetamorphosed foreland molasse sediments on top of young fluvial sediments and units of the stable Indian craton, is thought to be younger than 5 Ma [*Long et al.*, 2012]. The MBT system, plausibly having a slip history spanning ~10 to 3 Ma [*Long et al.*, 2012], has carried lower amphibolite facies to unmetamorphosed rocks of the Lesser Himalayan sequence over the molasse sequence in the MFT hanging wall. The structurally higher MCT system carries upper amphibolite



Figure 2. Geography, geology, and geomorphology of Bhutan. (a) Elevation map from 30 m Advanced Spaceborne Thermal Emission Radiometer data. White lines denote the political boarders. Red and white dots mark the locations of the photos in Figures 4 and 5. Magenta box denotes the swath area of data in Figure 1. Red dotted line on inset map is the location of the Nepal swath in Figure 1a. Blue polygons are modern glaciers [*Raup et al.*, 2007]. MFT, Main Frontal thrust system; MBT, Main Boundary thrust system; Main Central thrust system; KT, Kakhtang thrust; STF, South Tibetan fault system; PW, Paro Window; JF, Jomolhari fault system; LF, Lhuentse fault. (b) Local-relief calculated as the range of elevations within a 5 km radius, moving window. The river channels are colored by channel steepness values (see text for description). Green lines mark the location of Physiographic Transition 2. White lines show the extent of the low-relief landscapes. Magenta lines highlight the high, glaciated terrains south of the range crest. Surface names are shown in black: TS, Thimpu surface; PS, Phobjikha surface; BS, Bumthang surface; YS, Yarab surface. River names are shown in white: WA, Wang Chu, PT, Puna Tsang Chu, KI, Kissna Chu, MA, Mangde Chu, CH, Chamkhar Chu, KR, Kuri Chu, SH, Sheri Chu, KL, Kulong Chu. White arrows mark the river reaches north of the low-relief landscapes that were used for profile reconstructions.

to granulite facies units of the Greater Himalayan sequence in its hanging wall. Various researchers have estimated a slip history for this system that began at least 23 Ma and continued until ~10 Ma [*Chambers et al.*, 2011; *Tobgay et al.*, 2012; *Stüwe and Foster*, 2001; *Daniel et al.*, 2003]. In general, the developmental sequence of the MCT, MBT, and MFT systems implies southward propagation of the locus of major thrusting—toward the orogenic foreland—with time, as predicted by the canonical model of orogenic wedge development [e.g., *Davis et al.*, 1983].

However, there are a few known structures that add complexity to the orogenic history of Bhutan. One complication is the Kakhtang thrust [e.g., Grujic et al., 1996], which is located within the Greater Himalayan sequence and strikes broadly subparallel to the MCT system (Figure 2a). The age of Kakhtang thrusting has been estimated as ~14-10 Ma [Grujic et al., 2002], making it an out-of-sequence structure, but the throw on this structure appears to be less than those of the MCT, MBT, and MFT systems. In addition, interpretive geologic cross sections consistent with observed surface geology in Bhutan have led researchers to propose the existence of two major duplex systems resulting in the imbrication of Lesser Himalayan rocks [McQuarrie et al., 2008; Long et al., 2012; Tobgay et al., 2012]. A "lower" duplex is exhumed and exposed at the foreland of the range in the hanging wall of the MBT system. The "upper" duplex is blind (i.e., not exposed at the surface) and positioned under the outcrop extent of the MCT sheet in eastern and central Bhutan [McQuarrie et al., 2008; Long et al., 2012], or beneath other Lesser Himalayan structural packages in western Bhutan [Tobgay et al., 2012; McQuarrie et al., 2014]. While the position, size, and geometry of these duplexes likely vary along the strike of the range, any line of longitude or transverse river in Bhutan is likely to cross at least one major duplex between the range crest and foreland. It was recently suggested that the youngest activity of the upper duplex may date to the middle or late Miocene [Long et al., 2012; Tobgay et al., 2012; McQuarrie et al., 2014] based on geochronometric and thermochronometric data. Invoking upper duplex development as a possible causative mechanism for normal faulting in the hinterland of central Bhutan, Adams et al. [2013] suggested that the upper duplex was active in the Quaternary.

Several studies utilizing geochronometry and thermochronometry show that there was a considerable decrease in shortening rates across Bhutan around 9–6 Ma [*Long et al.*, 2012; *McQuarrie et al.*, 2014; *Coutand et al.*, 2014; *McQuarrie and Ehlers*, 2015; *Adams et al.*, 2015]. However, recent GPS studies show that modern shortening rates are 14–17 mm/yr [*Banerjee et al.*, 2008; *Vernant et al.*, 2014], suggesting that rates may have increased again sometime after the 9–6 Ma deceleration. Unfortunately, the youngest thermochronometers are Pliocene in age, which leaves a considerable gap in our knowledge of the evolution of the Bhutan Himalaya.

3. The High-Elevation, Low-Relief Landscapes of Bhutan

Duncan et al. [2003] first noted the belt of high-elevation (~3000 m) terrain with low hillslope gradients and low local relief in the middle latitudes of the Bhutan Himalaya (Figures 1a and 2b) . These low-relief landscapes are found in broad valleys upstream of major convex-up knickpoints (an abrupt downstream increase in channel steepness), and contain thick (perhaps a few hundreds of meters based on the degree of infilling of previously V-shaped valleys), sometimes dissected, packages of sediment. (Following convention, hence-forth convex-up and concave-up will be simply refrred to as convex and concave, respectively.) These sub-dued, filled landscapes were identified within the Thimpu, Bumthang, Phobjikha, and Yarab regions (Figures 2b and 4) [*Baillie and Norbu*, 2004; *Grujic et al.*, 2006]. The abundance of aeolian, colluvial, and alluvial deposits; thick saprolite horizons (>8 m) [*Baillie et al.*, 2004]; and bogs on these low-relief landscapes (Figure 4) suggests very low erosion rates. Large N-S rivers incised deep canyons that isolated these landscapes into smaller patches: the Puna Tsang Chu, Mangde Chu, and Kuri Chu (Figures 2b and 5). Interestingly, despite the considerable relief in these canyons, there are broad, aggraded reaches of the Puna Tsang Chu and Kulong Chu (Figure 3) that are located adjacent to the low-relief landscape patches.

There is no evidence for glacial deposits or glacial modification of topography on these low-relief landscapes. Most cirque and valley glaciers are currently restricted near the crest of the range above 4200 m (Figure 1b) [*lwata et al.*, 2002]. These glaciers did not advance much in the Holocene and Pleistocene, although some may have reached elevations ~3800 m [e.g., *lwata et al.*, 2002; *Meyer et al.*, 2009].

Grujic et al. [2006] noted that the Phobjikha, Bumthang, and Yarab surfaces are not correlated with any particular lithology or structure and suggested that they are remnants of an ancient low-relief, low-elevation landscape that was uplifted ~2 km. On the basis of low-temperature thermochronometry, *Grujic et al.* [2006] argued that the mechanism of surface uplift was a reduction in erosional efficiency, brought on by the rain shadow cast by the rising Shillong Plateau to the south, in the presence of constant rock uplift rates. However, *Adams et al.* [2015] suggested that the elevated, low-relief landscapes in Bhutan were more likely formed via a tectonic mechanism. They showed that the Thimpu surface (TS; Figure 2b) is a transient landscape just as the Phobjikha, Bumthang, and Yarab surfaces, despite the fact that it lies to the west of the **AGU** Journal of Geophysical Research: Earth Surface



Figure 3. Examples of longitudinal river profiles and linearized channel profiles from the Bhutan Himalaya (see Figure 2b for locations). (a) Longitudinal profiles from the four low-relief landscapes. (b) Longitudinal profiles from the fluvial systems that dissect the low-relief landscapes. (c) Linearized profiles of river from Figure 3a. (d) Linearized profiles of river from Figure 3b. See text for discussion. Reference values used in calculations are $A_0 = 1 \text{ m}^2$ and $\theta_{ref} = 0.45$. Regions with accumulation areas less that 2 km² have been omitted to remove the affects of hillslopes. Slopes of χ plots are the channel steepness values seen in Figure 2b.

supposed rain shadow of the Shillong Plateau. This suggests that the climate change mechanism does not work for all high-elevation, low-relief landscapes in Bhutan. They also used multiple thermochronometers and a thermal-kinematic model to demonstrate that the reduction in erosion rates previously observed [*Grujic et al.*, 2006] was the result of reduced shortening rates in the Bhutan Himalaya, which would not cause surface uplift. *Adams et al.* [2015] were, however, able to deduce that the surface uplift occurred after 3 Ma, and more likely after 1.75 Ma, a condition necessary to preserve the low-temperature cooling ages observed on the surface in Bhutan.

Hodges and Adams [2013] and *Adams et al.* [2013] attempted to simplify the enigmatic topography of Bhutan by separating it into two landforms: (1) the low-relief landscape and associated downstream convex knickpoint and canyons and (2) the higher-gradient topography upstream of these landscapes (Figures 1 and 2b). The transition from the first to the second was referred to in those papers as Physiographic Transition 2 (PT₂) using a terminology originally developed to describe a similar topographic profile in central Nepal [*Hodges et al.*, 2001]. *Hodges and Adams* [2013] suggested that PT₂ in Bhutan might be associated with an active structure generating higher uplift rates to the north like PT₂ in central Nepal [*Wobus et al.*, 2003, 2005, 2006a; *Hodges et al.*, 2004]. *Adams et al.* [2013] did locate a young structure coincident with PT₂ in Bhutan, the Lhuentse fault, but thermal histories of the bedrock north and south of this north dipping fault suggested a normal-sense displacement—opposite the sense required to create the observed step in topography. However, they

suggested that the position of PT_2 at the northern edge of the low-relief landscapes could mean that the two had a related formation mechanism related to their hanging wall position above an active duplex structure.

Figure 2b illustrates these observations. We use a map of local relief to highlight the position of the low-relief landscapes across Bhutan as shown by *Adams et al.* [2013, 2015]. We separately identify low-relief regions of high glacial topography to the south of the range crest and adjacent to the southern portions of the fluvial low-relief landscapes. The mean elevations of the glacial surfaces are significantly higher than the fluvial landscapes. As will be discussed in more detail in later sections, we suggest that this is an important designation between fluvial and glacial landscapes, the forms of which are governed by different processes [e.g., *Brozović et al.*, 1997]. The variation in topographic form across Bhutan is also highlighted in a map of channel steepness. Steady state longitudinal river profiles often have a form set by a power law relationship between channel slope and drainage area [e.g., *Hack*, 1957; *Flint*, 1974; *Tarboton et al.*, 1989]:

$$\mathsf{S} = k_{\mathsf{S}} \mathsf{A}^{-\theta} \tag{1}$$

where k_s is the channel steepness and θ is the channel concavity. Because we found that $\theta = 0.45$ adequately describes the concavity of equilibrium fluvial systems in Bhutan based on regressions of slope-area data, we used that value to normalize measures of local channel slope (*S*) for the change in upstream drainage area (*A*) along the length of the channel profiles, and we then calculated a normalized channel steepness (k_{sn}). In this way, we could compare channel gradients for all drainage areas [*Wobus et al.*, 2006b].

Changes exhibited by regional topography are clear from river profile data. In Figure 3 we show longitudinal river profiles as well as linearized profiles. Linearized profiles are shown in χ plots where the profile distance (*x*) is replaced by a dimensionless term, χ . The integration of equation (1) shows that χ is the integral of the upstream accumulation area (*A*) [*Perron and Royden*, 2013]:

$$z(x) = z(x_b) + k_s \chi \tag{2a}$$

with

$$\chi = \int_{x_b}^{x} \left(\frac{A_0}{A(x)}\right)^{\theta} dx$$
 (2b)

where x_b is the position of the mouth of the river, A_0 is a reference area ($A_0 = 1 \text{ m}^2$ in this study). As indicated in equation (2a), on plots of elevation versus χ , the channel steepness determines the slope of the linearized river profile. Convex and concave knickpoints can be readily identified as positive and negative changes in slope (channel steepness) in these χ plots. Much like the landscapes themselves across Bhutan, profiles of major transverse rivers are highly variable. Every large trunk stream has at least one major convex knickpoint, but these range in style, magnitude, and elevation. The fluvial systems that drain the elevated, low-relief landscapes (e.g., Wang, Kissna, Chamkhar, and Sheri) contain major convex knickpoints that split the basin into two distinct relief regimes (Figures 2b and 3). The very high channel steepness values (likely higher than required by local rock uplift rates, or oversteepened) directly downstream of major convex knickpoints and the low-relief landscapes (Figure 3) make these fluvial systems appear to be on the verge of becoming hanging valleys [e.g., *Wobus et al.*, 2006b; *Crosby et al.*, 2007]. These oversteepened reaches are at least 3 times steeper than surrounding steady state river channels (Figure S1 in the supporting information). Satellite images of the Kissna Chu display sequences of waterfalls downstream of the convex knickpoint.

4. Plausible Mechanisms of Low-Relief Surface Formation

There are two broadly defined tectonic mechanisms that could have created landscapes similar to those observed in Bhutan. The first is a spatially uniform increase in rock uplift rates, perhaps caused by increased fault slip rates of thrust faults near the foreland (e.g., MCT, MBT, or MFT). Such a mechanism would act similarly to that advocated by *Grujic et al.* [2006] in that low-relief surfaces of relict topography formed on grade with the foreland would be uplifted nearly 2 km. Unfortunately, this creates significant problems as the regions to the north of the low-relief landscapes, including the range crest, would have to have experienced ~2 km of surface uplift as well. Such a scenario is highly unlikely as there is no apparent increase in the mean elevation of the range crest or Tibetan Plateau in this portion of the eastern Himalaya. Furthermore, it would suggest that the regions of Bhutan that now appear to be in steady state would have experienced ~2 km of



Figure 4. Examples of the low-relief landscapes and alluvial reaches of otherwise deeply incised valleys (see Figure 2a for locations). (a) Looking north at the city of Thimpu on the Thimpu surface. (b) Looking east on the Phobjikha surface. (c) Looking northwest near the town of Jakar on the Bumthang surface. (d) Looking north at the Punakha Dzong (fortress) on the Puna Tsang Chu. (e) Looking north in the Kulong Chu floodplain north of Tashigang.

exhumation since this change in rock uplift rate. However, such a high amount of exhumation is not permitted by the cooling history of rocks within Bhutan [*Adams et al.*, 2015]. Moreover, this mechanism would not explain the accumulation of valley fill on these low-relief landscapes (Figure 4).

Another mechanism that could explain the in situ production of sediment filled, low-relief landscapes is backtilting in the hinterland. Such back-tilting could be caused by an antiformal uplift pattern associated with activity on a ramp/duplex structure at depth (e.g., one of the LHS duplexes mentioned above). The deformation of duplex systems at depth result in a pattern of rock uplift similar to that across a generic detachment fold [*Plesch et al.*, 2007], specifically the establishment of an antiform roughly orthogonal to the thrust transport direction.

The response of fluvial systems to increased downstream rock uplift rates has been described for foreland basins [e.g., *Burbank et al.*, 1996; *Humphrey and Konrad*, 2000]. Fluvial systems behave dynamically by aggrading to maintain or change their course, in order to adjust to an impinging zone of higher rock uplift downstream [*Burbank et al.*, 1996; *Wang et al.*, 2014]. The peak of river incision is co-located with the peak of the rock uplift rate, which decreases sharply upstream where rivers must aggrade to maintain a sufficient gradient and counteract the upstream tilting on the back limb of the antiform. This produces a wedge of detritus that propagates upstream as downstream uplift continues. Figure 6 provides an

illustration of the predicted patterns of fluvial system response tailored to the landscapes and Late Cenozoic geology of Bhutan described above (section 3).

Uniform and spatially variable rock uplift patterns have predictable erosion rate patterns in portions of the landscape that have completely (or nearly completely) adjusted to the new rock uplift rates. A uniform increase in rock uplift rates would tend to create a uniform increase in erosion rates in portions of the landscapes that have adjusted. However, a spatially variable pattern of rock uplift will lead to spatially variable erosion rates where adjusted portions of the landscape will exhibit higher erosion rates in the presence of higher rock uplift rates. These predictions suggest that either hypothesis could be recognizable from a spatially expansive suite of erosion rate estimates. Cosmogenic radionuclide concentrations in fluvial sands sampled in carefully selected locations can provide the necessary data.

5. Basin-Averaged Erosion Rates

Erosion rates were estimated based on measured concentrations of cosmogenic ¹⁰Be in amalgamated quartz sand from modern fluvial systems in Bhutan. This approach is designed to reveal the average erosion rate integrated across a drainage basin [e.g., *Granger et al.*, 1996; *Bierman and Steig*, 1996]. We based our sampling strategy on the hypothesis that some basins in Bhutan are in steady state (or near steady state, as this condition is difficult to demonstrate with 100% certainty), and some are not. Following the protocols established in earlier studies [*Ouimet et al.*, 2009; *DiBiase et al.*, 2010], we identify plausibly steady state basins as those with well-graded channel profiles that are likely eroding all parts of the basin at similar rates (which reflect rock uplift rates). These basins have relatively uniform hillslope gradients, local-relief, and lack major convex knickpoints (Figures S2 and S3). We also sampled basins on the low-relief landscapes that were assumed to be out of equilibrium with modern rock uplift rates. Such landscapes are, instead, likely to be responding to the local baselevel set by the main stem river draining the low-relief landscape patch. Because of this, the basins in these low-relief landscapes are insulated from incised canyons above major convex knickpoints that define local baselevel for the low-relief landscape and were presumed to be eroding well below rock uplift rate (a hypothesis tested in the next sections).

We avoided basins glaciated during the late Pleistocene, and with sediment loads dominated by recent landslides or flood deposits. All sampled catchments lie within the Greater Himalayan sequence, where quartz is ubiquitous at the basin scale, or within quartz-rich portions of the Lesser Himalayan sequence. Basins with upper reaches underlain by Tibetan Sedimentary Sequence rocks were also avoided, as the distribution of quartz in these carbonate-rich units is decidedly nonuniform. As noted earlier, there is a very strong precipitation gradient from south to north in Bhutan created by the effects of orographic precipitation dynamics at the range front (Figure 7). To minimize complicating signals of variable erosivity due to variation in climate, we only analyze here basins from the drier (mean annual rainfall from 0.43 to 1.2 m/yr) interior of the country. The size of the 45 sampled basins ranges from 13 to 274 km²—large enough to allow an accurate assessment of the channel steepness index (k_{sn}) and to minimize the impact of stochastic landslide contributions to sediment flux [e.g., *Niemi et al.*, 2005; *Yanites et al.*, 2009; *Kober et al.*, 2012], but small enough to sample a single tectonic and topographic terrain.

All samples were processed at the Arizona State University, Surface Processes WOMBAT Laboratory. Quartz grains were separated from the 250–1000 µm fraction of fluvial sands utilizing acid and gravimetric techniques. Sieved sediments were placed in aqua regia at room temperature for 12 h. The samples were then leached in a 5% hydrofluoric and nitric acid solution and rolled on heat for 24 h. Feldspars and micas were floated off using a wetting technique, and dense minerals were removed via heavy liquids. While samples were in heavy liquids special care was taken to separate lighter and denser portions of the quartz fractions to ensure that lithics or crystals with significant inclusions were removed. During the cleaning and separation process, quartz grains were leached at least 5 times with hydrofluoric and nitric acids on heated rollers. These leaching sessions lasted at least 24 h and the final leach lasted for 7 days. The quartz separates were then spiked with ⁹Be and digested with concentrated hydrofluoric and nitric acids. We removed interfering cations and anions using liquid chromatography techniques. Oxidized beryllium was mixed with a matrix of niobium and loaded into cathodes for analysis on an accelerator mass spectrometer at PRIME Lab, Purdue University. Beryllium isotope ratios were referenced to the isotope ratio standards described by *Nishiizumi et al.* [2007].

5.1. Calculating Basin-Averaged Erosion Rates

We follow the approach of *Portenga and Bierman* [2011] to calculate an effective elevation, latitude, and longitude value that can be used for each sample in the CRONUS online calculator [*Balco et al.*, 2008]. Based on the Advanced Spaceborne Thermal Emission Radiometer 30 m resolution digital elevation data set, we calculated the scaled production rate based on the elevation and latitude of each pixel in a basin. To be internally consistent with the procedures of the CRONUS calculator, we calculated the production rate from spallation reactions using the scheme of *Stone* [2000] and the production rate from muon reactions using the equations of *Heisinger et al.* [2002a, 2002b]. We then calculated the mean of all total production rates (e.g., spallation and muon) within the basin and found the elevation and latitude values corresponding to this mean scaling factor, referred to here as the effective elevation and latitude of the basin. Afterward, we employed the CRONUS calculator to calculate our erosion rates (see Table S1 in the supporting information for CRONUS input data). Because we were not able to adjust the production rate of muons for the erosion rate at each pixel in the basin, it is not accurate to report any time-dependent erosion rate as calculated by the CRONUS calculator. We therefore report erosion rates based on the constant production rates determined by the models of *Lal* [1991] and *Stone* [2000].

5.2. ¹⁰Be Basin-Averaged Erosion Rate Results

Our calculated erosion rates vary between ~42 and 2539 m/Ma (Table 1). We estimate the time scales over which these erosion rates integrate by dividing the *e*-folding depth of the penetration of cosmic particles in solid rock (~0.6 m) by the erosion rate. These calculations suggest that our data yield mean rates over at least the last ~0.2–14 ka. The mean erosion rate from the samples collected from the low-relief landscapes is 74 m/Ma with a standard deviation of 24 m/Ma. The mean erosion rate from the surrounding higher relief canyons is 483 m/Ma with a standard deviation of 544 m/Ma.

Our basin-averaged erosion rates reveal a pattern similar to the overall pattern reported by Portenga et al. [2015] and Le Roux-Mallouf et al. [2015] using the same detrital CRN method. They suggested that latitudinal zones of varying erosion rate could be identified in the Puna Tsang Chu and Wang Chu valleys where a zone of low relief and low erosion rates (27.35°N–27.70°N) is bound by regions of higher erosion rates to the north and south. In the one instance of duplicated sample location from the Le Roux-Mallouf et al. [2015] data set, our erosion rates are the same within uncertainty. However, our duplicated basin samples do not always yield the same erosion rates. Of the 49 basins sampled from the Puna Tsang Chu drainage presented by Portenga et al. [2015], only 16 met our sampling criteria as described above (others either crossed major knickpoints, incorporated glaciated landscapes, were too small or were too large to sample a single tectonic and topographic zone) (Figure S4). Six of these basins represent duplicate analyses of our samples, of which three are within error of each other. We are not able to explain the disagreement between the other three basin erosion rates—two of our rates are higher and one is lower than those previously published. We ascribe these differences to sampling uncertainty, such as the influx of low ¹⁰Be concentration guartz from a flood or mass wasting event, or the addition of high ¹⁰Be concentration quartz from the recycling of older terrace deposits. The variability seen in these replicate samples is similar to that observed between samples taken 3 years apart elsewhere in the Himalaya [Lupker et al., 2012; Scherler et al., 2014].

The systematics of possible native ⁹Be within the samples cannot explain these discrepancies, as the presence of native ⁹Be would suggest that calculated erosion rates are always too high [*Portenga et al.*, 2015]. In addition, our sample data show a clear relationship between mean basin slope and erosion rate in agreement with that of the sixteen basins from *Portenga et al.* [2015] (Figure S5), adding more compelling evidence that native ⁹Be has not significantly affected our data set and demonstrating that although sampling uncertainty adds scatter to erosion rate estimates, consistent and robust relationships between erosion rate and controlling variables are reliably obtained. Furthermore, the investigations of *Le Roux-Mallouf et al.* [2015] show that native ⁹Be is not prevalent in the quartz crystal structure, and any source of native ⁹Be can be eliminated via targeted laboratory techniques designed to remove inclusions in quartz (see our sample processing procedures above).

The catchments within the low-relief landscapes are eroding much slower than the catchments within the steep flanking terrains (Figures 7 and 8). This pattern confirms that erosion rates on the low-relief landscapes are not reflective of regional rock uplift rates and that the low-relief surfaces are actively being incised and

Currents Resultant Currents	Conditional Descriptional Descripional Descriptional Description	Construction Tangent	Unggude Technol Result Name		n-Average	d Erosion Kat	e sample Dat		000040	000040								
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0.00108 2.06 1.0 2.4 0.00 1.0 2.4 <th2.4< th=""> 2.4 2.4 <th2.4< td=""><td>3665 50 193 24 26 060 243,386 2590 115 22 52 5 90118800 313<!--</td--><td>Obsolve 246 00 193 24 00 193 24 260 193 24 253 113 253 123 253 133 253 133 253<td>90.0018 2.865 50 103 2.4 2.4 0.60 31.831 5.300 115 2.2 5.2 9118303 1045 2.3 36 1.2 1.3 1.3 2.3 3.5</td><td>90.001 2.85 50 193 24 0.60 243.348 2390 115 23 23 52 23 52 23 53 51 53 53 51 53 53 51 51 53 53 51 53 53 51 53 53 51 51 53 53 51<td></td><td>90.89055</td><td>2,777</td><td>57</td><td>153</td><td>16</td><td>18</td><td>0.61</td><td>351,628</td><td>41,298</td><td>27</td><td>14</td><td>8.4</td><td>I</td></td></td></td></th2.4<></th2.4<>	3665 50 193 24 26 060 243,386 2590 115 22 52 5 90118800 313 </td <td>Obsolve 246 00 193 24 00 193 24 260 193 24 253 113 253 123 253 133 253 133 253<td>90.0018 2.865 50 103 2.4 2.4 0.60 31.831 5.300 115 2.2 5.2 9118303 1045 2.3 36 1.2 1.3 1.3 2.3 3.5</td><td>90.001 2.85 50 193 24 0.60 243.348 2390 115 23 23 52 23 52 23 53 51 53 53 51 53 53 51 51 53 53 51 53 53 51 53 53 51 51 53 53 51<td></td><td>90.89055</td><td>2,777</td><td>57</td><td>153</td><td>16</td><td>18</td><td>0.61</td><td>351,628</td><td>41,298</td><td>27</td><td>14</td><td>8.4</td><td>I</td></td></td>	Obsolve 246 00 193 24 00 193 24 260 193 24 253 113 253 123 253 133 253 133 253 <td>90.0018 2.865 50 103 2.4 2.4 0.60 31.831 5.300 115 2.2 5.2 9118303 1045 2.3 36 1.2 1.3 1.3 2.3 3.5</td> <td>90.001 2.85 50 193 24 0.60 243.348 2390 115 23 23 52 23 52 23 53 51 53 53 51 53 53 51 51 53 53 51 53 53 51 53 53 51 51 53 53 51<td></td><td>90.89055</td><td>2,777</td><td>57</td><td>153</td><td>16</td><td>18</td><td>0.61</td><td>351,628</td><td>41,298</td><td>27</td><td>14</td><td>8.4</td><td>I</td></td>	90.0018 2.865 50 103 2.4 2.4 0.60 31.831 5.300 115 2.2 5.2 9118303 1045 2.3 36 1.2 1.3 1.3 2.3 3.5	90.001 2.85 50 193 24 0.60 243.348 2390 115 23 23 52 23 52 23 53 51 53 53 51 53 53 51 51 53 53 51 53 53 51 53 53 51 51 53 53 51 <td></td> <td>90.89055</td> <td>2,777</td> <td>57</td> <td>153</td> <td>16</td> <td>18</td> <td>0.61</td> <td>351,628</td> <td>41,298</td> <td>27</td> <td>14</td> <td>8.4</td> <td>I</td>		90.89055	2,777	57	153	16	18	0.61	351,628	41,298	27	14	8.4	I
0.007154 2.735 114 169 12 19 0.46 31.891 2.2969 80 19 7.5 9113833 1045 21 353 94 28 053 103 131 21 24 26 9113833 1045 21 353 94 28 053 31 110 23 44 20 9113030 1273 91 33 85 31 112 5555 31 31 24 65 45	(18) (13) (14) (15) (14) (15) (14) (15) <th< td=""><td>Octor 233 114 168 12 19 0.66 311,69 12,296 10 10 7.5 9118333 1015 23 23 12 19 2060 13 31 13 31 35 9118333 1015 23 33 102 33 112 25,468 7.33 131 32 4.6 </td><td>9.667154 2.735 114 168 12 19 0.46 31.361 23.35 14 68 13 35 35 31 35 31 35 35 31 35 31 35 35 31 35 35 31 35 35 31 31 32 31 35 35 31<</td><td>06.715 213 114 168 12 19 0.66 31.58 12.58 13 22.56 13 22.5 13 23 24.56 23 23 24.56 25 23 23 23 24.56 24.56 25 23 23 23 23 23 23 23 23 23 23 23 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 25 25 25 24 26 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 26 24 25 24 26 24 26 24 26 24 26</td><td></td><td>90.90198</td><td>2,865</td><td>50</td><td>193</td><td>24</td><td>24</td><td>0.60</td><td>243,388</td><td>23,907</td><td>115</td><td>22</td><td>5.2</td><td>I</td></th<>	Octor 233 114 168 12 19 0.66 311,69 12,296 10 10 7.5 9118333 1015 23 23 12 19 2060 13 31 13 31 35 9118333 1015 23 33 102 33 112 25,468 7.33 131 32 4.6	9.667154 2.735 114 168 12 19 0.46 31.361 23.35 14 68 13 35 35 31 35 31 35 35 31 35 31 35 35 31 35 35 31 35 35 31 31 32 31 35 35 31<	06.715 213 114 168 12 19 0.66 31.58 12.58 13 22.56 13 22.5 13 23 24.56 23 23 24.56 25 23 23 23 24.56 24.56 25 23 23 23 23 23 23 23 23 23 23 23 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 25 25 25 24 26 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 25 24 26 24 25 24 26 24 26 24 26 24 26		90.90198	2,865	50	193	24	24	0.60	243,388	23,907	115	22	5.2	I
91.18330 910 33 42 28 0.5 97.58 10.204 18 31 36 91.18330 107 53 94 20 0506 5553 11 10 31 36 91.3083 107 53 34 0 30 0.60 55946 5533 131 21 24 91.3086 177 137 146 13 23 34 20 553 14 56 90.6304 3.444 10 148 133 26 0.64 30 066 570 213 14 56 46 57 14 20 44 57 24 57 24 57 24 57 24 57 24 57 24 57 24 57 24 57 24 57 24 57 24 57 57 24 57 57 </td <td>91.8380 930 59 536 42 28 0.57 70,58 10,294 18 31 36 - 91.8380 10/7 53 36 42 28 0.57 70,58 5555 191 36 - - 91.93806 10/71 53 36 32 31 11.2 95,408 57.32 14 36 - - 91.95006 1/780 13 26 0.45 66.543 42.77 14 31 27 246 -</td> <td>9118380 930 59 536 42 28 0.59 97.598 10.24 13 36 - 9118380 930 53 42 28 0.05 95.468 5555 13 11 25 14 56 - 9113016 1,278 91 346 12 31 11 23 5555 13 131 22 43 -</td> <td>91.18580 90 59 356 42 28 0.57 17024 168 31 35 91.18580 10/45 31 353 60 30 057 1738 131 32 24 91.10016 1/280 1/2 31 1/2 55468 5713 313 31 3</td> <td>91.8330 39 53 34 23 94 36 3 35 36 - 91.8330 39 13 31 10 53 35 36 35 46 - - - - - - - - - - 35 35 45 35 45 35 45 46 -<td></td><td>90.67154</td><td>2,735</td><td>114</td><td>168</td><td>12</td><td>19</td><td>0.46</td><td>311,891</td><td>52,989</td><td>80</td><td>19</td><td>7.5</td><td>ı</td></td>	91.8380 930 59 536 42 28 0.57 70,58 10,294 18 31 36 - 91.8380 10/7 53 36 42 28 0.57 70,58 5555 191 36 - - 91.93806 10/71 53 36 32 31 11.2 95,408 57.32 14 36 - - 91.95006 1/780 13 26 0.45 66.543 42.77 14 31 27 246 -	9118380 930 59 536 42 28 0.59 97.598 10.24 13 36 - 9118380 930 53 42 28 0.05 95.468 5555 13 11 25 14 56 - 9113016 1,278 91 346 12 31 11 23 5555 13 131 22 43 -	91.18580 90 59 356 42 28 0.57 17024 168 31 35 91.18580 10/45 31 353 60 30 057 1738 131 32 24 91.10016 1/280 1/2 31 1/2 55468 5713 313 31 3	91.8330 39 53 34 23 94 36 3 35 36 - 91.8330 39 13 31 10 53 35 36 35 46 - - - - - - - - - - 35 35 45 35 45 35 45 46 - <td></td> <td>90.67154</td> <td>2,735</td> <td>114</td> <td>168</td> <td>12</td> <td>19</td> <td>0.46</td> <td>311,891</td> <td>52,989</td> <td>80</td> <td>19</td> <td>7.5</td> <td>ı</td>		90.67154	2,735	114	168	12	19	0.46	311,891	52,989	80	19	7.5	ı
91.1833 1045 21 333 94 28 0.57 17.092 0.5463 5555 191 32 33 31	91.1333 101 5 3 94 26 05 7/092 5555 19 14 68 - 91.12060 12.40 13 36 60 375 13 13 12 44 - 91.7010 12.40 13 365 31 11 75 555 13 31 31 31 - - 90.56330 3.44 20 54.9 83 10 12 555.44 30.05 513 31 31 22 44 -	91,2086 10/45 21 333 64 26 0.05 17/055 1050 88 14 68 - 91,7006 1,200 13 366 325 31 112 354 65 555 13 13 31	9 1.853 1045 21 333 94 28 05 1050 88 14 68 9 1.1009 1.240 13 366 323 31 125 355 131 23 45 9 1.1009 1.240 13 366 323 31 120 313 23 34 90.6534 3.440 114 183 89 23 044 133 26 45 90.90343 140 114 183 89 23 045 133 26 45 45 90.90343 140 114 183 89 23 044 130 26 45 90.90433 66 65 235 14 23 0053 653 13 26 45 90.90433 66 65 14 23 045 133 26 45 90.90446 128 14 23 643 133	91.1833 1045 21 333 64 32 105 133 36 64 35 13 36 64 35 13 36 64 35 13 36 64 35 13 36 64 35 13 36 64 35 13 36 45		91.18580	930	59	356	42	28	0.59	97,598	10,294	168	31	3.6	I
91.2088 1071 53 345 60 30 0.00 85.483 5555 191 31 31 31 21 91.10106 1.280 91 240 13 31 11 2 344 25 31 11 2 31 31 24 5 31 31 24 24 31 24 24 32 34 25 34 35 31 24 25 34 25 34 25 34 25 34 25 34 25 34 25 34 25 34 25 34 25 34 25 34 35 34 25 34 35 34 25 34 25 34 35 35 35 35 35 35 35 35 36 34 35 35 36 36 36 36 36 36 36 36 36 36 <td< td=""><td>91/2008 1/201 33 345 60 30 060 55 31 32 31 31 31 32 31 31 32 31</td><td>91,2086 10/1 53 345 60 30 066 5353 131 23 31 21 24 46 2 91,7016 1,72 81 31 10 25 31 11 2 55,463 513 31 22 34 46 2 9056791 1,440 114 183 32 20 034 54,461 203 14 233 23 23 24 203 233 23 24 203 233 23 24 203 233 23 24 203 233 24 203 233 24 203 233 24 233 24 233 24 233 24 233 24 233 24 233 24 233 24 233 24 233 24 23 24 23 24 23 23 24 23 24 23 24 23 23</td></td<> <td>9 1,01 33 345 60 36 555 191 31 <!--</td--><td>91/2016 1,0/1 33 345 60 30 31 11 23 31</td><td></td><td>91.18533</td><td>1,045</td><td>21</td><td>353</td><td>94</td><td>28</td><td>0.57</td><td>170,952</td><td>10,500</td><td>88</td><td>14</td><td>6.8</td><td>I</td></td>	91/2008 1/201 33 345 60 30 060 55 31 32 31 31 31 32 31 31 32 31	91,2086 10/1 53 345 60 30 066 5353 131 23 31 21 24 46 2 91,7016 1,72 81 31 10 25 31 11 2 55,463 513 31 22 34 46 2 9056791 1,440 114 183 32 20 034 54,461 203 14 233 23 23 24 203 233 23 24 203 233 23 24 203 233 23 24 203 233 24 203 233 24 203 233 24 233 24 233 24 233 24 233 24 233 24 233 24 233 24 233 24 233 24 23 24 23 24 23 23 24 23 24 23 24 23 23	9 1,01 33 345 60 36 555 191 31 </td <td>91/2016 1,0/1 33 345 60 30 31 11 23 31</td> <td></td> <td>91.18533</td> <td>1,045</td> <td>21</td> <td>353</td> <td>94</td> <td>28</td> <td>0.57</td> <td>170,952</td> <td>10,500</td> <td>88</td> <td>14</td> <td>6.8</td> <td>I</td>	91/2016 1,0/1 33 345 60 30 31 11 23 31		91.18533	1,045	21	353	94	28	0.57	170,952	10,500	88	14	6.8	I
9117010 12.0 13 396 325 31 12 95408 7.18 131 22 46 9117010 17.28 0 54.9 8.5 11 10.0 7.3 131 22 46 9056307 1/40 114 108.3 23 0.02 165.344 20.00 131 25 46 890043 1/190 74 133 36 0.02 165.344 20.00 131 25 14	91:17010 12.40 13 36 32.5 31 1.2 95.408 7.138 131 22 46 - 90:15001 1.270 94.5 10 0.9365 7.13 131 22 46 - 90:55041 3.441 20 54.9 5.5 10 0.935 95.24 133 25 45 - 90:55043 3.441 20 54.9 5.5 10 0.93 95.8 71 20 23 45 - - - - - - 95.9 45 45 45 -	9 1/1010 1/24 0 13 30 325 31 12 7954 8 7/13 13 22 46 - 91/5010 1/37 108 13 89 23 16 0.45 642.631 202/15 131 22 46 - 89377 1/37 108 13 89 23 002 116524 2377 715 13 22 4 5 - 893677 1/37 108 13 89 23 002 116524 2377 713 13 22 4 5 - 893677 1/37 108 13 89 23 002 16524 123 23 45 - 893677 236 45 130 23 37 05 13 2 23 45 - 8936677 2355 45 166 14 34 33 92 30 003 5470 65 13 2 23 45 - 91/476 133 77 916 14 31 93 54 003 5470 65 132 23 45 - 91/476 133 77 916 14 33 003 5470 65 132 23 45 - 91/476 133 77 916 14 33 003 5470 65 13 2 24 - 91/476 133 77 916 14 33 003 5470 65 13 2 24 - 91/476 133 77 916 14 23 003 5470 65 5378 1500 23 13 2 24 - 91/476 133 77 916 11 23 26 53 78 150 133 26,44 193 003 - 91/476 133 77 916 11 23 065 5378 15,00 600 94 2 1 10 23 013 - 90/475 236 57 13 13 2 65 374 10773 64 13 002 024 W W 90/475 236 57 10 31 23 065 63 74 10773 64 13 002 024 W W 90/475 133 17 90 13 32 005 65 374 10773 64 13 002 039 113 2 - 90/196 846 23 003 134 0770 153 013 32 55 04 5 - 91/376 15 206 32 11 10/710 1530 193 273 003 73 64 1 13 - 91/376 15 206 32 11 10/710 1530 193 273 0079 6 - 91/376 140 140 133 013 45 7 252 44 10 7 3 6 - 91/376 140 146 130 024 11 16468 203 736 50 179 23 24 - 91/376 140 146 20 23 20 007 193 23 253 73 005 70 24 - 91/376 140 146 13 0002 13 3 275 045 24 - 91/376 140 146 13 0002 13 3 275 045 24 - 91/376 140 146 13 0002 13 3 275 045 24 - 91/376 140 146 14 13 0002 13 3 256 14 - 91/376 140 146 14 13 0002 13 3 256 14 - 91/376 140 146 14 13 0002 13 3 256 14 - 91/376 140 146 14 13 0002 13 3 256 14 - 91/376 140 146 14 13 0002 146 14 14 14 14 14 14 14 14 14 14 14 14 14	91.1010 1.200 1.20 3.44 3.2 3.1 1.2 5.4.68 7.1.8 3.11 2.2 4.6 91.1010 1.200 1.20 3.4.4 20 2.4.6 1.2 5.4.63 4.2.777 1.11 2.2 4.6 90.905434 1.400 1.14 188.3 8.9 2.3 1.2 5.4.63 4.2.777 7.1.5 7.2 1.4 90.905434 1.190 7.4 2.33 3.7 2.6 0.64 10.9994 5.65.70 7.13 3.6 4.5 4.5 90.905434 7.01 1.4 3.83 2.6 0.65 1.4 2.3 6.2 3.1 3.2 <	9113010 124 13 36 325 31 12 9548 570 31 22 46 - 9113016 1278 13 23 55 16 0.45 63.55 57.0 31 23 45 - 900333 139 23 13 23.77 41 35 45 - 900333 139 23 14 133 23 45 - - 900433 66 67 337 136 33 453 45 - - 900433 66 67 337 14 23 0.04 103 353 45 3 35 45 -		91.20886	1,071	53	345	60	30	0.60	85,463	5,555	191	31	3.1	I
9115010 1278 91 248 12 31 10 79985 6/70 215 27 28 72 28 72 137 203 37 28 27 148 27 148 27 214 23 </td <td>91:5010 1.278 91 248 1.2 31 1.0 7.985 6.70 2.5 2.3 2.8 2.9 90:90501 3.444 1.0 5.43 8.2 10 0.45 6.42.61 1.43 2.3</td> <td>9115016 1278 91 248 12 31 10 79085 6700 215 23 23 23 24 25 24 25 24 25 26 26 31 25</td> <td>91.15016 1.278 91 248 12 31 10 7998 6700 215 37 28 99.06634 3.444 20 543 3 20.05 134 20 37 16 72 14 99.06644 750 4 133 23 0.05 165.24 133 23 0.53 99.0644 750 4 133 23 0.07 318,378 133 23 0.53 99.0644 750 4 133 23 23 0.07 318,378 318 23 0.53 99.0644 750 4 133 3 23 0.33 34,706 7519 318 0.23 14 133 0.24 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.24 0.24</td> <td>91:3016 1.278 91 2,8 12 31 10 739,55 6/70 215 37 28 - 958077 1,372 108 2.44 13 25 0.45 642,63 13.14 130 233 0.53 - - 958077 1,372 108 2.34 33 8.9 233 13.2 133 263 133 233 0.53 -</td> <td></td> <td>91.17019</td> <td>1,240</td> <td>13</td> <td>396</td> <td>325</td> <td>31</td> <td>1.2</td> <td>95,408</td> <td>7,138</td> <td>131</td> <td>22</td> <td>4.6</td> <td>I</td>	91:5010 1.278 91 248 1.2 31 1.0 7.985 6.70 2.5 2.3 2.8 2.9 90:90501 3.444 1.0 5.43 8.2 10 0.45 6.42.61 1.43 2.3	9115016 1278 91 248 12 31 10 79085 6700 215 23 23 23 24 25 24 25 24 25 26 26 31 25	91.15016 1.278 91 248 12 31 10 7998 6700 215 37 28 99.06634 3.444 20 543 3 20.05 134 20 37 16 72 14 99.06644 750 4 133 23 0.05 165.24 133 23 0.53 99.0644 750 4 133 23 0.07 318,378 133 23 0.53 99.0644 750 4 133 23 23 0.07 318,378 318 23 0.53 99.0644 750 4 133 3 23 0.33 34,706 7519 318 0.23 14 133 0.24 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.24 0.24	91:3016 1.278 91 2,8 12 31 10 739,55 6/70 215 37 28 - 958077 1,372 108 2.44 13 25 0.45 642,63 13.14 130 233 0.53 - - 958077 1,372 108 2.34 33 8.9 233 13.2 133 263 133 233 0.53 -		91.17019	1,240	13	396	325	31	1.2	95,408	7,138	131	22	4.6	I
9006334 3.444 20 54.9 85 16 0.45 6.42331 4.2.777 11.6 7.2 14 7 990733 1/370 137 131	0.006334 3.44 20 54.9 8.5 16 0.45 64.5.61 42.777 41.6 7.2 14	906/95/4 3.44 20 54,9 65 16 0.45 64.261 4.2777 11.6 7.2 14 - 98/96707 1,400 14 188 35 0.92 0.85 133 130 7.2 14 - 98/96707 1,400 74 233 37 20 0.85 132 23 45 - <td< td=""><td>000384 3.44 20 5.43 8.5 16 0.45 6.5.34 2.2.03 134 23 24 98.6707 1.340 114 188.3 23 23 23 23 23 35 45 98.77 1.340 114 188.3 23 23 23 23 45 89.0564 55 237 14 34 23 36 31 32 23 45 98.0647 5.335 42 14 34 092 26.534 150 31 23 42 31 98.06475 5.335 42 13 36 24 05 51 13 32 23 13 33 42 31 33 23 34 31 33 23 34 33 03 43 33 03 43 33 03 43 33 03 43 33 03 33 03 <</td><td>906834 314 20 843 15 043 64.341 27.77 14.6 72 14 2 98/77 1/372 108 38 5 15 65.341 20.351 131 26 14 25 98/77 1/372 108 2/3 3 5 55.348 3.13 23 0.53<td></td><td>91.15016</td><td>1,278</td><td>91</td><td>248</td><td>12</td><td>31</td><td>1.0</td><td>79,985</td><td>6,700</td><td>215</td><td>37</td><td>2.8</td><td>I</td></td></td<>	000384 3.44 20 5.43 8.5 16 0.45 6.5.34 2.2.03 134 23 24 98.6707 1.340 114 188.3 23 23 23 23 23 35 45 98.77 1.340 114 188.3 23 23 23 23 45 89.0564 55 237 14 34 23 36 31 32 23 45 98.0647 5.335 42 14 34 092 26.534 150 31 23 42 31 98.06475 5.335 42 13 36 24 05 51 13 32 23 13 33 42 31 33 23 34 31 33 23 34 33 03 43 33 03 43 33 03 43 33 03 43 33 03 33 03 <	906834 314 20 843 15 043 64.341 27.77 14.6 72 14 2 98/77 1/372 108 38 5 15 65.341 20.351 131 26 14 25 98/77 1/372 108 2/3 3 5 55.348 3.13 23 0.53 <td></td> <td>91.15016</td> <td>1,278</td> <td>91</td> <td>248</td> <td>12</td> <td>31</td> <td>1.0</td> <td>79,985</td> <td>6,700</td> <td>215</td> <td>37</td> <td>2.8</td> <td>I</td>		91.15016	1,278	91	248	12	31	1.0	79,985	6,700	215	37	2.8	I
8986707 1440 114 1883 89 23 0.02 165.244 20.205 134 26 45 45 45 990733 1/307 1/30 7 23 33 37 26 0.647 100.994 368 132 23 45 45 9906434 750 41 239 38 237 130 233 45 5 139 0.53 45 5 9906435 7.03 7 131 36 28 0.077 318,378 266,434 139 0.23 45 19 19 19 19 19 13 5 19 13 5 14 23 0.073 56,334 173 36 31 13 <td>995/7 1/30 1/40 1/41 1/83 89 23 0.02 165.244 0.0205 134 26 45 5 46 45<td>98,6707 1,40 1,40 1,83 89 23 0,02 165,244 20.205 134 26 45 5 98,96747 1,372 106 233 37 26 0,47 5519 313 25 0,53</td><td>BB&6707 1 440 114 1833 89 32 0.02 165,244 32,05 134 130 25 645 99.74 1,372 106 74 333 37 29 0.047 16662 31,34 1130 233 645 99.0434 7.90 44 239 38 247 731 3163,78 65 123 645 99.04736 2.355 45 706 731 316,378 24,411 65 113 23 0.33 99.0416 2.355 47 106 14 23 0.07 318,378 24,411 65 113 23 0.33 99.0416 2.391 37 90.3 13 24,411 103 24 31 32 13 23 14 92 99.04317 2.916 37 30 33 24,411 103 24 31 99.14370 139.2 316 373</td><td>988/7/7 1/40 1/48 38.9 23 0.82 165.24 3.12.4 1130 273 0.63 132 23 0.65 132 23 0.65 132 23 0.65 132 23 0.65 132 23 0.53 24 0.53 23 0.53 23 0.53</td><td></td><td>90.96384</td><td>3,444</td><td>20</td><td>54.9</td><td>8.5</td><td>16</td><td>0.45</td><td>642,631</td><td>42,777</td><td>41.6</td><td>7.2</td><td>14</td><td>I</td></td>	995/7 1/30 1/40 1/41 1/83 89 23 0.02 165.244 0.0205 134 26 45 5 46 45 <td>98,6707 1,40 1,40 1,83 89 23 0,02 165,244 20.205 134 26 45 5 98,96747 1,372 106 233 37 26 0,47 5519 313 25 0,53</td> <td>BB&6707 1 440 114 1833 89 32 0.02 165,244 32,05 134 130 25 645 99.74 1,372 106 74 333 37 29 0.047 16662 31,34 1130 233 645 99.0434 7.90 44 239 38 247 731 3163,78 65 123 645 99.04736 2.355 45 706 731 316,378 24,411 65 113 23 0.33 99.0416 2.355 47 106 14 23 0.07 318,378 24,411 65 113 23 0.33 99.0416 2.391 37 90.3 13 24,411 103 24 31 32 13 23 14 92 99.04317 2.916 37 30 33 24,411 103 24 31 99.14370 139.2 316 373</td> <td>988/7/7 1/40 1/48 38.9 23 0.82 165.24 3.12.4 1130 273 0.63 132 23 0.65 132 23 0.65 132 23 0.65 132 23 0.65 132 23 0.53 24 0.53 23 0.53 23 0.53</td> <td></td> <td>90.96384</td> <td>3,444</td> <td>20</td> <td>54.9</td> <td>8.5</td> <td>16</td> <td>0.45</td> <td>642,631</td> <td>42,777</td> <td>41.6</td> <td>7.2</td> <td>14</td> <td>I</td>	98,6707 1,40 1,40 1,83 89 23 0,02 165,244 20.205 134 26 45 5 98,96747 1,372 106 233 37 26 0,47 5519 313 25 0,53	BB&6707 1 440 114 1833 89 32 0.02 165,244 32,05 134 130 25 645 99.74 1,372 106 74 333 37 29 0.047 16662 31,34 1130 233 645 99.0434 7.90 44 239 38 247 731 3163,78 65 123 645 99.04736 2.355 45 706 731 316,378 24,411 65 113 23 0.33 99.0416 2.355 47 106 14 23 0.07 318,378 24,411 65 113 23 0.33 99.0416 2.391 37 90.3 13 24,411 103 24 31 32 13 23 14 92 99.04317 2.916 37 30 33 24,411 103 24 31 99.14370 139.2 316 373	988/7/7 1/40 1/48 38.9 23 0.82 165.24 3.12.4 1130 273 0.63 132 23 0.65 132 23 0.65 132 23 0.65 132 23 0.65 132 23 0.53 24 0.53 23 0.53 23 0.53		90.96384	3,444	20	54.9	8.5	16	0.45	642,631	42,777	41.6	7.2	14	I
89.77 1372 108 274 13 29 097 150 273 053 27 053 273 053 273 053 273 053 273 053 273 053 273 053 273 053 273 053 273 133 253 263 133 253 263 133 253 263 263 263 263 263 263 263 263 263 273 263 273 <td>8977 1372 108 274 13 29 077 1372 108 274 13 23 053 3 0533 15 123 053 15</td> <td>89.77 1,372 108 274 13 273 0,53 -5 89.043 1,90 74 233 23 20 047 131 23 053 45 23 45 -7 89.0644 750 41 233 33 5,334 16.680 735 533 0.53 45 74 89.0647 750 41 23 0.02 36.334 16.802 73 533 0.53 45 7 91.4786 1,233 71 313 36 23 0.04 17.083 26.434 193 42 31 23 45 90.01012 273 105 10 0.05 54.340 10.73 64 11 92 -7 92 90.0116 846 25 10 0 23 44 10.7 16.40 11.5 23 44 -7 93 13 93 44 -7 93<</td> <td>89.77 1,372 108 274 13 29 0.037 1662 31.24 1130 273 0.53 89.06414 750 47 233 37 26 0.04 109.04 533 470 533 450 533 650 533 450 533 533 505 533 533 506 533 450 533 450 533 450 533 450 533 633 643 933 42 313 533 903</td> <td>89.77 1,372 108 274 13 29 097 16682 3124 1130 273 0.33 - 9 59.9664 790 465 123 213 23 45 - 9 20473 565 65 123 71 313 36 23 45 75 166 7519 318 2941 65 12 9 22 19 W 89.6644 750 2335 47 66 7519 318 2941 65 2 19 W 7 9.9664 750 2335 42 166 7519 318 2941 65 2 19 W 90.6133 71 313 36 28 0.03 54,706 7519 318 2941 65 2 19 W 90.6133 71 313 36 28 0.03 54,706 7519 318 2941 65 2 19 W 90.6123 71 313 36 28 0.03 54,706 7519 26 41 9 2 2 1 9 0.0416 2918 77 901 87 23 0.63 70 44 11 0,713 64 193 0.93 7 24 9 27 9 0.0416 2918 77 905 11 33 36 29 0.055 65,796 35,764 55 11 9 22 41 9 2 7 9 0.01186 86 2 239 11 3 32 0.65 63,796 35,764 55 11 9 22 0.05 73 8,557 45 11 9 22 0.05 9 0.921 107 15 0.001186 86 2 239 11 0 22 0.055 65,796 35,764 1077 64 138 0.93 7 0 0.01186 86 2 239 11 0 22 0.055 65,796 35,798 17,793 239 738 0.93 75 0.95 0.95 0.95 0.95 0.95 0.95 10.002 1133 273 0.93 73 0.93 9.94 1 9 2 9 0.001186 86 2 239 11 0,710 153 01 133 273 0.93 73 0.93 9.74 9 9 0.01186 86 2 239 11 0,710 153 01 133 273 0.95 0.45 7 0 9 0.01186 86 2 239 11 0,710 153 01 133 273 0.95 0.45 7 0 9 0.01186 86 2 235 11 0,710 153 01 133 273 0.95 0.45 7 0 9 0.01186 86 0 9 127,235 0.35 0.35 0.35 0.35 0.35 0.35 0.35 0.</td> <td></td> <td>89.86707</td> <td>1,440</td> <td>114</td> <td>188.3</td> <td>8.9</td> <td>23</td> <td>0.82</td> <td>165,244</td> <td>20,205</td> <td>134</td> <td>26</td> <td>4.5</td> <td>I</td>	8977 1372 108 274 13 29 077 1372 108 274 13 23 053 3 0533 15 123 053 15	89.77 1,372 108 274 13 273 0,53 -5 89.043 1,90 74 233 23 20 047 131 23 053 45 23 45 -7 89.0644 750 41 233 33 5,334 16.680 735 533 0.53 45 74 89.0647 750 41 23 0.02 36.334 16.802 73 533 0.53 45 7 91.4786 1,233 71 313 36 23 0.04 17.083 26.434 193 42 31 23 45 90.01012 273 105 10 0.05 54.340 10.73 64 11 92 -7 92 90.0116 846 25 10 0 23 44 10.7 16.40 11.5 23 44 -7 93 13 93 44 -7 93<	89.77 1,372 108 274 13 29 0.037 1662 31.24 1130 273 0.53 89.06414 750 47 233 37 26 0.04 109.04 533 470 533 450 533 650 533 450 533 533 505 533 533 506 533 450 533 450 533 450 533 450 533 633 643 933 42 313 533 903	89.77 1,372 108 274 13 29 097 16682 3124 1130 273 0.33 - 9 59.9664 790 465 123 213 23 45 - 9 20473 565 65 123 71 313 36 23 45 75 166 7519 318 2941 65 12 9 22 19 W 89.6644 750 2335 47 66 7519 318 2941 65 2 19 W 7 9.9664 750 2335 42 166 7519 318 2941 65 2 19 W 90.6133 71 313 36 28 0.03 54,706 7519 318 2941 65 2 19 W 90.6133 71 313 36 28 0.03 54,706 7519 318 2941 65 2 19 W 90.6123 71 313 36 28 0.03 54,706 7519 26 41 9 2 2 1 9 0.0416 2918 77 901 87 23 0.63 70 44 11 0,713 64 193 0.93 7 24 9 27 9 0.0416 2918 77 905 11 33 36 29 0.055 65,796 35,764 55 11 9 22 41 9 2 7 9 0.01186 86 2 239 11 3 32 0.65 63,796 35,764 55 11 9 22 0.05 73 8,557 45 11 9 22 0.05 9 0.921 107 15 0.001186 86 2 239 11 0 22 0.055 65,796 35,764 1077 64 138 0.93 7 0 0.01186 86 2 239 11 0 22 0.055 65,796 35,798 17,793 239 738 0.93 75 0.95 0.95 0.95 0.95 0.95 0.95 10.002 1133 273 0.93 73 0.93 9.94 1 9 2 9 0.001186 86 2 239 11 0,710 153 01 133 273 0.93 73 0.93 9.74 9 9 0.01186 86 2 239 11 0,710 153 01 133 273 0.95 0.45 7 0 9 0.01186 86 2 239 11 0,710 153 01 133 273 0.95 0.45 7 0 9 0.01186 86 2 235 11 0,710 153 01 133 273 0.95 0.45 7 0 9 0.01186 86 0 9 127,235 0.35 0.35 0.35 0.35 0.35 0.35 0.35 0.		89.86707	1,440	114	188.3	8.9	23	0.82	165,244	20,205	134	26	4.5	I
89.00343 1,190 74 233 37 26 0.64 109.94 9.655 132 23 45 90.04733 696 6 5 233 133 33 54,706 736 531 082 149 W 90.04733 696 6 5 237 14 33 354,706 736 531 082 19 W 90.04735 7.133 37 96 21 0.033 54,70 133 202 14 9.2	89.00343 11.90 74 233 37 26 0.04 109.94 96.85 132 23 45 15<	8900443 1/10 74 233 37 26 0.04 10994 968 132 23 45 - 900473 750 65 237 14 34 023 54,706 551 323 45 23 04 900473 5355 42 166 14 23 0.07 313,378 24,411 65 12 92 - 900473 12335 42 18 0.05 56,3796 85,54 65 13 023 07 900466 5716 570 36 53,59 53 11 13 24 13 13 54 14 13 14 23 0.55 54,71 65 13 23 23 14 13 14 23 23 14 13 13 13 13 13 13 13 14 13 14 13 14 13 13 13 13	89,00343 1,190 74 233 37 26 0.64 109,994 9.685 132 23 45 90,0133 666 6 739 33 54,000 736 531 032 90,0173 666 6 14 23 0.03 54,000 55 12 92 91,14786 1233 71 313 36 0.03 70,1376 60.009 45.0 81 13 91,14786 737 915 71 313 36 54 0.03 715 92 92 91,14786 73 91 36 21 0.05 54,000 45.0 81 73 93 90,01616 298 77 96 73 0.075 544 133 0.24 90,4356 17 101 23 0.35 65.7 14 92 94 90,4356 16 11 23 0.563 173 <td>8990343 1,190 74 233 37 26 0.64 109.994 9.685 123 23 45 - 89.06473 66 5 237 14 23 0.77 318 52 19 20 7 - 91.1478 1233 71 213 56 28 0.83 701.376 630.99 450 81 13 0.82 W - 91.1478 1233 71 213 56 28 0.73 718 75 12 29 2 - 91.1478 1233 71 213 56 28 0.73 718 75 12 92 2 - 91.1478 1233 71 213 56 28 0.71 71837 2644 193 0.93 - 86.000118 86 5 2393 17 31 56 28 0.73 718 65 14 13 0.82 W - 90.0118 86 5 239 11 3 0.65 53,798 17.236 55,798 17 28 0.93 - 90.0118 86 5 291 33 0.65 11 31 25 64 11 31 5 - 90.0118 86 15 291 33 0.65 53,798 17.236 53,798 17.236 53,798 17 13 0.93 - 90.0118 86 2 29 210 10 22 0.55 55,3798 17.236 53,798 17.238 73 14 91 - 90.0118 86 15 206 13 20 0.75 16,60 11,912 0.69 1337 138 0.93 - 90.0118 86 5 20 10 22 0.75 16,60 11,912 0.69 1337 138 0.93 - 90.0118 86 5 20 10 22 0.75 16,60 11,912 0.90 133 275 0.45 W - 90.0118 86 5 20 10 22 0.170 113 1,912 239 133 275 0.45 W - 90.0118 86 5 20 139 27 148 275 113 0.87 138 0.93 - 91.4370 1,968 12 206 13 20.73 1363 1373 264 113 1,122 253 44 12 - 91.2356 1,94 137 148 275 113 1,912 66 111 1,152 253 738 756 113 2,75 0.45 - 91.4370 1,988 5 2 215 0.170 105 20 133 2,75 24 2 24 11 - 91.4300 1,968 5 2 23 113 10,323 557 113 1,33 2,35 27 0.45 - 91.4300 1,968 5 2 23 10,071 130 557 134 213 233 275 24 2 24 - 91.4300 1,162 34 23 10,071 130 20 20 20 20 - 91.6303 1,370 24 33 2,327 257 24 3 31 2,328 570 179 26 3.6 - 91.6303 1,370 24 33 2,327 254 130 10 2 0 23 3.6 - 91.6303 1,370 24 33 103,233 557 173 2,44 3 30 2,3 - 91.6001 1,162 34 23 0.01 190 20 20 3.6 - 91.63731 2,318 2,41 3 0,01 10 10 10 10 10 10 10 10 10 10 10 10 1</td> <td></td> <td>89.77</td> <td>1,372</td> <td>108</td> <td>274</td> <td>13</td> <td>29</td> <td>0.97</td> <td>16,682</td> <td>3,124</td> <td>1130</td> <td>273</td> <td>0.53</td> <td>I</td>	8990343 1,190 74 233 37 26 0.64 109.994 9.685 123 23 45 - 89.06473 66 5 237 14 23 0.77 318 52 19 20 7 - 91.1478 1233 71 213 56 28 0.83 701.376 630.99 450 81 13 0.82 W - 91.1478 1233 71 213 56 28 0.73 718 75 12 29 2 - 91.1478 1233 71 213 56 28 0.73 718 75 12 92 2 - 91.1478 1233 71 213 56 28 0.71 71837 2644 193 0.93 - 86.000118 86 5 2393 17 31 56 28 0.73 718 65 14 13 0.82 W - 90.0118 86 5 239 11 3 0.65 53,798 17.236 55,798 17 28 0.93 - 90.0118 86 5 291 33 0.65 11 31 25 64 11 31 5 - 90.0118 86 15 291 33 0.65 53,798 17.236 53,798 17.236 53,798 17 13 0.93 - 90.0118 86 2 29 210 10 22 0.55 55,3798 17.236 53,798 17.238 73 14 91 - 90.0118 86 15 206 13 20 0.75 16,60 11,912 0.69 1337 138 0.93 - 90.0118 86 5 20 10 22 0.75 16,60 11,912 0.69 1337 138 0.93 - 90.0118 86 5 20 10 22 0.75 16,60 11,912 0.90 133 275 0.45 W - 90.0118 86 5 20 10 22 0.170 113 1,912 239 133 275 0.45 W - 90.0118 86 5 20 139 27 148 275 113 0.87 138 0.93 - 91.4370 1,968 12 206 13 20.73 1363 1373 264 113 1,122 253 44 12 - 91.2356 1,94 137 148 275 113 1,912 66 111 1,152 253 738 756 113 2,75 0.45 - 91.4370 1,988 5 2 215 0.170 105 20 133 2,75 24 2 24 11 - 91.4300 1,968 5 2 23 113 10,323 557 113 1,33 2,35 27 0.45 - 91.4300 1,968 5 2 23 10,071 130 557 134 213 233 275 24 2 24 - 91.4300 1,162 34 23 10,071 130 20 20 20 20 - 91.6303 1,370 24 33 2,327 257 24 3 31 2,328 570 179 26 3.6 - 91.6303 1,370 24 33 2,327 254 130 10 2 0 23 3.6 - 91.6303 1,370 24 33 103,233 557 173 2,44 3 30 2,3 - 91.6001 1,162 34 23 0.01 190 20 20 3.6 - 91.63731 2,318 2,41 3 0,01 10 10 10 10 10 10 10 10 10 10 10 10 1		89.77	1,372	108	274	13	29	0.97	16,682	3,124	1130	273	0.53	I
89:96644 750 41 239 38 54,706 7519 318 62 19 W 90:04733 666 65 233 14 23 0.21 14 23 0.21 14 23 0.21 14 23 0.21 0.22 25.534 16.802 731 0.82 0.81 1.13 0.82 0.82 0.81 1.13 0.82 0.81 1.13 0.82 0.82 0.81 1.13 0.82 0.81 1.13 0.82 0.81 0.72 0.81 0.72 0.81 0.72 0.81 0.72 0.81 0.72 0.81 0.72 0	99:9664 750 41 239 38 28 0.33 54/70 7519 318 62 19 W 90:04733 656 65 237 14 23 0.07 313,374 10801 736 531 0.82 W 90:04736 656 65 237 0.07 313,374 10801 736 531 92 23 13 32 31 92 31 92 31 92 31 92 31 92 92 92 92 93	89:0664 750 41 239 38 24,706 7519 318 62 193 W 90:0473 656 65 233 166 75 331 66 13 92.2 193 W 91:14766 1233 71 313 36 23 0.77 313,378 54,411 193 42 311 531 92.2 92.2 92.2 92.2 92.2 92.2 92.2 92.2 92.2 92.2 92.2 92.2 92.2 92.2 92.2 92.2 92.2 92.2 93.2 <	89,9664 750 41 239 38 28 0.03 54,706 7519 318 62 19 89,66173 656 65 127 14 233 0.02 3133 26 531 0.82 91,14786 1,233 71 313 36 23 0.03 710,813 26,434 193 42 31 91,14786 1,233 71 313 36 23 0.03 70,376 66,000 45.0 81 31 0.82 99,01016 2918 37 201 14 23 0.03 56,434 193 42 31 99,01016 2918 37 30 12 13 36 13 32 31 33 36 31 33 34 33 34 33 34 33 34 33 34 31 34 31 34 34 34 34 34 33 34 <td>B99664 750 11 239 84 023 54,706 75,19 318 62 19 70 90.04733 56 65 12 14 34 0.02 26,534 150 14 32 0.22 23 10 28 0.14 31 0.80 65 13 0.82 W 9568776 2355 42 13 35 37 133 26,434 139 42 31 - - 9568776 2355 47 105 11 23 0.63 57,013 54,44 139 42 31 - - 90.10416 2910 11 33 0.63 46,11 11,52 53,34 13 33 -</td> <td></td> <td>89.90343</td> <td>1,190</td> <td>74</td> <td>233</td> <td>37</td> <td>26</td> <td>0.64</td> <td>109,994</td> <td>9,685</td> <td>132</td> <td>23</td> <td>4.5</td> <td>I</td>	B99664 750 11 239 84 023 54,706 75,19 318 62 19 70 90.04733 56 65 12 14 34 0.02 26,534 150 14 32 0.22 23 10 28 0.14 31 0.80 65 13 0.82 W 9568776 2355 42 13 35 37 133 26,434 139 42 31 - - 9568776 2355 47 105 11 23 0.63 57,013 54,44 139 42 31 - - 90.10416 2910 11 33 0.63 46,11 11,52 53,34 13 33 -		89.90343	1,190	74	233	37	26	0.64	109,994	9,685	132	23	4.5	I
90.04733 696 65 237 14 34 0.02 26.354 16.802 736 531 0.82 W 91.4786 1.3333 7 10 14 70 138.378 23 14 0.82 14 10.83 24 133 36 23 14 10.83 24 133 36 23 14 10.83 24 133 26 14 10.83 24 133 24 23 11 23 0.053 701.376 60.009 45.0 81 133 24 23 11 23 0.053 68.274 10.33 64.4 133 0.33 24 24 25 25 25 25 25 25 25 26 27 26 27 26 27 26 27 26 27 26 27 26 27 26 27 26 27 26 27 26 27 26 27	90.04733 6.66 6.7 237 14 34 0.02 2.5.354 16.802 7.36 531 0.82 W 91.14786 1.233 71 201 14 23 0.71 313.3 2.6434 193 42 31 - 91.14786 1.233 37 201 14 23 0.05 543.41 193 42 31 - - 89.48227 2.203 37 201 14 23 0.63 70.1376 60.009 45.0 81 13 -	9004733 666 65 237 14 34 002 26334 16802 736 531 082 W 90.46176 1,233 71 313 36 23 0.01 1 23 0.02 1 9.3 1 1 1 9.3 1 1 1 1 9.3 1 9.3 1 9.3 1 1 9.3 1 9.3 1 9.3 1 9.3 1 1 9.3 1 1 </td <td>90.04733 696 65 237 14 34 0.02 25,334 16,802 736 531 0.02 90.04776 2335 42 166 14 23 0.071 16,802 736 531 0.02 25 92 92 90.04776 1233 71 13 35 201 14 23 0.073 544 13 0.02 90.10416 2918 37 985 8.6 21 0.056 543,906 8.15 1 9.2 90.1186 846 25 239 11 23 0.056 64,011 1,152 233 0.13 90.1186 846 25 206 13 33 0.663 7,123 644 138 0.24 90.2376 91.037 85 2.0 13 33 644 138 0.24 90.24780 1,047 16 0.23 10301 153 1343 275<!--</td--><td>0.00/133 666 65 237 14 34 092 26354 16802 736 531 082 W 9.04715 2.335 42 166 14 23 0.07 318.37 20411 65 12 92 2 9.048277 2.303 37 201 14 23 0.63 701.376 6.000 45.0 81 13 22 1 2 2 2 2 1 2 3 1 2 3 1 2 3 1 3 2 3 1 3 2 3 1 3 2 3 1 3 3 3 3 1 3</td><td></td><td>89.96644</td><td>750</td><td>41</td><td>239</td><td>38</td><td>28</td><td>0.83</td><td>54,706</td><td>7,519</td><td>318</td><td>62</td><td>1.9</td><td>8</td></td>	90.04733 696 65 237 14 34 0.02 25,334 16,802 736 531 0.02 90.04776 2335 42 166 14 23 0.071 16,802 736 531 0.02 25 92 92 90.04776 1233 71 13 35 201 14 23 0.073 544 13 0.02 90.10416 2918 37 985 8.6 21 0.056 543,906 8.15 1 9.2 90.1186 846 25 239 11 23 0.056 64,011 1,152 233 0.13 90.1186 846 25 206 13 33 0.663 7,123 644 138 0.24 90.2376 91.037 85 2.0 13 33 644 138 0.24 90.24780 1,047 16 0.23 10301 153 1343 275 </td <td>0.00/133 666 65 237 14 34 092 26354 16802 736 531 082 W 9.04715 2.335 42 166 14 23 0.07 318.37 20411 65 12 92 2 9.048277 2.303 37 201 14 23 0.63 701.376 6.000 45.0 81 13 22 1 2 2 2 2 1 2 3 1 2 3 1 2 3 1 3 2 3 1 3 2 3 1 3 2 3 1 3 3 3 3 1 3</td> <td></td> <td>89.96644</td> <td>750</td> <td>41</td> <td>239</td> <td>38</td> <td>28</td> <td>0.83</td> <td>54,706</td> <td>7,519</td> <td>318</td> <td>62</td> <td>1.9</td> <td>8</td>	0.00/133 666 65 237 14 34 092 26354 16802 736 531 082 W 9.04715 2.335 42 166 14 23 0.07 318.37 20411 65 12 92 2 9.048277 2.303 37 201 14 23 0.63 701.376 6.000 45.0 81 13 22 1 2 2 2 2 1 2 3 1 2 3 1 2 3 1 3 2 3 1 3 2 3 1 3 2 3 1 3 3 3 3 1 3		89.96644	750	41	239	38	28	0.83	54,706	7,519	318	62	1.9	8
89.661762.3554216614230.77318,37829,116512922291.147861,2837131336280.74 $7(0813)$ $26,434$ 1934231290.104162,9183790.316210.66356,09656,379817.33131290.104162,9183792.116210.66356,379817.255531631290.104162,918379010512180.0.7656,379817.255531192190.104162,918379010512180.0.7556,379817.255530.871190.01126728921010290.7516,4051,2906921120.871090.021126728921010290.7516,4051,2906921120.871090.02112672892101029230.864511100736441380.24W90.042501,91718230.8645011,90731343230.44190.042501,94718230.8645011,90731343230.44191.213561,94718230.8616093109211350.450.441	89.68176 2.335 42 166 14 23 0.77 318,378 20.411 65 12 92 92 92 92 92 92 92 92 92 92 92 92 92 92 92 92 93 83 63 17 31 33 56 23 0.03 45.03 81.0 13 92 92 92 93 93 81 133 92 92 92 93	89:06176 2.355 4.2 166 14 23 0.77 313.37 20.41 6.5 12 9.2 <	89.68176 2.355 4.2 166 14 23 0.77 318,378 2.9411 65 12 9.2 91,4736 1.203 3.7 201 4 23 0.74 170813 26,344 193 42 31 91,4736 1.203 3.7 201 4 23 0.05 56,3768 65.03 47 11 92 90,10416 2.918 3.7 105 12 12 12 93 46 1 153 14 92 90,010416 2.918 3.7 105 12 18 0.05 563,788 17.7 13 91 92 90,01186 846 2.6 10 3.2 0.05 563,788 127,225 53 71 92 90,01356 15 2.06 10 3.2 0.15 0.15 0.15 0.15 0.25 0.15 0.25 0.15 0.25 0.16 0.25 0.1	80.68176 2.35 4.2 16 14 23 0.77 318.378 23411 65 12 9.2 - 90.48277 2.03 37 201 14 23 0.63 71375 5.434 193 42 31 - - 90.10416 2.03 37 201 14 23 0.63 543,906 83,564 65 14 9.2 - - 90.10416 2.91 105 12 18 0.63 54,611 1/122 533 733 0.24 W W -		90.04733	696	65	237	14	34	0.92	26,354	16,802	736	531	0.82	×
91.4736 1,283 71 313 36 28 0.74 170,813 26,434 193 42 31 42 31 42 90.48327 2.03 37 2.01 14 2.3 0.633 71,375 5.3 15 11 13 42 31 42 31 42 31 42 31 42 31 42 31 42 31 42 31 42 31 42 31 42 31 42 31 42 31 43 32 36 31 33 31 31 31 36 31 </td <td>91.14736 1,233 71 313 36 28 0.74 17.0813 36.4.34 193 42 31 5 90.04327 2.033 37 9.03 17 313 36 28 6.3 70.33 57 30.1 14 23 0.63 70.1376 6.000 4.50 8.1 133 0.23 9.1 23 23 15 11 33 0.24 33 0.24 34 133 0.24 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 37 36 37 37 37 37 37 37 36 37 37 37 37 36 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37</td> <td>91.4736 1.283 71 313 36 28 0.74 170813 2.6434 193 42 31 -2 90.43227 2.203 37 2.01 14 23 0.63 701313 2.6434 193 42 31 13 -2 90.043247 2.595 57 105 12 18 0.76 563.798 127.285 53 13 13 23 0.24 W 90.0118 846 26 23 0.75 16.405 1.530 133 275 0.41 13 0.24 W 90.0118 846 25 035 16.405 1.530 1333 275 0.41 13 0.24 W 90.04126 1930 85 206 12 133 275 0.41 13 13 23 0.41 13 13 13 13 13 13 13 13 13 13 13 13</td> <td>91.14786 1283 71 313 36 28 0.74 170.813 26.434 193 42 31 90.14776 1283 77 98.5 86 21 0.033 770.813 26.434 193 42 31 90.14775 2503 57 98.5 86 21 0.033 57.345 55 14 92.3 90.01186 846 23 105 12 0.669 4611 11/12 2539 733 0.93 90.01186 846 23 0.69 4611 11/15 2539 733 0.34 90.04284 930 84 201 11 10/710 1,530 1343 275 0.45 90.44263 123 206 7555 49.37 3773 264 138 0.27 90.4254 103 23 0.650 7555 10,710 1,530 1343 275 0.45 90.4256 1</td> <td>91,14786 1,283 71 313 36 28 0.74 170,813 26,434 193 42 31 99,49375 2,318 37 361 37 363 37 363 37 361 37 363 354,966 53,176 61,007 544 133 0,13 544 133 0,3 461 133 134 323 14 32 54 133 0,3 461 133 0,3 445 134 0,3 445 544 133 0,3 445 544 133 0,3 445 110 110 110 1111 1111 1111</td> <td></td> <td>89.68176</td> <td>2,355</td> <td>42</td> <td>166</td> <td>14</td> <td>23</td> <td>0.77</td> <td>318,378</td> <td>29,411</td> <td>65</td> <td>12</td> <td>9.2</td> <td>I</td>	91.14736 1,233 71 313 36 28 0.74 17.0813 36.4.34 193 42 31 5 90.04327 2.033 37 9.03 17 313 36 28 6.3 70.33 57 30.1 14 23 0.63 70.1376 6.000 4.50 8.1 133 0.23 9.1 23 23 15 11 33 0.24 33 0.24 34 133 0.24 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 37 36 37 37 37 37 37 37 36 37 37 37 37 36 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37	91.4736 1.283 71 313 36 28 0.74 170813 2.6434 193 42 31 -2 90.43227 2.203 37 2.01 14 23 0.63 701313 2.6434 193 42 31 13 -2 90.043247 2.595 57 105 12 18 0.76 563.798 127.285 53 13 13 23 0.24 W 90.0118 846 26 23 0.75 16.405 1.530 133 275 0.41 13 0.24 W 90.0118 846 25 035 16.405 1.530 1333 275 0.41 13 0.24 W 90.04126 1930 85 206 12 133 275 0.41 13 13 23 0.41 13 13 13 13 13 13 13 13 13 13 13 13	91.14786 1283 71 313 36 28 0.74 170.813 26.434 193 42 31 90.14776 1283 77 98.5 86 21 0.033 770.813 26.434 193 42 31 90.14775 2503 57 98.5 86 21 0.033 57.345 55 14 92.3 90.01186 846 23 105 12 0.669 4611 11/12 2539 733 0.93 90.01186 846 23 0.69 4611 11/15 2539 733 0.34 90.04284 930 84 201 11 10/710 1,530 1343 275 0.45 90.44263 123 206 7555 49.37 3773 264 138 0.27 90.4254 103 23 0.650 7555 10,710 1,530 1343 275 0.45 90.4256 1	91,14786 1,283 71 313 36 28 0.74 170,813 26,434 193 42 31 99,49375 2,318 37 361 37 363 37 363 37 361 37 363 354,966 53,176 61,007 544 133 0,13 544 133 0,3 461 133 134 323 14 32 54 133 0,3 461 133 0,3 445 134 0,3 445 544 133 0,3 445 544 133 0,3 445 110 110 110 1111 1111 1111		89.68176	2,355	42	166	14	23	0.77	318,378	29,411	65	12	9.2	I
89.482.7 2.03 37 201 14 23 0.63 71,376 60,009 45.0 81 13 - 90.10416 2.918 37 01 14 23 0.63 544,306 83,564 65 14 9.2 - 90.10416 2.918 37 36 12 0.69 544,306 83,564 65 14 9.2 - - 90.7118 846 26 239 0.55 68.274 10073 644 138 0.93 -	89.482.7 2.03 37 2.01 14 2.3 0.63 701,376 6.0009 45.0 8.1 13 - 99.10416 2.918 37 0.01 12 0.65 53.546 65 14 9.2 - 99.10416 2.918 377 36 2.3 0.65 53.546 65 13 0.3 - - - 90.01186 8.46 2.8 0.55 68.274 10.073 6.4 138 0.93 - <t< td=""><td>89-442.7 2.203 37 201 14 23 0.03 7 (1,37) 6.009 45.0 8.1 13 0</td><td>89.4827 2.203 37 201 14 23 0.63 701,376 6.000 45.0 8.1 13 90.10416 2.918 37 96. 12 0.69 543,906 83.564 65 14 92 90.10416 2.918 377 36 29 0.55 68.274 10073 64 138 0.93 90.20112 677 89 210 11 33 0.69 4.611 1,152 2339 0.73 90.02112 677 89 210 10 23 0.75 16.405 1,520 133 0.74 90.4253 2,177 45 181 23 23 0.75 16.405 1,520 133 0.74 91.3716 934 27 45 10 0.75 16.405 1.320 0.87 112 0.87 91.32544 1,047 45 180 23 0.35 0.45 113 0.45</td><td>89.482.77 2.03 37 201 14 23 0.63 701.376 6.009 45.0 8.1 13 - 90.10416 2.5915 57 105 12 0.66 54.798 13.3 64.1 11.32 23.39 13.3 0.93 -<td></td><td>91.14786</td><td>1,283</td><td>71</td><td>313</td><td>36</td><td>28</td><td>0.74</td><td>170,813</td><td>26,434</td><td>193</td><td>42</td><td>3.1</td><td>I</td></td></t<>	89-442.7 2.203 37 201 14 23 0.03 7 (1,37) 6.009 45.0 8.1 13 0	89.4827 2.203 37 201 14 23 0.63 701,376 6.000 45.0 8.1 13 90.10416 2.918 37 96. 12 0.69 543,906 83.564 65 14 92 90.10416 2.918 377 36 29 0.55 68.274 10073 64 138 0.93 90.20112 677 89 210 11 33 0.69 4.611 1,152 2339 0.73 90.02112 677 89 210 10 23 0.75 16.405 1,520 133 0.74 90.4253 2,177 45 181 23 23 0.75 16.405 1,520 133 0.74 91.3716 934 27 45 10 0.75 16.405 1.320 0.87 112 0.87 91.32544 1,047 45 180 23 0.35 0.45 113 0.45	89.482.77 2.03 37 201 14 23 0.63 701.376 6.009 45.0 8.1 13 - 90.10416 2.5915 57 105 12 0.66 54.798 13.3 64.1 11.32 23.39 13.3 0.93 - <td></td> <td>91.14786</td> <td>1,283</td> <td>71</td> <td>313</td> <td>36</td> <td>28</td> <td>0.74</td> <td>170,813</td> <td>26,434</td> <td>193</td> <td>42</td> <td>3.1</td> <td>I</td>		91.14786	1,283	71	313	36	28	0.74	170,813	26,434	193	42	3.1	I
90.10416 2918 37 98.5 8.6 21 0.69 548,906 83,564 6.5 14 9.2 - 89.7473 1/714 80 373 12 18 0.76 563,798 127,285 53 13 0.93 - - 99.7473 1/714 80 273 11 32 0.65 563,798 12.90 69.2 11 9.2 - <td< td=""><td>90.100416 2918 37 98.5 8.6 21 0.69 548,906 83,564 65 14 9.2 - 90.100416 2,918 37 96 27 16 0.76 563,798 173 16 9.2 - - 90.02112 672 89 377 36 29 0.55 9.611 1,152 2539 738 0.24 W 90.02112 672 89 270 10 23 0.11 10710 1,530 1343 273 0.44 $-$ 90.04356 15 200 18 23 0.550 193 23 0.44 $-$ - 91.02364 193 217 10 23 23 0.69 4.611 1,152 253 0.44 0 - - - - - - - - - - - - - - - - -</td><td>90.10416 2918 37 98.5 8.6 21 0.69 543,906 83.554 6.5 14 9.2 - 89.99476 2,593 57 105 12 18 0.76 563,798 105 13 9.0 3 15 011 - <</td><td>90.10416 2.918 37 98.5 8.6 21 0.69 548,906 83.564 6.5 14 9.2 89.2437 2,995 57 105 12 18 0.765 563.738 13 11 9.2 89.2473 1,714 8 37 36 12 18 0.76 563.738 15 11 9.2 90.01186 846 26 239 11 33 0.69 4,611 1,152 2539 738 0.24 90.01186 846 26 19 32 0.69 4,611 1,152 2539 738 0.45 90.41266 1,926 15 206 32 23 0.35 0.45</td><td>90.10416 2918 37 98.5 8.6 21 0.69 548,06 83,564 6.5 14 9.2 - 89.24976 2.595 57 105 12 18 0.76 563.795 53 14 9.2 - 89.24976 2.595 57 105 12 18 0.75 563.795 53 138 0.93 - - 90.01186 846 26 21 0.75 16.407 1.152 2539 738 0.24 0 90.44250 1.93 86 1.1 1.0710 1.530 184 138 0.93 -</td></td<> <td></td> <td>89.48227</td> <td>2,203</td> <td>37</td> <td>201</td> <td>14</td> <td>23</td> <td>0.63</td> <td>701,376</td> <td>600'09</td> <td>45.0</td> <td>8.1</td> <td>13</td> <td>I</td>	90.100416 2918 37 98.5 8.6 21 0.69 548,906 83,564 65 14 9.2 - 90.100416 2,918 37 96 27 16 0.76 563,798 173 16 9.2 - - 90.02112 672 89 377 36 29 0.55 9.611 1,152 2539 738 0.24 W 90.02112 672 89 270 10 23 0.11 10710 1,530 1343 273 0.44 $-$ 90.04356 15 200 18 23 0.550 193 23 0.44 $-$ - 91.02364 193 217 10 23 23 0.69 4.611 1,152 253 0.44 0 - - - - - - - - - - - - - - - - -	90.10416 2918 37 98.5 8.6 21 0.69 543,906 83.554 6.5 14 9.2 - 89.99476 2,593 57 105 12 18 0.76 563,798 105 13 9.0 3 15 011 - <	90.10416 2.918 37 98.5 8.6 21 0.69 548,906 83.564 6.5 14 9.2 89.2437 2,995 57 105 12 18 0.765 563.738 13 11 9.2 89.2473 1,714 8 37 36 12 18 0.76 563.738 15 11 9.2 90.01186 846 26 239 11 33 0.69 4,611 1,152 2539 738 0.24 90.01186 846 26 19 32 0.69 4,611 1,152 2539 738 0.45 90.41266 1,926 15 206 32 23 0.35 0.45	90.10416 2918 37 98.5 8.6 21 0.69 548,06 83,564 6.5 14 9.2 - 89.24976 2.595 57 105 12 18 0.76 563.795 53 14 9.2 - 89.24976 2.595 57 105 12 18 0.75 563.795 53 138 0.93 - - 90.01186 846 26 21 0.75 16.407 1.152 2539 738 0.24 0 90.44250 1.93 86 1.1 1.0710 1.530 184 138 0.93 -		89.48227	2,203	37	201	14	23	0.63	701,376	600'09	45.0	8.1	13	I
89.99476 2.595 57 105 12 18 0.76 563.798 127.285 53 15 11 -1 90.72473 $1/714$ 89 377 36 295 663.748 10073 644 138 0.93 -1 90.72473 $1/714$ 89 277 064 1383 0.23 0.93 -1 90.04250 127 86 26 110 29 0.75 6647 138 0.93 -1 90.04250 1297 86 265 19 32 111 $10/710$ 1133 275 0.45 0.75 0.45 0.75 0.45 0.75 0.45 0.75 0.45 0.75 0.45 0.75 0.45 0.75 0.45 0.75 0.45 0.75 0.45 0.75 0.45 0.75 0.45 0.75 0.45 0.75 0.45 0.75	89:72473 1,74 89 77 10 12 13 13 13 11 $-$ 90:71873 1,714 89 377 36 29 0.55 68.37,78 17.32 5539 73 0.03 $-$ 90:72182 672 89 270 10 29 0.75 16,405 1,152 2539 738 0.93 $-$ 90:04350 156 19 32 11 10,710 1,530 1343 275 0.45 $-$ 0 90:04350 156 19 32 0.76 5555 4,927 148 23 0.45 24 -	89.99476 2,595 57 105 12 137 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 37 0.03 37 0.04 37 0.04 37 37 0.04 37 36 37 36 37 36 37 36 37 36 37 36 37 36 37 37 0.04 37 37 36 37 37 36 37 37 36 37 37 36 37 37 36 37 37 36 37 37 36 37 36 37 36 37 37 36 37 37 37	89.99476 2.595 57 105 12 18 0.76 5.63.798 127.285 53 15 11 99.72473 1,714 89 377 36 29 0.55 68.274 10073 6.44 138 0.93 90.02112 672 89 210 10 29 0.75 16,405 1,290 692 112 0.87 90.02112 672 89 210 10 29 0.75 16,405 1,290 692 112 0.87 90.02112 672 89 210 10 29 0.75 16,405 1,290 692 112 0.87 90.4456 1,57 206 32 0.75 16,405 1,530 134 275 0.45 90.4456 1,970 15 206 32 18,065 2.038 756 139 0.79 91.7015 934 27 536 0,75 242 24	8939476 2.555 57 105 12 18 9939476 2.555 57 105 11 12 21 13 03 14 10 13 13 13 13 14 14 12 13 13 14 12 13 <td></td> <td>90.10416</td> <td>2,918</td> <td>37</td> <td>98.5</td> <td>8.6</td> <td>21</td> <td>0.69</td> <td>548,906</td> <td>83,564</td> <td>65</td> <td>14</td> <td>9.2</td> <td>I</td>		90.10416	2,918	37	98.5	8.6	21	0.69	548,906	83,564	65	14	9.2	I
89.72473 $1,714$ 89 377 36 29 0.55 68274 10073 644 138 0.93 -1 90.01186 846 26 239 111 33 0.24 W 90.01186 846 26 29 0.75 16405 $1,530$ 332 210 0.37 0.64 1133 273 0.47 W 90.04256 15 206 32 0.75 16405 $1,530$ 1333 275 0.47 0.67 0.67 16405 $1,720$ 0.37 0.44 -1 90.44250 $1,937$ $2,127$ 45 317 0.75 0.47 0.77 0.67 0.77	89.72473 1/714 89 377 36 29 0.053 68.274 10.073 644 138 0.033 - 90.01186 846 26 239 11 33 0.69 46.11 1,152 2539 738 0.03 - - 90.01186 846 26 19 32 0.15 10405 1,530 6324 10 0 90.04263 2,127 45 181 23 0.85 12902 135 23 0.45 C 90.44263 2,127 45 181 23 0.85 12902 135 23 0.45 C 90.44263 2,177 45 181 23 0.85 13605 1333 275 0.45 C C 91.23264 1,047 45 32 0,47 26 139 0.71 9 275 0.45 C 91.23264 1,047 16 11	89.72473 1/714 89 377 36 29 0.55 6.8.274 10073 6.44 138 0.93 90.01186 8.46 2.6 239 11 33 0.69 4.611 1.152 2339 738 0.93 90.44263 1.3 3 0.69 1.5 16,405 1.530 1343 275 0.45 C 90.44263 1.3 2.06 32 2.076 166,069 11,837 98 0.44 91.2356 1.9 2.2 0.06 76,555 4.537 2.56 1.9 2.4 91.2356 1.98 5.2 0.60 76,555 4.57 2.8 4.1 91.2356 1.98 5.2 0.65 0.33 3.756 1.39 0.79 8 91.2356 1.88 5.7 0.85 3.756 1.39 0.79 8 91.485	89/2473 1/714 89 377 36 29 0.55 68,274 10073 644 138 0.93 90/01186 846 26 239 11 11 1152 2539 738 0.24 90/01186 846 26 19 32 1.1 10/710 1,530 1343 275 0.45 90/04250 1,595 15 206 32 0.75 16,615 139 0.75 0.45 90/4256 15 206 32 0.75 16,615 139 0.75 0.45 90/4250 1,596 15 206 32 0.76 16,655 203 134 275 0.45 91/2716 1,996 1,6 1,1 16,515 148 23 44 91/2716 934 274 218 0.75 0.85 366 0.79 375 34 91/2716 189 9 11 16,436	89.72473 $1/74$ 89 377 36 29 055 68.274 10073 644 138 0933 -1 90.01186 846 26 23 211 10710 $1,152$ 2539 713 024 W 90.01186 846 26 19 32 11 10710 $1,530$ 1343 275 045 C 90.44263 2117 20 32 20 076 168.089 11837 98 22 045 C		89.99476	2,595	57	105	12	18	0.76	563,798	127,285	53	15	11	I
90.01186 846 26 239 11 33 0.69 4,611 1,152 2539 738 0.24 W 90.02112 672 89 210 10 29 0.75 16,405 1,530 1343 275 0.87 W 90.02112 672 89 210 10 29 0.75 16,405 1,530 1343 275 0.445 V 90.44250 1,956 15 206 32 23 0.76 168,089 11,837 98 16 61 - - 91.20338 783 170 14 212 72 0.60 76,555 4,927 148 23 4,11 - 91.2706 1,888 274 235 1,630 9,756 139 0,75 6 1 - - - - - - - - - - - - - - - - <td>90.01186 846 26 239 11 33 0.69 4.611 1,52 2539 738 0.24 W 90.02112 672 89 210 10 29 0.75 16,405 1,930 1343 275 0.87 V 90.02112 672 89 210 10 22 0,4755 15,90 692 112 0.87 0.87 0.902 1343 275 0.87 V V 90.44250 1,956 15 206 32 23 0.85 129,722 10,902 135 275 0.43 V</td> <td>9001186 846 26 239 11 33 0.69 4.611 1.122 2539 738 0.24 W 90021312 672 89 210 10 22 0.75 16.405 1.290 692 112 0.87 W 90.04326 15 206 32 23 0.85 19772 10.902 133 23 44 - - 90.44250 1,956 15 206 32 23 0.85 129,722 10.902 133 23 44 -</td> <td>9001186 846 26 239 11 33 0.69 4,611 1,152 2539 738 0.24 90.02112 672 89 210 10 29 0.75 16,405 1,290 692 112 0.87 90.02112 672 89 210 10 29 0.75 16,405 1,530 1343 275 0.45 90.44563 1,956 15 206 32 233 0.76 168,089 11,837 98 16 61 91.23354 1,047 45 209 18 25 0.66 76,555 4,927 148 23 41 91.23354 1,047 45 209 18 23 0.79 9.41 9.75 9.74</td> <td>9001186 846 26 239 11 33 0.69 4.611 1,152 2339 738 0.24 W 90.01112 672 89 210 10 29 0.75 1.6405 1.290 692 113 23 4.4 $$ 90.44260 1,956 15 206 32 23 0.85 1.9710 1530 133 235 4.4 $$ 90.44250 1,956 15 206 32 23 0.65 365 4927 133 235 4.4 $$ 91.4716 194 45 206 75555 4927 138 2.7 2.4 W 91.49039 16.30 94 27 28 12 30 0.78 65,403 4557 226 23 4.4 $$ 91.4013 1,837 94 27 24 1.1 16,436 2.76 113 13 23 24</td> <td></td> <td>89.72473</td> <td>1,714</td> <td>89</td> <td>377</td> <td>36</td> <td>29</td> <td>0.55</td> <td>68,274</td> <td>10,073</td> <td>644</td> <td>138</td> <td>0.93</td> <td>I</td>	90.01186 846 26 239 11 33 0.69 4.611 1,52 2539 738 0.24 W 90.02112 672 89 210 10 29 0.75 16,405 1,930 1343 275 0.87 V 90.02112 672 89 210 10 22 0,4755 15,90 692 112 0.87 0.87 0.902 1343 275 0.87 V V 90.44250 1,956 15 206 32 23 0.85 129,722 10,902 135 275 0.43 V	9001186 846 26 239 11 33 0.69 4.611 1.122 2539 738 0.24 W 90021312 672 89 210 10 22 0.75 16.405 1.290 692 112 0.87 W 90.04326 15 206 32 23 0.85 19772 10.902 133 23 44 - - 90.44250 1,956 15 206 32 23 0.85 129,722 10.902 133 23 44 -	9001186 846 26 239 11 33 0.69 4,611 1,152 2539 738 0.24 90.02112 672 89 210 10 29 0.75 16,405 1,290 692 112 0.87 90.02112 672 89 210 10 29 0.75 16,405 1,530 1343 275 0.45 90.44563 1,956 15 206 32 233 0.76 168,089 11,837 98 16 61 91.23354 1,047 45 209 18 25 0.66 76,555 4,927 148 23 41 91.23354 1,047 45 209 18 23 0.79 9.41 9.75 9.74	9001186 846 26 239 11 33 0.69 4.611 1,152 2339 738 0.24 W 90.01112 672 89 210 10 29 0.75 1.6405 1.290 692 113 23 4.4 $$ 90.44260 1,956 15 206 32 23 0.85 1.9710 1530 133 235 4.4 $$ 90.44250 1,956 15 206 32 23 0.65 365 4927 133 235 4.4 $$ 91.4716 194 45 206 75555 4927 138 2.7 2.4 W 91.49039 16.30 94 27 28 12 30 0.78 65,403 4557 226 23 4.4 $$ 91.4013 1,837 94 27 24 1.1 16,436 2.76 113 13 23 24		89.72473	1,714	89	377	36	29	0.55	68,274	10,073	644	138	0.93	I
90.02112 672 89 210 10 29 0.75 16,405 1,290 692 112 0.87 W 90.64284 930 85 265 19 32 1,1 10,710 1,530 1343 275 0,45 C 90.64284 930 85 265 19 32 0.88 129,722 10,902 1343 275 0,45 C 90.44250 1,956 15 206 32 23 0,76 186,089 11837 98 16 6.1 - - 91.32564 1,047 45 209 18 25 0,75 45 23 4,44 - 91.37264 1,947 48 307 4,7 31 0,85 3,755 4927 16 6,1 - - 91.37760 1,898 52 236 4,557 252 4,2 2,4 - 91.40315 1,837	90.02112 672 89 210 10 29 0.75 16,405 1.290 692 1112 0.87 W 90.64284 930 85 265 19 32 1.1 10,710 1,530 1343 275 0.45 C 90.64284 930 85 265 19 32 0.85 1530 1343 275 0.45 C 90.44250 1,556 15 209 18 23 0.75 4,41 2 91.23264 1,047 45 209 18 23 0.76 168,095 2.038 756 139 0.79 6 91.23264 1,047 45 209 18 23 0.75 8,41 2 91.23264 1,047 45 209 18 23 0.75 8,41 2 91,43760 1,883 756 13,73 306 575 137 305 50 20	90.02112 672 89 210 10 29 0.75 16,405 1.290 692 112 0.87 W 90.64284 30 85 265 19 32 1.1 10,710 1;530 1343 275 0.45 C 90.64284 1,947 45 206 32 23 0.86 166,089 11,837 98 16 61 - 91.23264 1,047 45 209 18 25 0.60 76,555 4927 148 23 41 - 91.21755 934 274 218 30 0.78 56,403 3,773 306 50 2.09 16 91.43760 1,898 52 235 11 15,405 3,773 306 50 2.0 - - - - - - - - - - - - - - - - - -	90.02112 672 89 210 10 29 0.75 16,405 1,290 692 112 0.87 90.64284 930 85 265 19 32 1.1 10,710 1,530 1343 275 0.45 90.64284 930 85 265 19 32 0.85 129,722 10,902 135 23 44 90.44263 1,917 45 206 76 188,055 4927 148 23 41 91.23354 1,966 15 209 18 25 0.60 76,555 4927 148 23 41 91.20358 783 48 307 47 31 0.85 18,065 2.038 156 139 0.79 91.43760 1,930 92 275 41 1 154,66 9.276 139 0.79 91.48539 1,770 14 215 10 26 11 1	$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$		90.01186	846	26	239	11	33	0.69	4,611	1,152	2539	738	0.24	×
90.64284 930 85 265 19 32 1.1 10.710 1,530 1343 275 0.45 C 90.44263 2,127 45 181 23 23 0.385 129,722 10,902 135 23 4,4 - 90.44250 1,956 15 206 32 23 0.76 168,089 11,837 98 16 61 - 91.20358 783 48 307 47 31 0.60 76,555 4,927 148 23 4,1 - 91.20358 934 274 268 17 0.85 18065 2,038 756 139 0.79 6 - 91.43578 1,398 52 235 1,4 23 2,43 756 139 0,79 6 - - - - - - - - - - - - - - - -	90.64284 930 85 265 19 32 1.1 10/710 1,530 1343 275 0.45 C 90.44263 2,127 45 181 23 0.85 129,722 10,902 135 23 44 2 90.44263 2,127 45 181 23 0.85 129,722 10,902 135 23 44 2 91.43760 18 23 4,73 31 0.85 18,065 2,038 756 139 0.79 5 24 2 24 1 24 1 1 16,4367 3,773 306 59 23 41 24 1 1 16,4367 3,773 306 50 20 20 20 23 44 2 24 24 24 24 1 1 16,517 10 25 24 2 24 2 24 2 24 2 24 2	90.64284 930 85 265 19 32 1.1 10.710 1,530 1343 275 0.45 C 90.44263 2,112 45 18 23 23 0.85 129722 10902 135 23 44 2 91.43760 1,956 15 206 32 23 0.85 18,065 2,038 756 139 0.79 5 91.43760 1,87 48 307 47 31 0.85 18,065 2,038 756 139 0.79 5 91.43760 1,898 52 235 14 24 1.1 15,436 306 50 20 23 44 23 91.48538 1,770 14 212 72 24 1.1 15,436 306 50 20 23 44 23 34 23 24 23 24 25 24 23 24 25 24	90.64284 930 85 265 19 32 1.1 10,710 1,530 1343 2.75 0.45 90.44263 1,956 15 18 23 0.35 129,722 10,902 135 23 44 90.44250 1,956 15 206 32 23 0.85 10,972 135 23 44 91.20358 783 48 307 47 31 0.85 166,085 139 0.79 61 91.20358 783 48 307 47 31 0.85 165,403 4,557 252 24 24 21 91.43760 14 212 7/2 26 11 64,367 3773 306 50 20 20 91.43760 1,630 24 212 7/2 26 11 64,367 3773 306 50 20 20 91.48350 1,630 22 26 11	9064284 930 85 265 19 32 11 10/710 1,530 1343 275 045 C 9044263 2,127 45 181 23 23 0.045 15,55 4,927 184 23 4,4 - 91,23354 1,047 45 209 18 25 0.60 76,555 4,927 188 23 4,1 - 91,20358 783 48 307 47 31 0.85 18,065 2,038 756 139 0.79 E 91,20358 783 48 307 47 31 0.85 18,065 2,038 756 139 0.79 E 91,4316 1,709 22 23 1,1 16,4367 3,773 3,06 2,6 3,6 756 139 0,79 E 9,3467 17 5,8 2 2,4 2 2,4 2 2,4 2 2,6 13<		90.02112	672	89	210	10	29	0.75	16,405	1,290	692	112	0.87	×
90.44263 2.127 45 181 23 23 0.85 129.722 10.902 135 23 44 - 90.44250 1,956 15 206 32 23 0.85 129,722 10,902 135 23 44 - 91.23564 1,947 45 209 18 25 0.60 76,555 4,927 148 23 411 - 91.20358 783 48 307 477 31 0.85 168,089 11,837 98 16 61 - - 91.43760 1,83 274 5,138 756 139 0.79 5 2 41 - - 91.43760 1,898 57 3,773 306 9.73 42 -	90.44263 $2,127$ 45 181 23 23 0.85 129,722 10,902 135 23 44 90.44256 1,956 15 200 18 23 0.76 168,089 11,837 98 16 61 91.23264 1,947 45 200 18 25 0.60 7,5555 4,927 148 23 4,11 91.23256 1,936 55 129 0.755 4,557 252 42 24 1 91.43760 1,898 52 235 14 24 1.1 154,680 9,276 103 177 58 91,4039 1,62 34 23 3,773 306 50 20 20 20 20 20 20 20 21 24 24 24 24 24 24 24 24 24 24 24 24 25	90.44253 2,1127 45 181 23 23 0.85 129,722 10,902 135 23 44 - 91.4256 1,956 15 206 32 23 0.76 168,089 11,837 98 16 61 - 91.12526 1,956 15 206 32 23 0.76 168,089 11,837 98 16 61 - 91.17115 934 274 268 12 30 0.78 65,403 4,557 252 42 - - 91.43760 1,898 52 235 14 24 1.1 15,418 23 67 20 23 21 - </td <td>90.44263 2,127 45 181 23 23 0.88 129,722 10,902 135 23 44 90.44250 1,956 15 206 32 23 0.68 166.089 11,837 98 16 61 91.32364 1,947 45 209 18 25 0.60 76,555 4,927 148 23 41 91.32364 1,947 45 209 18 25 209 18 23 41 91.32368 783 48 307 47 31 0.05 16,60 9,276 139 0.79 91.48538 1,770 14 212 72 26 1,1 154,660 9,276 103 177 58 91.49039 1,630 94 217 10 26 033 103,263 5,670 179 28 3,7 91.5216 1,162 34 23 3,733 5,180 1</td> <td>90.44263 2,127 45 181 23 23 0.385 129,722 10,902 135 23 4,4 - 90.44250 1,956 15 206 165,555 1837 93 4,4 - 91.20358 783 48 307 4,7 31 0.85 18,065 2,038 756 139 0.79 6 1 - - 91.20358 783 48 307 4,7 31 0.85 18,065 2,038 756 139 0.79 6 1 -</td> <td></td> <td>90.64284</td> <td>930</td> <td>85</td> <td>265</td> <td>19</td> <td>32</td> <td>1.1</td> <td>10,710</td> <td>1,530</td> <td>1343</td> <td>275</td> <td>0.45</td> <td>υ</td>	90.44263 2,127 45 181 23 23 0.88 129,722 10,902 135 23 44 90.44250 1,956 15 206 32 23 0.68 166.089 11,837 98 16 61 91.32364 1,947 45 209 18 25 0.60 76,555 4,927 148 23 41 91.32364 1,947 45 209 18 25 209 18 23 41 91.32368 783 48 307 47 31 0.05 16,60 9,276 139 0.79 91.48538 1,770 14 212 72 26 1,1 154,660 9,276 103 177 58 91.49039 1,630 94 217 10 26 033 103,263 5,670 179 28 3,7 91.5216 1,162 34 23 3,733 5,180 1	90.44263 2,127 45 181 23 23 0.385 129,722 10,902 135 23 4,4 - 90.44250 1,956 15 206 165,555 1837 93 4,4 - 91.20358 783 48 307 4,7 31 0.85 18,065 2,038 756 139 0.79 6 1 - - 91.20358 783 48 307 4,7 31 0.85 18,065 2,038 756 139 0.79 6 1 -		90.64284	930	85	265	19	32	1.1	10,710	1,530	1343	275	0.45	υ
90.44250 $1,956$ 15 206 32 23 0.76 $168,089$ $11,837$ 98 16 61 $ 91.23264$ $1,047$ 45 209 18 25 0.60 76555 4927 148 23 411 $ 91.23264$ $1,047$ 45 209 18 25 0.60 76555 4927 148 23 0.79 E 91.17115 934 274 268 12 30 0.78 $65,403$ $4,557$ 252 422 244 $ 91.43760$ $1,898$ 52 235 14 212 12 23 0.78 65 224 $ 91.43760$ $1,898$ 52 235 14 212 72 14 212 22 235 475 222 224 $ 91.43760$ $1,898$ 52 235 14 1.1 $65,403$ $4,557$ 252 422 24 20 91.43039 $1,630$ 94 212 10 22 257 31 27 29 3407 244 39 25 91.52150 $1,709$ 22 257 18 30 0.64 $49,382$ 3407 244 39 25 25 91.6307 968 56 229 3726 179 229 346 26 26 91.63275 968 56 229 229 229 229 25	90.44250 1,556 15 206 32 23 0.76 168,089 11,837 98 16 6.1 - 91.23264 1,047 45 209 18 25 0.60 76,555 4,927 148 23 4.1 - 91.20358 783 78 307 47 31 0.85 18,065 2.038 756 139 0.79 E 91.17115 934 274 268 1.1 154,680 9.276 103 17 5.8 209 23 91.43760 1,700 14 212 7.2 2.6 1.1 154,680 9.276 103 17 5.8 2.0	90.44250 1956 15 206 32 23 0.76 168,089 11,837 98 16 61 - 91.23358 783 45 209 18 25 0.60 76,555 4,927 148 23 411 - 91.20358 783 85 209 18 25 0.60 76,555 4,927 148 23 411 - - 91.1715 934 274 266 1.1 154,680 9,276 103 177 58 - - 91.43760 1,898 52 235 14 24 1.1 154,680 9,276 103 177 58 - - 91.43750 968 56 20 206 20 20 20 - - 91.2375 968 56 23 3773 306 56 23 347 24 36 16 - - - <td>90.44250 1,956 15 206 32 223 0.76 168,089 11,837 98 16 61 91.23254 1,047 45 209 18 25 0.60 76,555 4,927 148 23 41 91.20358 783 48 307 47 31 0.85 16,655 4,927 148 23 41 91.20358 783 574 30 0.78 65,403 4,557 23 42 24 17 55 24 24 24 11 15,4680 9276 103 17 58 26 23 34 56 26 23 34 23 41 56 35 56 26 26 26 26 26 35 56 26 26 35 56 26 35 56 26 26 36 26 26 36 26 36 26 26 36 2</td> <td>90.44250 1,956 15 206 32 223 0.76 168,089 11,837 98 16 61 - 91.23254 1,047 45 209 18 25 0.60 76,555 4927 148 23 0.79 61 - 91.23254 1,047 45 209 18 25 0.60 76,555 4927 148 23 0.79 61 - - 91.43760 1,898 52 235 14 24 1.1 154,680 9276 103 17 58 - - 91.48538 1,770 14 212 7.2 26 1.1 154,680 9276 103 17 58 -</td> <td></td> <td>90.44263</td> <td>2,127</td> <td>45</td> <td>181</td> <td>23</td> <td>23</td> <td>0.85</td> <td>129,722</td> <td>10,902</td> <td>135</td> <td>23</td> <td>4.4</td> <td>I</td>	90.44250 1,956 15 206 32 223 0.76 168,089 11,837 98 16 61 91.23254 1,047 45 209 18 25 0.60 76,555 4,927 148 23 41 91.20358 783 48 307 47 31 0.85 16,655 4,927 148 23 41 91.20358 783 574 30 0.78 65,403 4,557 23 42 24 17 55 24 24 24 11 15,4680 9276 103 17 58 26 23 34 56 26 23 34 23 41 56 35 56 26 26 26 26 26 35 56 26 26 35 56 26 35 56 26 26 36 26 26 36 26 36 26 26 36 2	90.44250 1,956 15 206 32 223 0.76 168,089 11,837 98 16 61 - 91.23254 1,047 45 209 18 25 0.60 76,555 4927 148 23 0.79 61 - 91.23254 1,047 45 209 18 25 0.60 76,555 4927 148 23 0.79 61 - - 91.43760 1,898 52 235 14 24 1.1 154,680 9276 103 17 58 - - 91.48538 1,770 14 212 7.2 26 1.1 154,680 9276 103 17 58 -		90.44263	2,127	45	181	23	23	0.85	129,722	10,902	135	23	4.4	I
91.33264 1,047 45 209 18 25 0.60 76,555 4,927 148 23 4,1 - 91.20358 783 48 307 47 31 0.85 18,065 2.038 756 139 0.79 E 91.17115 934 274 268 12 30 0.78 65,403 4,577 252 42 24 - 91.43760 1,898 52 235 14 24 1.1 154,680 9276 103 177 58 - 91.48538 1,770 14 212 72 26 1.1 154,680 9276 103 177 58 - 91.49039 1,630 94 215 72 26 1.1 154,680 9276 103 177 58 - - 91.49039 1,630 94 215 72 26 13 103 177 58 17 58 - - - - 91,93 58 56 29	91.23264 1,047 45 209 18 25 0.60 76,555 4,927 148 23 4,1 - 91.20358 783 48 307 47 31 0.85 18,065 2,038 756 139 0.79 E 91.17115 934 274 268 1.1 16,4367 3,773 306 50 2.0 - 91.43760 1,4 212 7.2 2.6 1.1 16,4,367 3,773 306 50 2.0 - - 91.48538 1,770 14 212 7.2 2.6 0.11 163,463 9,276 103 17 5.8 2.0 2.0 - - - - - - - - - 91,4933 5,670 179 2.9 3,47 5.8 -	91.23264 1,047 45 209 18 25 0.60 76,555 4,927 148 23 4,1 91.20358 783 48 307 47 31 0.85 18,065 2.038 756 139 0.79 E 91.77115 934 274 268 12 30 0.73 65,403 4,577 252 42 2.4 91.43760 1,898 52 235 14 24 1.1 154,680 9276 109 20 20 20 20 20 20 20 20 20 20 20 20 20 20 21 27 291,57 31 27 091,374 5180 166 26 36 25 25 29 25 25 25 25 25 25 25 25 26 20 20 26 26 26 26 26 26 26	91.23264 1,047 45 209 18 25 0.60 76,555 4,927 148 23 4,1 91.23264 1,047 45 209 18 25 0.00 76,555 4,927 148 23 4,1 91.20358 783 48 307 47 31 0.85 18065 2,038 756 139 0,79 91.47105 14 212 7.2 26 1,1 15,4,680 9,276 103 177 5,6 34 24 24 21 177 24 21 17 56 23 306 56 20 34 91.45003 1,630 94 212 7.2 26 0.83 103,263 5,670 179 26 34 91.454680 9,13204 5,180 166 26 34 375 36 35 36 35 36 35 36 35 36 35 36 </td <td>91.332641,0474520918250.60$76,555$$4,927$1482341-91.3056878378387730675,4033773306502079E91.17115918852235110.8565,40337733065020-91.485381/70142127.2261.1154,6809,276103175.8-91.485381/700142127.2261.1154,6809,276103175.8-91.485381/700142127.2260.11154,6809,276103175.8-91.487381/7002225731270.970.83103,2635,6701795.8-91.45237596202026270.9714315413120.39291.672111.03866286200.64493823,4072443925991.672111.03866286200.7324439259991.672111.03866286200.7916102103101091.672111.038662863.72443120.395.95.91091.672111.03866286202055.4101102<td></td><td>90.44250</td><td>1,956</td><td>15</td><td>206</td><td>32</td><td>23</td><td>0.76</td><td>168,089</td><td>11,837</td><td>98</td><td>16</td><td>6.1</td><td>I</td></td>	91.332641,0474520918250.60 $76,555$ $4,927$ 1482341-91.3056878378387730675,4033773306502079E91.17115918852235110.8565,40337733065020-91.485381/70142127.2261.1154,6809,276103175.8-91.485381/700142127.2261.1154,6809,276103175.8-91.485381/700142127.2260.11154,6809,276103175.8-91.487381/7002225731270.970.83103,2635,6701795.8-91.45237596202026270.9714315413120.39291.672111.03866286200.64493823,4072443925991.672111.03866286200.7324439259991.672111.03866286200.7916102103101091.672111.038662863.72443120.395.95.91091.672111.03866286202055.4101102 <td></td> <td>90.44250</td> <td>1,956</td> <td>15</td> <td>206</td> <td>32</td> <td>23</td> <td>0.76</td> <td>168,089</td> <td>11,837</td> <td>98</td> <td>16</td> <td>6.1</td> <td>I</td>		90.44250	1,956	15	206	32	23	0.76	168,089	11,837	98	16	6.1	I
91.20358 783 48 307 47 31 0.85 18,065 2.038 7.56 139 0.79 E 91.17115 934 274 268 12 30 0.78 65,403 4,577 252 42 2.4 - 91.43760 1,898 52 235 14 24 1.1 154,680 9276 103 177 58 - 91.48538 1,770 14 212 7.2 26 1.1 154,680 9276 103 177 58 - 91.49039 1,630 94 215 10 26 0.83 103,263 5670 177 58 - 91.52150 1,709 22 231 23 3773 5180 166 26 36 - - 91.52150 1,162 34 225 13 223 347 24 10 17 9 25 - -	91.20358 783 48 307 47 31 0.085 18065 2.038 7.56 139 0.79 E 91.17115 934 274 268 12 30 0.78 65,403 4,557 252 42 2.4 - 91.43760 1,898 52 235 14 2.6 1.1 154,680 9,776 103 17 5.8 - 91.43760 1,700 14 212 7.2 26 1.1 154,680 9,776 103 17 5.8 - 91.43709 1,630 94 215 10 209 26 038 10,3263 5,670 179 29 3.4 - 91.52150 1,700 24 23 3,07 244 39 2.5 - 91.62375 968 56 24 49,382 3,407 244 39 2.5 - 91.62211 1,038 66	91.20358 783 48 307 47 31 0.85 18,065 2.038 756 139 0.79 E 91.17115 934 274 268 12 30 0.78 65,403 4,557 252 24 2 91.17115 934 274 268 12 30 0.78 65,403 4,557 252 42 2.4 2 91.43760 1,898 52 235 14 24 1.1 154,680 9,276 103 17 5.8 20 20 20 20 20 20 20 20 20 20 20 20 20 21 21 23 3407 24 31 25 24 25 29 16 26 36 36 20 20 20 20 20 20 20 20 20 21 21 21 21 21 21 21 21 21 <td>91.20358 783 48 307 47 31 0.85 18065 2.038 756 139 0.79 91.17115 934 274 268 12 30 0.78 65,403 4,577 252 42 24 91.17115 934 274 268 12 30 0.78 65,403 4,577 252 42 24 91.43760 1,898 52 235 14 212 72 26 13 0.79 91.43760 1,898 52 235 14 212 72 26 131 179 27 26 91.43750 1,709 22 257 31 27 0.97 97,374 5,180 16 26 3.6 91.5375 968 56 286 3.29 3,407 244 39 2.5 91.67211 1,038 66 286 0.83 10,401 1,431 1541 312</td> <td>91.17115 934 307 47 31 0.85 18,065 2,038 756 139 0.79 E 91.17115 934 274 268 12 30 0,78 65,403 4,557 252 42 2,4 - 91.17115 934 274 268 12 30 0,78 65,403 4,557 252 42 2,4 - 91.48538 1,770 14 212 72 26 1,1 154,568 3,773 306 50 23 -</td> <td></td> <td>91.23264</td> <td>1,047</td> <td>45</td> <td>209</td> <td>18</td> <td>25</td> <td>0.60</td> <td>76,555</td> <td>4,927</td> <td>148</td> <td>53</td> <td>4.1</td> <td> </td>	91.20358 783 48 307 47 31 0.85 18065 2.038 756 139 0.79 91.17115 934 274 268 12 30 0.78 65,403 4,577 252 42 24 91.17115 934 274 268 12 30 0.78 65,403 4,577 252 42 24 91.43760 1,898 52 235 14 212 72 26 13 0.79 91.43760 1,898 52 235 14 212 72 26 131 179 27 26 91.43750 1,709 22 257 31 27 0.97 97,374 5,180 16 26 3.6 91.5375 968 56 286 3.29 3,407 244 39 2.5 91.67211 1,038 66 286 0.83 10,401 1,431 1541 312	91.17115 934 307 47 31 0.85 18,065 2,038 756 139 0.79 E 91.17115 934 274 268 12 30 0,78 65,403 4,557 252 42 2,4 - 91.17115 934 274 268 12 30 0,78 65,403 4,557 252 42 2,4 - 91.48538 1,770 14 212 72 26 1,1 154,568 3,773 306 50 23 -		91.23264	1,047	45	209	18	25	0.60	76,555	4,927	148	53	4.1	
91.1/11 934 2.4 2.0 1/2 30 0.5,403 4,557 232 42 2.4 - 91.43760 1,898 52 235 14 24 11 64,367 3773 306 50 20 20 - 91.43760 1,898 52 235 14 24 11 154,680 9276 103 17 58 - - 91.49039 1,630 94 215 72 26 1,1 154,680 9276 103 17 58 - - 91.49039 1,630 22 257 31 27 097 179 179 26 36 - <	91.1/115 934 2.4 20 0.78 05,403 4,557 24 - 91.43760 1,898 52 235 14 24 1.1 15,4680 9,773 306 50 20 20 - 91.43760 1,898 52 235 14 24 1.1 154,680 9,776 103 17 5.8 - - 91.43709 1,630 94 212 72 26 1.1 154,680 9,776 103 17 5.8 - - 91.52150 1,700 14 212 72 0,83 10,3263 5,670 179 29 3.4 - <	91.1/115 934 2/4 208 12 30 0.5/403 4,557 252 42 24 - 91.43760 1,898 52 235 14 24 1.1 154,680 9,276 103 17 58 - - 91.43760 1,898 52 235 14 24 1.1 154,680 9,276 103 17 5.8 -	91.17115 954 2/4 208 12 30 0.78 4,357 3,773 222 42 24 91.43760 1,898 52 235 14 24 1.1 154,680 9,276 103 17 58 91.43760 1,898 52 235 14 24 1.1 154,680 9,276 103 17 58 91.439039 1,630 94 212 7.2 26 0.83 103,263 5,670 179 29 34 91.53375 968 56 299 26 0.97 97,374 5,180 166 26 36 25 36 26 36 25 36 25 36 26 36 </td <td>91.1/113 934 2.14 2.08 12 30 0.5,403 4,557 2.24 2.4 2.4 91.43760 1,898 52 235 14 24 1.1 64,367 3,773 306 50 20 20 2 91.43760 1,898 52 235 14 24 1.1 154,680 9,276 103 17 58 2 91.48039 1,700 24 212 10 26 0.83 103,263 5,700 179 29 3,4 2 91.52150 1,709 22 257 31 27 0.97 97,374 5,180 166 26 3,6 26 3,6 2 2 2 2 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3</td> <td></td> <td>91.20358</td> <td>/83</td> <td>48 8</td> <td>307</td> <td>4/</td> <td>- C</td> <td>0.85 07.0</td> <td>200,81</td> <td>2,038</td> <td>/20</td> <td>139</td> <td>0./9</td> <td>ц</td>	91.1/113 934 2.14 2.08 12 30 0.5,403 4,557 2.24 2.4 2.4 91.43760 1,898 52 235 14 24 1.1 64,367 3,773 306 50 20 20 2 91.43760 1,898 52 235 14 24 1.1 154,680 9,276 103 17 58 2 91.48039 1,700 24 212 10 26 0.83 103,263 5,700 179 29 3,4 2 91.52150 1,709 22 257 31 27 0.97 97,374 5,180 166 26 3,6 26 3,6 2 2 2 2 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3		91.20358	/83	48 8	307	4/	- C	0.85 07.0	200,81	2,038	/20	139	0./9	ц
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erased as river reaches downstream steepen to erode at higher rates, and knickpoints migrate headward. Erosion rates of the higher-relief catchments are highest near the southern margins of the low-relief landscapes adjacent to high, isolated glacial terrains (~27.2–27.4°N), and decrease to the north. The northern tributaries in the Puna Tsang Chu also exhibit high erosion rates and channel steepness values; however, this pattern is only based on two data points. There is also no strong correlation between erosion rates and rainfall across Bhutan (Figure 8).

Since erosion rates are generally set by rates of rock uplift relative to baselevel [e.g., *Whipple and Tucker*, 1999], we interpret our map of erosion rates in catchments not part of low-relief landscapes as a map of rock uplift rates, which suggests that the rock uplift rate pattern is nonuniform in Bhutan, and likely highest in the middle latitudes (~27.2–27.4°N). Importantly, not all of the basins flanking the low-relief landscapes are equally steep nor eroding at similar rates, which would be expected from a scenario involving a simple increase in regional rock uplift rate. These findings also imply that higher rock uplift rates in the middle latitudes of the range may have promoted the development of high terrain such as the abundant glacial land-scapes flanking the low-relief landscapes, and near the western and eastern borders of Bhutan. Taken together, these observations suggest an antiformal pattern of rock uplift rate such as might be associated with growth of a duplex stack at depth [*Boyer and Elliott*, 1982] (see Figure 2). To test our hypothesis that the topography of Bhutan may be adjusting to an antiformal uplift pattern, we turn to a landscape evolution model.

6. Landscape Evolution Modeling

We used the Channel Hillslope Integrated Landscape Development Model (CHILD) landscape evolution model [Tucker et al., 2001] to explore how fluvial systems in mountainous landscapes respond to the onset of an antiformal uplift consistent with duplex deformation midway between the crest of a range and the range front. The results of our model experiments are heuristic and illustrative to simply test the hypothesis that rock uplift and landscape back-tilting associated with the onset of duplex deformation could produce landforms analogous to the high-elevation, low-relief, landscapes in Bhutan. We do not seek a best fit model to constrain a full suite of model parameters that most completely explain the topography of Bhutan. Instead, we only focus on developing systems analogous to the Chamkhar and Wang rivers that developed low-relief, aggradational surfaces upstream of major convex knickpoints with oversteepened reaches downstream (Figures 1–5). Beyond evaluating whether the back-tilt hypothesis is plausible to explain (1) the formation of high-elevation, low-relief landscapes, (2) the wedges of sediment accumulation characteristic of these landscapes, (3) the chain of high, glaciated peaks along their southern margins, and (4) the enigmatic physiographic transition that marks their northern boundaries, we do not use the model results quantitatively. Rather, rates magnitude, and timing of Bhutanese landscape evolution are addressed independently using a combination of topographic analysis and detrital cosmogenic radionuclide erosion rates informed and guided by the landscape evolution models and presented in later sections.

To model landscape response to blind duplex growth, it is necessary to represent river incision into bedrock, as well as the transport and deposition of the sediment load, which generally precludes simple 1-D profile evolution models. It is also important that as convex knickpoints continue to migrate upstream (both laterally and vertically), the model be able to simulate the erosion of weak, recently deposited, river gravels. The simplest model that meets these requirements is the mixed or hybrid detachment and transport model [e.g., *Whipple and Tucker*, 2002]. We have configured the CHILD model to run in this mode as described in the next sections.

The formation and maintenance of major convex knickpoints and hanging valleys have been investigated using nonlinear incision models based on the availability of river gravels (tools) or their overabundance (cover) [e.g., *Gasparini et al.*, 2007; *Crosby et al.*, 2007]. While we infer that the oversteepening of large rivers draining low-relief landscapes is a manifestation of the lack of tools in response to simultaneous downstream steepening and upstream trapping of gravels in piggyback basins, we suggest, based on prior experience with such models, that current implementations of tools versus cover river incision models are incapable of effectively capturing the complexity and scale of the Bhutan landscape. Thus, we choose to work with simpler models and to focus on the question of low-relief surface formation at the scale of our larger low-relief landscapes. We return to this topic in the discussion of our model results.



Figure 5. Examples of the deep canyons that dissect low-relief landscapes in Bhutan (see Figure 2a for locations). (a) Looking south (downstream) on the Puna Tsang Chu, south of the town of Wangdue. (b) Looking south (downstream) on the Mangde Chu north of the town of Zhemgang. (c) Looking northwest in a tributary basin of the Kuri Chu northwest of the town of Mongar. (d) Looking north (upstream) on the Kulong Chu north of the city of Tashigang.

6.1. Model Formulation

In mixed or hybrid mode, CHILD tracks the evolution of surface elevations using the conservation of mass:

$$\frac{dz(x,y)}{dt} = U(x,y) - E(x,y)$$
(3)

where z(x,y), U(x,y), and E(x,y) are the spatial patterns of elevation (m), rock uplift rate relative to baselevel (m/yr), and erosion rate (m/yr) (defined as positive downward—where deposition is negative erosion). The erosion rate, E(x,y), is dictated by either detachment of bed material or the divergence of the sediment flux, whichever predicts the slower, and thus limiting, rate. With this formulation, erosion rates are determined as detachment-limited incision whenever volumetric sediment transport capacity, Q_c (m³/yr), exceeds volumetric sediment flux, Q_s (m³/yr), and as transport-limited erosion or deposition whenever $Q_c \leq Q_s$ [e.g., *Whipple and Tucker*, 2002]. In our experiments detachment-limited incision was computed using the well-known stream power incision model [e.g., *Howard and Kerby*, 1983; *Whipple and Tucker*, 1999]:

$$E = \mathcal{K}_b Q^{m_b} S^{n_b}. \tag{4}$$

where K_b is the bedrock erodibility coefficient (here K_b has the units of m^{1-3mb} yr^{mb-1}) Q is the water discharge (m³/yr), S is the channel slope (m/m), and m_b and n_b are dimensionless constants, held fixed at 0.5 and 1, respectively, in our experiments. A value of 0.5 for the m_b/n_b ratio is consistent with the findings of channel shear stress river incision models and observed steady state channel concavity [e.g., *Whipple and Tucker*, 1999]. When previously deposited sediments (tracked and termed "regolith" in CHILD) are incised under detachment-limited conditions ($Q_c > Q_s$) a higher detachment coefficient, referred to as K_r with subscript r denoting erosion of regolith rather than bedrock, is used because these are more easily eroded. Under transport-limited conditions, fluvial erosion, E, was calculated as the downstream divergence of the sediment flux [e.g., *Willgoose et al.*, 1991; *Tucker and Bras*, 1998]:

$$E = \frac{dQ_c}{dA}$$
(5a)

where

$$Q_c = K_f Q^{m_f} S^{n_f} \tag{5b}$$

 K_f is the sediment transport coefficient (here K_f has the units of m^{3-3mf} yr^{mf-1}), and m_f and n_f are dimensionless constants held fixed at values of 1.5 and 1, respectively, following *Whipple and Tucker* [2002], again to approximate typically observed concavities of steady state or graded channels [e.g., *Tucker and Whipple*, 2002]. K_f was assigned the same value as K_r in our experiments, to ensure consistent river profiles during aggradation or sediment re-incision, and to ensure that discrete convex knickpoints developed during transient channel-profile adjustment to an increase in rock uplift rate (i.e., detachment-limited incision would prevail at steady state and during a response to renewed or accelerated rock uplift), as observed in Bhutan.

At steady state (E = U), channel slope, S, increases monotonically with rock uplift rate relative to baselevel, regardless of whether incision is detachment-limited or transport-limited such that

$$S = \left(\frac{U}{K'}\right)^{\frac{1}{n}} A^{-\theta'} \tag{6}$$

where $K' = K_b$ (or K_r if incising regolith), $n' = n_b$, and $\theta' = m_b/n_b$ if incision is detachment-limited, and $K' = K_f$, $n' = n_f$, and $\theta' = (m_f-1)/n_f$ if incision is transport-limited [e.g., *Whipple and Tucker*, 2002]. Equation (6) is analogous to equation (1); the first term on the right-hand side of equation (6) is the channel steepness index (k_s).

In our modeling experiments, we used a value of $5e^{-6}$ for the erosion coefficient of bedrock (K_b) and $5e^{-5}$ for the erosional coefficient of regolith (K_r), and transport coefficient of sediment (K_f). Using equation (6), it becomes clear how the order of magnitude difference between our chosen coefficients will affect the topography within our models. For a given basin of a certain size (A) and rock uplift rate (U), the channel slope will scale inversely with the coefficients (K'). Therefore, river reaches that are incising into regolith, or those that are transport limited, will be 10 times less steep than reaches that are detachment limited.

6.2. Experimental Setup and Initial Steady State Landscape

Experiments were performed on a 30×30 km, regular triangular lattice of 250 m node spacing, with a southern open boundary. In our experiments, an antiformal uplift pattern was imposed upon a steady state landscape. To create the initial landscape, we assumed uniform regional uplift (1 mm/yr) of a random topography described by a mean elevation of 10 m and a standard deviation of 0.5 m, and we allowed the landscape to evolve until a steady state topography associated with uniform channel steepness and erosion rate was reached (Figure 9a). At steady state, this landscape was in a detachment-limited condition. A selection of longitudinal river channel profiles of varying lengths illustrates the smooth, concave profiles with uniform channel steepness values (Figure 9b). In this landscape, fluvial relief scales with catchment size and thus increases steadily toward the crest of the modeled mountain range (Figure 9b).

6.3. Imposing an Active Duplex

It is well known that fault-bend folds associated with simple thrust faults or those with multiple blind splays (horses), as is the case in a duplex, create an antiformal rock uplift pattern [*Suppe*, 1983]. Such patterns have been measured in the Siwalik mountains of the central Himalaya. The work of *Lave and Avouac* [2000] produced a detailed assessment of the rock uplift gradient associated with the MFT in central Nepal. That gradient was a peaked function with a broad apex and was significantly skewed toward the foreland. Without knowing the exact position, size, or geometry of an active blind duplex in Bhutan, we chose a similar, simple, geologically reasonable geometry. The pattern of uplift above the duplex was modeled as a strike-parallel, 20 km wide, triangular (isosceles) ridge. The front limb was pinned to the southern edge of the landscape. Uplift rates increased linearly toward the crest on each limb of the duplex. Figure 9c shows the duplex uplift pattern that we applied to our initial steady state topography. This antiformal geometry was chosen as a conservative end-member of possible uplift patterns. More extreme end-member conditions could include broader spatial patterns of high rock uplift or sharper gradients (e.g., stepped changes). However, such rock uplift patterns would only act to perturb river incision patterns more aggressively. North of the back limb of the duplex (*U*₀), which was set equal to the initial uniform rock uplift rate such that the only perturbation to the steady state landscape was the increase in uplift rate above the modeled duplex.

The maximum uplift rate at the crest of the duplex (U_h) was varied between 1.5 and 8 times greater than the initial, background uplift rate (U_h). This range of U_h/U_l ratios spans a reasonable range of expected spatial changes in vertical rock uplift rates due to the spatial variability in rock transporation vectors. For example, if the regional rock uplift rate is controlled by transportation over a 4° dipping basal décollement [*Long et al.*, 2011] and 16° dipping structures within duplexes, then we could expect a fourfold change in the regional rock uplift gradient regardless of the slip rate (see Table S2 for more details).

Although there is some evidence for orders of magnitude differences between K_b for intact bedrock and K_r for weakly indurated sedimentary sequences [*Stock and Montgomery*, 1999], the channel steepness across boundaries where channels switch from eroding bedrock channels to depositing alluvial channels often decreases only by a factor of 2–10 in Bhutan (e.g., across PT₂ and at the front of the range). As our models are not importantly sensitive to K_{fr}/K_b ratios (see Table S3), we use the intermediate value of 10 (a high-end estimate from observations in Bhutan, a and low-end estimate from previous studies [*Stock and Montgomery*, 1999]) as a representative value in the model runs presented here.

The model run with $U_h = 4U_l$ and $K_{f/r} = 10K_b$ was selected for illustration (Figure 10) as this condition effectively created convex knickpoints separating steep, rapidly eroding downstream reaches from aggradational upstream reaches, but was not so severe as to tectonically defeat rivers and cause drainage reversal [e.g., *Sobel et al.*, 2003]. We emphasize that the $K_b/K_{f/r}$ and U_h/U_l ratios used in our modeling are reasonable values but are not unique to the process of forming elevated, low-relief landscapes, nor do these ratios necessarily quantitatively describe conditions in Bhutan. The degree to which landscapes similar to observations in Bhutan form depends on the relative values of these two ratios (see Table S3 for experiment parameters tested). However, we find that our models were most sensitive to the U_h/U_l ratios are less than 3. Rock uplift ratios of greater than 5 tend to defeat and reverse drainage patterns regarless of the $K_b/K_{f/r}$ ratio. We present the above values as they permit the formation of convex knickpoints and sediment wedges upstream, similar to actual observations in Bhutan, as will be documented below.

6.4. Landscape Response to an Active Duplex

Figures 10a–10c show the initial response of our experimental landscape to the onset of active duplex deformation. The elevations of mountain peaks near the crest of the duplex have increased, and deep canyons with higher channel steepness values have formed. All channel reaches on the front limb of the duplex and a few on the back limb have remained detachment-limited. Local relief has increased greatly near the crest of the duplex and decreased in parts of the back limb and behind the duplex. However, the local relief near the back of the modeled landscape has not changed because the rivers are still detachment-limited and the rock uplift rate relative to baselevel has not changed (Figure 10c, Profile 1).

The map of erosion rates exhibits a similar pattern, but only a small fraction of the landscape has adjusted to a new erosion rate set by higher rock uplift rates. Figure 10b shows focused incision in the front limb near the

crest of the duplex. However, in the back limb deposition is prominent, as rivers adjust to the new high rock uplift rate downstream by raising their bed elevations via aggradation. Failure to match the rising local base-level set by the migrating knickpoints with a similar deposition rate would have led to a defeated, ponded river and an internally drained basin [e.g., *Humphrey and Konrad*, 2000].

River profiles within the front limb of the duplex have steepened, and fluvial relief has increased (Figure 10c). Convex knickpoints have formed in the longitudinal profiles of channels that cross the crest of the duplex. As the knickpoints migrate headward they move vertically, and set the rate of baselevel rise upstream. These knickpoints also track an important boundary between detachment- and transport-limited reaches within the landscape. The vertical movement is associated with continued surface uplift created by disequilibrium of erosion rates and rock uplift rates upstream of the knickpoint. The surface uplift rates of landscapes vary as a function of the rock uplift rate at the position of the convex knickpoints as the knickpoints migrate laterally relative to the nonuniform rock uplift pattern. Larger basins that extend to the back of the model also develop transient concave knickpoints where upper detachment-limited river reaches aggrade and become transport-limited (Figure 10c, Profile 1). The landscape created by this dichotomy in local relief and fluvial character associated with these concave knickpoints generates a subtle physiographic transition to gentler slopes and local relief downstream.

Figures 10d–10f show further response of our experimental landscape. The development of low-relief landscapes has continued behind the crest of the duplex, and detachment-limited channel reaches behind the duplex have nearly disappeared. However, convex knickpoints have migrated farther upstream into the back limb and have removed thick packages of sediment that were previously deposited. The elevation of mountain peaks and local relief has increased in the front limb and near the crest of the duplex. The region near the foreland has eroded rapidly, but the landscapes behind the crest of the duplex have been dominated by active deposition.

The sediment wedge that formed from continued deposition has migrated farther upstream, and thus, the concave knickpoint and associated physiographic transition have moved headward. This knickpoint migration decreased the area of steeper landscapes above the low-relief landscape and has made it difficult in these models to resolve the associated physiographic transition. Surface uplift has continued, but the magnitude of surface uplift, and therefore the elevation of convex knickpoints, is not the same for all rivers. The magnitude of surface uplift is greater for rivers with convex knickpoints that remained close to the crest of the duplex, as the rock uplift rate is greater at these positions. Fluvial relief no longer simply increases from the front to the back of the modeled landscape, and large peaks near the crest of the duplex have reached similar elevations as the former steady state range crest of the modeled landscape.

6.5. Model Comparison With Bhutan

The goal of our landscape evolution model experiments was to evaluate whether the key topographic characteristics of Bhutan could be created by an antiformal uplift pattern. Therefore, the patterns—more than absolute values, of channel steepness, mean elevation, and local-relief in the simulated landscapes -are the most useful metric to compare to the observed patterns of landscape morphology in Bhutan. We monitored the pattern of channel steepness because this metric contains information regarding the state of the river (i.e., if it is in, or out of equilibrium), the uplift rate it is experiencing, and its channel incision regime (i.e., K'). Despite not directly attempting to reproduce the evolution of the Bhutan Himalaya, our modeled landscape is similar in form, except for the lack of deeply incised canyons interspersed between aggraded, elevated valleys across the strike of our synthetic mountain range. The modeled landscape exhibits high mountain peaks much closer to the front of the range coincident with the region of highest uplift rate at the crest of the duplex. These high peaks are interpreted as analogous to the regions of glaciated peaks outboard of the Himalayan crest in Bhutan. To the north of the high peaks, the modeled landscape is filled with fluvial sediments and local relief has been reduced. This is very similar to our observations of the low-relief landscapes of Bhutan. A pattern of high-to-low-to-high channel steepness and local relief, from the front to the back of the model, has developed much like that observed in Bhutan. The southern transition (high-to-low channel steepness and local relief) marks the position of transient convex knickpoints in the model and in Bhutan. The northern transition (low-to-high channel steepness and local relief) marks the position of a transient concave knickpoint in the model and in Bhutan (e.g., PT₂).



Figure 6. Cartoon cross section showing the evolution of a hinterland landscape affected by a downstream zone of high rock uplift rate. Dashed gray line shows the initial river profile before duplex activity (when uniform uplift was equal to the lower uplift rate U_{l}). The black line denotes the shape of the perturbed river profile after (a) the nonuniform rock uplift rate pattern was imposed. The stippled pattern marks the packages of sediment accumulating upstream of a migrating convex knickpoint (black dot) and forming the migrating concave knickpoint upstream (white dot). Portions of the original fluvial landscape are preserved between the concave knickpoint and glacial terrains. The magnitude of surface uplift (ΔZ) can be easily calculated as the greatest difference between the former and current river profile. This magnitude calculated in this way (black markers) is much smaller than if the aggraded reaches are extrapolated to the foreland of the range (gray markers). (b) Landscape soon after duplex activation. (c) Landscape long after duplex activation. Note that older packages of sediment are cut and rotated as duplex activity continues. The upper discontinuity in the profile is created by glacial incision. U_{h} , high uplift rate at the crest of the duplex.

Armed with these observations from our experimental landscape, morphometric analysis, field observations, and new erosion rate map, we have developed a new conceptual model for the formation of the low-relief landscapes of the Bhutan Himalaya. Figure 6 shows a cartoon of this conceptual model and highlights a few key points. First and foremost, the low-relief landscapes of Bhutan are not relicts of an uplifted portion of the Himalayan foothills [e.g., Grujic et al., 2006]. This means that the magnitude of surface uplift cannot be measured by assuming the low-relief landscapes once graded to the current elevation of the mouth of the river at the foreland of the range. Second, the idea behind this new conceptual model implies that the best method for calculating the magnitude of surface uplift is measuring the difference between the modern river profile and the profile of the paleo-river projected from the modern river reaches upstream of the low-relief surfaces at the position of the convex knickpoint (ΔZ in Figure 6). Estimates of surface uplift based on projections of the low-relief surfaces themselves would lead to a gross overestimate.

7. Magnitude and Timing of Surface Uplift

7.1. Quantifying Surface Uplift

To calculate the magnitude of surface uplift (the total rock uplift since surface uplift initiation, minus the total erosion on the main stem river crossing the uplifting landscapes since surface uplift initiation), we reconstructed the form of river profiles that reflect the landscape before surface uplift occurred, and then calculated the difference between the paleo-river profiles and the modern river

profiles. We conducted our paleo-river reconstructions by projecting existing river reaches downstream using the relationship between drainage area and channel gradient along an upstream segment that has preserved the presurface uplift form [e.g., *Schoenbohm et al.*, 2004]. Our method utilized the simplicity of χ plots to make straightforward linear regressions and extrapolations of preserved river reaches. We predict new elevation values for the downstream reconstructed river based on the channel steepness (the slope of the χ plot). We report the amount of surface uplift as the difference between the modern linearized river profile (*z* versus χ) and the reconstructed linearized profile at the position of the convex knickpoint (Figure 11). Because inherent quantitative errors associated with our elevation or χ data are minimal we evaluated the uncertainty in our surface uplift calculation based on the scatter in our elevation and χ data. This was achieved by using a jackknife technique where a random subset of our preserved reach data was used in each regression. The number of data pairs used in each regression was equal to the square root of the total number of pairs in the preserved reach, which yields a rigorous assessment of the scatter. We report the magnitude of surface uplift for each preserved river reach as the mean and 2 standard deviations of 10,000 jackknifed regressions.

To produce the most accurate reconstructions of the rivers of Bhutan, we selected channel reaches within regions not apparently affected by recent rock uplift change, aggradation, or glaciation (Figure 3). Comparisons with our landscape evolution model and the observed sediment deposits both suggest that the low-relief landscapes of Bhutan were actively aggrading as they adjusted to the local baselevel rise created by a migrating convex knickpoint and are therefore not useful for reconstruction of paleo-river profiles. Thus, we restricted the downstream extent of reaches selected for analysis to upstream of the concave knickpoints found at the physiographic transition to the north of the low-relief landscapes (Figure 2b). As the Lhuentse fault may lie at or near the concave knickpoints at the northern boundary of the low-relief landscapes, we took special care to avoid the use of these reaches for our reconstructions. Of the four elevated, low-relief landscapes highlighted in this study, the Yarab and Phobjikha surfaces could not be reconstructed due to lack of suitable upstream river reaches. Therefore, we focused our river profile reconstructions on the channels of the Thimpu and Bumthang surfaces (Figure 11).

The magnitude of surface uplift each low-relief landscape experienced was calculated as the weighted mean surface uplift value of multiple tributary profiles within that landscape. Uncertainties on the mean values were calculated by propagating the individual uncertainness (described above) through the weighted mean calculation in quadrature, and then multiplying this value by the square root of the mean square weighted deviation to account for external uncertainties [see *Wendt and Carl*, 1991]. The mean surface uplift magnitudes from the Thimpu and Bumthang surfaces are 870 ± 90 m (2σ , five tributaries) and 748 ± 56 m (2σ , three tributaries), respectively.

The slight difference in magnitude may be due to variability in rock uplift rate along strike of the duplex, noise within the elevation data used to define each river reach, or the degree to which selected reaches faithfully record presurface uplift channel profiles. It is also important to note that the pattern of surface uplift along each profile cannot be simply interpreted as a spatial distribution in rock uplift rate. The difference between the modern profile and a reconstruct profile is a function of the rock deformation at the position of the convex knickpoint, minus the erosion rate at that point, but upstream of this position the surface uplift rate is the sum of the rock uplift rate and the deposition rate. In this case, the pattern of rate of rock uplift upstream of the knickpoint cannot be known without constraints on the deposition rate and geometry of the fill.

7.2. Timing of Initiation of Surface Uplift

While independent thermochronometric data constrain the recent phase of surface uplift to no earlier than 3 Ma [*Adams et al.*, 2015], our river profile reconstructions and detrital CRN erosion rates can be used to derive a more precise estimate of the timing of young surface uplift, and thus the timing of inferred duplex deformation. We used the definition of the magnitude of surface uplift given by the conservation of mass (equation (3)):

$$\Delta Z = t(U - I) \tag{7}$$

where *U* is the rock uplift rate, *I* is the incision rate into bedrock at the position of the migrating convex knickpoint, and *t* is the duration of surface uplift. We assumed that the high-relief basins adjacent to the low-relief landscapes have adjusted to a new rock uplift rate (as illustrated in the landscape evolution simulations in Figure 10) and substituted the rock uplift rate with the erosion rates in the canyons yielding:

$$t = \Delta Z(E - I) \tag{8}$$

where *E* is the characteristic erosion rate in the deep canyons near the convex knickpoint. Although *I* will be nonzero in the early stage of the landscape response, the incision rate into bedrock at the position of the knickpoint (within the back-tilted zone) has been effectively zero for most of the duration of surface uplift. This condition is created by active deposition upstream of the rising knickpoint, and the resulting protection of the bedrock channel until the instant that the knickpoint migrates past a given location and re-erodes the alluvial deposits. As such, equation (8) can be further simplified by setting I = 0, and we can use our estimates of surface uplift magnitude and rock uplift rate in the vicinity of the major convex knickpoints to calculate our best estimates of the initiation of surface uplift along each of our transects (Figure 8). The mean uncertainty of our erosion rates is 20% (2σ) of the rate. We apply a more conservative 30% (2σ) uncertainty for estimates of *E* and propagate these and the uncertainties of ΔZ in quadrature through the calculation of *t*. For the Western transect we used the following mean values: $\Delta Z = 870 \pm 90$ m and $E = 1071 \pm 321$ m/Ma (2σ , N = 3). For the Central transect we used the following mean values: $\Delta Z = 748 \pm 56$ m and $E = 823 \pm 247$ m/Ma (2σ , N = 4). For the Eastern transect we used the following mean values: $\Delta Z = 748 \pm 56$ m and $E = 957 \pm 287$ m/Ma (2σ , N = 4). For the Eastern transect, equation (8) yields durations of surface uplift of ~0.81 ± 0.29 Ma (2σ), 0.91 ± 0.29 Ma (2σ), and 0.78 ± 0.27 Ma (2σ) for the Western, Central, and Eastern transects, respectively, with a mean value of 0.8 Ma. Because the rate of incision into bedrock at the position of the convex knickpoint was likely nonzero early in the period of surface uplift (before the onset of local aggradation), our calculations will likely somewhat underestimate the duration of surface uplift. Because of this underestimation, we suggest a more conservative intiation of surface uplift to be in the last 1 Myr.

One caveat of this calculation is the assumption that our cosmogenic radionuclide erosion rates from plausibly steady state catchments (i.e., those not isolated from baselevel fall by major convex knickpoints on low-relief surfaces) reflect uplift rates that have been steady since the timing of surface uplift initiation, or the past ~1 Ma. Our topographic analysis and careful selection of basins—all those in critical landscape positions to constrain the uplift history have smooth concave profiles well described by a uniform channel steepness (k_{sn}) -strongly supports the interpretation that these landscapes are now in steady state (erosion rates balance rock uplift rates), and that rock uplift rates have been steady over the past 1-2 Ma given the response time of landscape adjustment [Whipple, 2001; Whipple and Meade, 2006]. It has also been demonstrated that cosmogenic nuclide erosion rates track well with independently measured estimates of rock uplift or longer-term erosion rates in numerous landscapes [Cyr and Granger, 2008; Matmon et al., 2003; Ouimet et al., 2009; Wittmann et al., 2007]. Similarly, modeled erosion rates from low-temperature thermochronometers averaged over the Quaternary yield similar values as nearby basin-averaged erosion rates within the Mangde and Kuri Chu valleys, ~100-300 m/Ma [Adams et al., 2015], upstream of the proposed duplex. Moreover, Adams et al. [2015] suggested that the thermochronometric data could also permit an increase in erosion rate (up to ~1000 m/Ma) during the Quaternary, provided this acceleration took place no earlier than 1.75 Ma. The consistency between the rates and timing implied by the detrital CRN erosion rates and the low-temperature thermochronometric constraints on exhumation rates supports the interpretation that the cosmogenic erosion rates are indeed quantitatively reflective of long-term erosion rates.

8. Synthesis and Discussion

8.1. Mecahnisms of In Situ Production of Low Relief

There has been a disconnect in Bhutan among (1) the temporal constraints of long-lived tectonic processes measured with geo- and thermochronometric data; (2) the more recent landscape response to tectonic and climatic processes, which are too recent to be detected with these techniques; and (3) the modern deformation field that can be measured using geodetic methods. In this study, we have attempted to bridge these gaps in order to develop a more complete picture of the evolution of the Bhutan Himalaya, and we suggest that there is a common history to all available data. Analyses of geochronometric and thermochronometric data have led past authors to suggest that shortening across Bhutan decreased secularly after the late Miocene due to the partitioning of slip between Himalayan and Shillong Plateau structures in the Miocene [Long et al., 2012; Coutand et al., 2014; Adams et al., 2015]. As described in Adams et al. [2015], the effect of this decrease would manifest as a wearing down of the Eastern Himalaya—a reduction in mean elevation, relief, and taper of the range. Nonetheless, geomorphic evidence for recent surface uplift in the Bhutanese hinterland requires a more complex tectonic scenario than that suggested by thermochronometric data alone. Indeed, if the shortening rates across the Bhutan Himalaya were once again increased (e.g., fast GPS shortening rates [Banerjee et al., 2008; Vernant et al., 2014]), after initiation of the Shillong Plateau structures, then the Himalayan range would need to return to a higher relief state and a higher taper angle. Increasing the taper of an orogen could be accommodated by duplexes in the hinterland [e.g., Robinson et al., 2003; DeCelles et al., 1995; Erickson et al., 2001; Mitra and Sussman, 1997; Ferrill and Dunne, 1989]. As such, this young duplex deformation may be associated with a structural adjustment within the Himalaya after returning to higher shortening rates from an earlier (late Miocene-Pliocene) period of reduced shortening rates.

Many previous authors have used the balanced cross sections across Bhutan to infer subsurface structure [Bhargava, 1995; McQuarrie et al., 2008; Long et al., 2011; Tobgay et al., 2012], while others have inverted erosion



Figure 7. Map of 12 year average, mean annual rainfall derived from Tropical Rainfall Measurement Mission 2B31 data set [*Bookhagen and Burbank*, 2010], and basin-averaged erosion rates in Bhutan. Low-relief fluvial landscapes are outlined in black lines. Outliers of glacial terrains are outlined with magenta lines. Dashed white boxes show the extent of transects in Figure 8. Note the high erosion rates in line with the high glacial landscapes. Low-relief landscapes are dominated by very low erosion rates.

rate data in an attempt to constrain fault geometries [Robert et al., 2011; Coutand et al., 2014; Le Roux-Mallouf et al., 2015]. There is, however, little agreement on the geometry of the sole thrust of the Bhutan Himalaya. The work of Long et al. [2011] and Tobgay et al. [2012] suggested that the size and position of exhumed and blind duplex structures are variable in size and geographic location across Bhutan, and the geometries of these structures are required to balance cross sections, but are not unique solutions. 2-D models used to invert erosion rates [Robert et al., 2011; Coutand et al., 2014; Le Roux-Mallouf et al., 2015] are limited due to their assumption of steady state topography, which we have demonstrated here and in a previous paper [Adams et al., 2013] to be false. Furthermore, these models assume that the only two free variables controlling surface erosion rates are the geometry of the sole thrust and the velocity of the upper plate, implying a complete lack of upper plate deformation (no duplex growth or out-of-sequence faulting). Our analysis recognizes and exploits the disequilibrium between rock uplift rate and erosion rate evident in Bhutan to derive a more robust estimate of temporal and spatial variability in rock uplift rate independent of limited constraints on the geometry of the sole thrust. Indeed, our estimate of the rock uplift rate at the crest of our inferred antiformal uplift (~1 mm/yr) suggests that no more than 1.5-3 mm/yr of horizontal shortening is absorbed on fault ramps within the growing antiformal stack, assuming ramp dips from 15 to 30°. The degree to which we can compare our findings to balanced cross sections and geophysical imaging of the sole thrust is limited by the fact that the dramatic re-structuring of the topography observed in Bhutan involves only ~1 km of rock uplift, well below the resolution of available balanced cross sections and knowledge of sole thrust geometry [e.g., Robert et al., 2011; Coutand et al., 2014].

Another mechanism for producing elevated, low-relief landscapes was recently proposed by *Yang et al.* [2015], whereby river capture events can create beheaded catchments with greatly reduced erosional capacity, leading to net surface uplift in response to a reduction in erosion rate. This mechanism fails in Bhutan for two primary reasons. First, according to the river capture hypothesis, relief and erosion rate reductions occur in response to reduced drainage areas. As erosion rate is proportional to A^{m_b} (equation (4)), the factor of ~10 reduction from high rates in deep canyons to low rates on the low-relief landscapes in Bhutan would require a factor of 10–100 reduction in drainage area (for $0.5 \le m_b \le 1$ as commonly assumed). Allowing for paleo-basins 10 to 100 times larger for even a fraction of the low-relief surfaces, nevermind all of them, is not plausible in Bhutan. Second, χ plots of the rivers draining low-relief landscapes show that they are shifted above the regional mean (Figures 3 and S1), which *Yang et al.* [2015] and *Willett et al.* [2014] would interpret as a signal of a drainage area *increase*, opposite that expected for the drainage capture mechanism. Moreover, our erosion rate data clearly show that these basins are losing area to adjacent basins with higher erosion rates. The high-elevation, low-relief landscapes in Bhutan are therefore incompatible with the drainage capture hypothesis of *Yang et al.* [2015].



Figure 8. Basin-averaged erosion rates from three transects in Bhutan. See Figure 7 for locations. (a–c) Basins are plotted by the mean channel steepness of each basin (ordinate; error bars are 2 standard errors), the mean latitude (abscissa; error bars denote latitude range), and erosion rate (color). Vertical gray bars mark the latitudes of glacial terrain in each transect. Black boxes denote samples from low-relief landscapes. The weaker correlation between channel steepness and erosion rate in Figure 8c may be caused by minor knickpoints not identified before sampling (see Figure S3). (d–f) Basins are plotted by the mean annual rainfall from Tropical Rainfall Measurement Mission data [*Bookhagen and Burbank*, 2010].

8.2. Analysis of Landscape Evolution Model Results

The results from our landscape evolution experiments suggest that even a small, active duplex can dramatically change the surface cover (e.g., alluvial and colluvial sediments, and bedrock) and topography of a mountain range. We designed these experiments with two important boundary conditions. (1) The sediment transport coefficient was higher than the bedrock erodibility coefficient. This relationship is observed in Bhutan where channel steepness values decrease dramatically downstream across PT₂ as fluvial processes transition from detachment- to transport-limited. (2) The uplift at the crest of the duplex was higher than the uplift rates at the ends of the limbs. This pattern is also observed in Bhutan as evident from our CRN erosion rate map (Figure 7). The flexibility of our models to allow river reaches to be either transport- or detachment-limited depending on the circumstances changed the relief structure spatially and temporally within the experimental landscape. The ratio of uplift rates set the equivalent of a rotational velocity of the back tilting in the back limb of the duplex. This uplift rate ratio $(U_h/U_l \approx 4)$ was required in our simulations to create a knickpoint that moved slowly enough to allow low-relief landscapes to form upstream but ensure that rivers were not completely defeated.

Beyond the initial testing to ensure low-relief landscapes were formed, subsequent adjustments to these boundary conditions modified the landscape response time and the scale of topographic parameters, but not the fundamental pattern of landscape response, which is the most meaningful result of our simulations. We adopted a symmetrical pattern of antiformal rock uplift for simplicity, but our main interpretations of landscape response are not contingent on this specific geometry. Indeed, the most important forcing factor within our models is the rock uplift rate gradient represented by the back limb of our modeled duplex, as this created the fluvial dynamics responsible for creating elevated, low-relief landscapes. A critical finding of these



Figure 9. (a) Initial steady state topography created using the CHILD landscape evolution model with a uniform uplift rate. Erosion rate and channel steepness values are equal in all parts of the landscape. (b) Longitudinal profiles of rivers from the initial steady state landscape. Numbers mark the locations of basins in Figure 9b. (c) Map of the rock uplift rate gradient later imposed on the initial steady state landscape. Cross section shows the shape of the uplift rate function. U_{h_r} high uplift rate at the crest of the duplex; U_h low uplift rate at the base of the duplex.

observations and experiments is that patterns of topography, erosion, and deposition in Bhutan signify that back-tilting has occurred in the middle latitudes between the southern glacial peaks and south of PT₂. As our analyses do not extend all the way to the range front, our findings do not rule out an asymmetrical rock uplift pattern. A combination of the oversteepening of major rivers draining the low-relief landscape patches, possibly due to the reduction of gravels transported across convex knickpoints, and plausible increases in erosional efficiency (higher precipitation rates and arguably more erodible rocks) at the range front would influence the uplift pattern required to explain the topography between the southern edge of the lowrelief surfaces and the range front.

By design, all drainages that crossed the active duplex in our experiments developed large convex knickpoints and the upper portions of the drainage appeared to be at least temporarily disconnected from the baselevel of the entire fluvial system by an extremely steep reach of the river (Figure 10f). This guasi-hanging valley topography was created by the selection of the uplift rate within the duplex. It was necessary to select a large uplift ratio because the basic rules for sediment transport and river incision (i.e., equations (4) and (5)) did not provide an adequate mechanism for the creation of hanging valleys in our model. Consequently, a lower uplift rate could have created hanging valleys in a model that includes a sediment-flux dependence on river incision (i.e., the tools and cover effects) [Gasparini et al., 2007; Crosby et al., 2007]. Whipple and Gasparini [2014] suggested a simple metric to consider the likelihood of creating a hanging valley. They find that, in general, the critical rock uplift rate (U_{cr}) required to create a hanging valley of a certain total drainage area (A) is dependent on the fraction of sediment passed

over the knickpoint in the form of gravel (β , dimensionless), where $U_{cr} \propto (\beta A)^{1/2}$. The form of this relationship shows that lower rock uplift rates can form hanging valleys as fewer gravels are transported across the knickpoint (i.e., as β tends toward zero). This relationship could explain why not all N-S trending rivers in Bhutan that cross the blind duplexes form elevated, low-relief landscapes (Figure 2b). Indeed, smaller basins (e.g., those of the Phobjikha and Yarab surfaces) could readily become hanging valleys, but slight differences in gravel transportation could also create hanging valleys in larger basins (e.g., the Thimpu and Bumthang surfaces). The oversteepened river reaches downstream of the large convex knickpoints

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Figure 10. (a and d) Transient topographies created using the CHILD landscape evolution model after initial, and further response to an active duplex. River channels are colored by channel steepness. (b and e) Erosion rate maps created after initial, and further response to an active duplex. Color ramps are in reference to initial steady erosion rate (e.g., portions of the landscape eroding at the initial rate are in yellow). (c and f) Longitudinal profiles created after initial, and further response to an active duplex. Red dots mark the locations of transient convex knickpoints. Numbers mark the locations of basins in Figures 10c and 10f. Blue dots mark the location of transient concave knickpoints and the juxtaposition of terrains similar to Physiographic Transition 2 in Bhutan. The dashed lines represent the initial profiles of steady state rivers (Figure 9b). The magnitude of surface uplift (ΔZ) at each time step can be measured directly. Lines mark the positions of changes in the rock uplift rate gradient seen in Figure 9c. Brown lines show the depth to bedrock and thus the depth of sediment deposits. U_{h_r} high uplift rate of at the crest of the duplex, U_{μ} low uplift rate at the base of the duplex.

in Bhutan, which are on average three times steeper than adjacent basins and trunk streams (Figure S1), suggest that the migration of these knickpoints is being retarded by the lack of tools needed to incise into bedrock. This affect could also allow for the production of low-relief landscapes from a more subtle backtiliting (i.e., lower rock uplift rate ratio). The reduction in gravel transport may be as important in the creation and preservation of the elevated, low-relief landscapes in Bhutan as the nonuniform rock uplift pattern. However, a mechanism for changes in rock uplift rate and/or the transportation of gravel is still required.

Importantly, we note that all major river systems in Bhutan do contain some portion of the low-relief landscapes (Figure 2b), if only in the headwaters of smaller tributaries. The Thimpu surface is completely contained within the Wang Chu drainage. Portions of the Phobjikha surface are located in the Puna Tsang Chu and Mangde Chu drainages. Portions of the Bumthang surface are located in the Mangde Chu, Chamkhar Chu, and Kuri Chu drainages. This observation makes it clear that while some trunk rivers were able to adjust to back-tilting and avoid significant aggradation, these drainage systems did experience this forcing and not all tributaries were able to keep up with the trunk river. In addition, aggraded sections of the Puna Tsang Chu and Kulong Chu (Figure 4) that appear as low channel steepness reaches in Figure 3 are located at the same latitudes as the elevated, low-relief landscapes, and may be further evidence that large, deeply incised streams struggle to keep up with an impinging zone of higher rock uplift rates.

Despite the simplicity of our landscape evolution model, the results of our experiments provide a useful guide to the interpretation of the low-relief landscapes of Bhutan. Our experiment confirmed that a hinterland duplex would create actively infilling and uplifting intermontane basins. There are many examples of similar processes occurring near the foreland of the Himalaya where actively growing antiforms impede drainages, and form sediment filled intermontane basins [e.g., *Valdiya*, 1993]. Among these examples, is the spectacular and well-known Kathmandu Basin [e.g., *Valdiya*, 1993], which has at times been the site of shallow lakes and low-gradient rivers from the Pliocene through the Quaternary [e.g., *Dill et al.*, 2003]. The many generations of lacustrine and alluvial and colluvial fills have dramatically reduced the local relief in this portion of the Central Nepal Himalaya.



Figure 11. Example paleo-river profile reconstructions from the (a) Thimpu and (b) Bumthang surfaces. Blue solid lines are the modern linearized profiles (see text for discussion). The gray envelope shows the range of 10,000 extrapolated linearized profiles of the preserved reaches (magenta lines). Surface uplift magnitudes (ΔZ) are reported as the mean and 2 standard deviations of the 10,000 regression results.

Our landscape evolution experiment also supports the hypothesis that such lowrelief landscapes are transient features whose positions are controlled by headward migrating, convex knickpoints, as evident from the dichotomy in erosion rates between the low-relief landscapes and adjacent canyons. Most importantly, we found that these low-relief landscapes could be formed in situ during uplift (Figure 6). This point leads us to an important new interpretation: that Bhutan's low-relief landscapes did not form a terrain analogous to the foothills of the central Himalaya, despite the similarity in topographic character.

Our experiments also provide interesting insight into the formation of PT_2 in Bhutan. A break in local relief and mean elevation formed upstream of the duplex in our experiment. Mountain peaks upstream of the duplex continued to erode, but the resulting sediments were stored locally in broad alluvial valleys because of the impinging zone of high rock uplift rate downstream. The results of our experiments suggest that the boundary of deposition and relief reduction migrates headward and that the

strength of this signal as detected in the local relief decreases as a function of time. If PT_2 in Bhutan was formed by a similar mechanism, it is a transient landform whose position is dictated by the migration of a concave knickpoint at the northern edge of the low-relief landscapes, and not a fault. While *Adams et al.* [2013] did note a correlation of PT_2 and the Lhuentse fault, they concluded that the kinematics of the fault were not suggestive of a causative mechanism for uplift of the physiographic higher Himalaya relative to the regions to the south. However, the correlation of PT_2 and the Lhuentse fault might be expected if both were formed near the northern edge of an active blind duplex, assuming the fault marks the hinterland extent of active duplex deformation [*Adams et al.*, 2013], and the zone of aggradation caused by duplex deformation and back tilting also reaches this position. In addition, the timing of surface uplift is interesting as it is around the same time that *Adams et al.* [2013] suggested that the Lhuentse fault was likely active (Quaternary).

9. Conclusion

The variability in the surface deposits, fluvial transport state, and mean elevation across the Bhutan Himalaya suggests a dynamic landscape incompatible with either simple foreland-propagating faulting or climate change independent of tectonic adjustments. We show that (1) the creation of high-elevation, low-relief landscapes covered by thick packages of sediment accumulation, (2) the chain of high, glaciated peaks along their southern margins, and (3) the enigmatic physiographic transition that marks their northern boundaries can be explained by landscape response to a complex rock uplift rate pattern, which could be created by an active blind duplex. To explore the plausibility of this hypothesis we utilized a landscape evolution model and demonstrated that landscapes with similar patterns of topography and erosion rate are readily formed when imposing a nonuniform rock uplift pattern where rates are higher in downstream portions of the landscape.

A similar uplift pattern in Bhutan is supported by the spatial pattern of basin-averaged cosmogenic radionuclide erosion rates. These erosion rates also revealed that the low-relief landscapes are, in fact, transient and

undergoing surface uplift, as surmised in analysis of river profiles and local relief. We exploited preserved reaches of rivers that did not experience syn-surface uplift, deposition, or glacial incision, to reconstruct river profiles that are representative of the form of landscapes before recent duplex deformation. Using these paleo-river profiles we calculated the surface uplift magnitude associated with the creation of the low-relief landscapes in Bhutan, resulting in ~800 m of surface uplift. With the magnitude of surface uplift constrained, we used estimates of the current rock uplift rates from our basin-averaged erosion rates to find that surface uplift was initiated ~0.8–1 Ma before the present. The recent activation of a duplex in the hinterland of the Bhutan Himalaya may suggest the range is adjusting to increase its relief and taper after a protracted period of decreased fault slip rates due to the development of the Shillong Plateau to the south during the Miocene.

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