Development of an objective terrain analysis based method for delineating the major landforms of catchments

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Abstract: The location and distribution of landform shape and size describes and categorises many features of a catchment. Landforms give insight into soil types, arability of land, geological features, hydrological influences and even shallow ground water systems. A new, rapid and objective method is presented for delineating major landforms of a catchment, allowing comparisons within and between catchments to be made. The method uses the UPNESS index from the FLAG model (Roberts *et al.*, 1997) that is derived from digital elevation data. UPNESS was developed as an index of surface and shallow sub-surface water accumulation. An approach is described that uses the probability distribution function (pdf) of the UPNESS index to segment the pdf into three regions that represent four different landform elements. Landform categories based on these points represent; ridge tops, upper and/or mid slopes, lower slope and in-filled valley / alluvial deposits. The cut off points defining the ridge tops and the in-filled valley / alluvial deposits are identified using the point of maximum curvature of the cumulative distribution function (cdf) that correspond to the inflection points of the pdf. The mid and lower slopes are differentiated using the mid point between the inflection points of the pdf. For the purposes of this study to assess the effectiveness of the method to represent landform elements the method was applied subjectively (but still explicitly) by obtaining the inflection points by eye from a cdf of the UPNESS index. By presenting the cdf, comparisons between catchments of the shape of the cdf could be done which provide a useful analytical tool to classify catchments based on major landform characteristics. Examples are given showing how landform discrimination compares to geological maps and slope indices. This method is currently being used in New South Wales Australia in conjunction with soil landscape mapping to parameterise the soil hydraulic properties for large catchments (Murphy *et al.*, this issue). The landforms index presented in this study offers a useful technique to differentiate complex landforms and warrants consideration and development into a mathematically objective landform delineation method.

Keywords: *Terrain analysis; modelling; landforms; FLAG*

1. INTRODUCTION

Physical descriptions of catchments at a land management scale are conveniently broken down into different landforms based on landscape toposequence. Many landform classification systems exist and in Australia, most are based around the work of Speight (1990). The landforms of catchments have been used to define landscape features to aid in soil and land capability mapping (Northcote, 1978; Emery, 1985). Landform shape and patterns are used to develop geological maps. More recently Murphy *et al.* (this issue) and Vaze *et al* (in press) have used the landforms along with soil landscape mapping and pedotransfer functions to parameterise soil hydraulic properties for large catchments. Summerell (2001) and Dowling *et al.* (in press) used alluvial landform distribution within catchments for determining areas that may have been influenced by shallow local groundwater systems.

With advances in computer technology and the increased availability of high resolution Digital Elevation Models (DEM), simple terrain based modelling techniques can be efficiently used to define different landforms. One such technique involves using a slope index derived from a DEM.

By selecting categories within a slope index a representation of the major landforms within a catchment can be obtained. However selection of the categories to be used is usually made on a subjective basis and invariably further processing is needed to create and refine a landform index. For example, if a slope class of 0-2 % is used to represent flat alluvial or infilled valley landforms, often the tops of ridges also get expressed with this slope category. Gallant and Dowling (in press) provide one solution to this problem. This paper describes a new method in development that can objectively determine different landforms. The approach may also enable catchments to be classified based on major landform characteristics.

2. METHODS

The UPNESS index from the Fuzzy Landscape Analysis Geographic Information System model FLAG (Roberts *et al.*, 1997) is used in this study. The UPNESS index is derived from raster DEM data. Summerell *et al.* (submitted) used UPNESS with the assumption that many of the factors that lead to soil pedogenesis are inter-correlated with landscape position. These include rainfall, vegetation, soils, geology and geomorphology. This model is a simplification, or integration, of many complex and inter-related processes. The Summerell *et al* (submitted) work demonstrated the use of this index to represent surface and sub-surface water accumulation. The notion being explored was that within a hillslope hydrological unit, downslope accumulation of groundwater causes increased secondary weathering and concentration of the products of weathering of primary minerals and thus influence soil pedogenic development. The authors demonstrated how UPNESS could be used at a catchment scale to explore relationships with seasonally and fully waterlogged, saline or sodic soils from the drier soils usually high in the landscape.

The UPNESS index is calculated by pooling a topological set of pixels that are connected by a continuous monotonic uphill path. This implies that the topographic catchment boundaries can be crossed if the subsequent cells are monotonically higher and connected (see Roberts et al., 1997 for details). The assumption made is that saturated subsurface flow connected by upslope areas can be different to the topographic divide.

The UPNESS index was calculated for three catchments (Figure 1) between 900 – 5000km^2 using a 25m resolution DEM supplied by the NSW Land Information Centre (NSW LIC, 1999). The UPNESS index was calculated using a threshold of 0.0 specifying that any neighbouring cell with a height difference greater than or equal to zero will be included in the UPNESS area computation. The resulting UPNESS areas for each pixel were normalised between 0 and 1 with 0 (hilltops) having the least accumulation and 1 (lowest valleys) the most.

Landscape toposequences are defined by concave and convex breaks of slope. At these locations in the toposequence, a significant difference in soil properties commonly occurs due to different soil depths, pedogenesis and hydrological properties. The assumption is made that specific changes in soil materials and soil forming processes are dependent on the landscape evolution processes and can be related to the upness index. These breaks of slope positions also significantly affect contributing cells in the accumulation algorithms. Therefore the UPNESS index should conceptually be able to discriminate major landform types of a given toposequence. The two inflection points of the pdf of the UPNESS index (on rising and falling limbs of the pdf) can be located objectively. The inflection point represents break of slope of the derivative of the UPNESS index plotted against the UPNESS index. A mid point or the point of central tendency between the inflection points can also be obtained. The inflection points represent a distinct variation in the accumulation areas corresponding to the UPNESS index.

Figure 1. Catchment locations. West Hume (973km^2), Tarcutta (1640km^2), Goulburn (4946km^2)

The mid point would indicate the location of the gradual change in upper/mid and lower landforms found on the side slopes of hills. Physically this represents gradual transition between the soils which is not easily discernible and likewise identifying this point is influenced by some inescapable subjectivity. However this does not make the selection of this point arbitrary as the point of central tendency is invariably bound by the limits of the two inflection points of the pdf. When the pdf is integrated, the two inflection points are still located at the same UPNESS index value even though they are not the inflection points of the cdf. It can be shown mathematically that locating the inflection points on a cdf is relatively more efficient especially when they are obtained from visual inspection as in this study. It is pointed out that the impact of locating the points visually will be insignificant for large catchments. To allow direct comparisons of UPNESS distribution between catchments, the UPNESS index was plotted as a normalised (cdf) on a log scale. The aim of this study is to assess if the method represents major landforms and to assess the physical features of catchments that cause differences in the shape of the UPNESS index cdf's. The UPNESS index cdf is sub-divided into four categories representing the following landforms: ridge tops (LF4), upper and/or mid slopes (LF3), lower slope (LF2) and in-filled valley / alluvial deposits (LF1) (Figure 2). These UPNESS index values for the three points are then used to derive the "FLAG landforms".

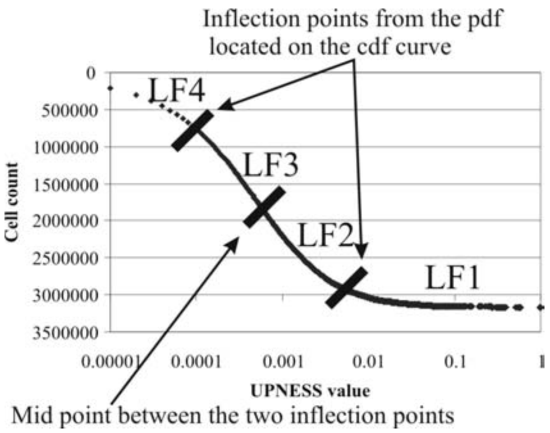

Figure 2. The UPNESS index cdf plotted on log scale showing three points discriminating the four-landform elements.

3. RESULTS AND DISCUSSION

Field verification of the FLAG landforms for all catchments was done with visual assessment of the soil toposequences. A detailed field study on the Little River catchment showed that the FLAG landforms represented soil toposequences reasonably accurately (Murphy *et al.*, this issue).

The distribution of slope across the FLAG landforms combined for three catchments is presented (Figure 3). The landform LF1 mainly contains areas with slopes in the range 0-2% along with some steeper areas. The areas steeper than 0-2% generally reflect steep sided features such as gullies and creeks that fall within the landform LF1. The landform LF2 also has a high percentage of 0-2% slopes. Summerell *et al* (submitted) found that the UPNESS index under represented areas of infilled valleys and alluvial landforms with deeply incised creeks. These under represented areas were assigned to the landform LF2. The 2-5% slopes are the next dominant category represented in the landform LF2. This would be expected as the landform LF2 covers gentle to undulating landforms. In the case of landforms LF3 and LF4 (mid slopes, upper slopes and ridge tops), most slope categories are generally represented by equal percentages. Given the highly variable nature of these landforms due to erosion patterns and the soil depth, this result is not unexpected.

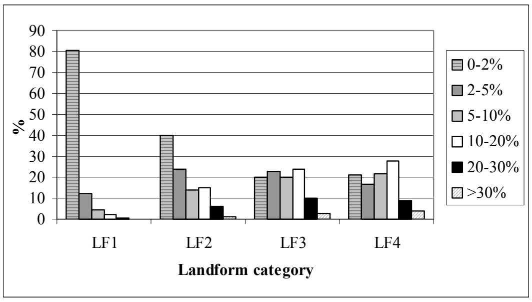

Figure 3. Distribution of slope classes for each FLAG landform class using data from all three catchments.

Geology plays a dominant role in determining the landscape formation and erosion processes. Figures 4 (a, d, g) show variations in landform distribution throughout each of the catchments. Figures 4 (b, e, h) show the dominant geological units within these catchments (Kingham, 1998). Comparisons between the FLAG landform index and the dominant geological units indicate that the landform distribution within the catchment is controlled by geological influence. For example the Tarcutta catchment (Fig 4a, b) is mainly dominated by hard weathering meta sediments and the landscape is dominated by steep hill slopes represented by the landform LF3 and LF4. However to the south east of the catchment, the landforms become more dominated by lower slopes represented by an increase in distribution of the landform LF2. At this location, the geology changes to granite, forming the undulating gentle sloped landscapes in this area. Similar associations between the FLAG landforms and geology can be seen in all the catchments presented even when subtle differences in the main units of the geology occur. The Goulburn catchment (Figure 4d, e) provides an example. The Tertiary Basalts have weathered to landscapes dominated by narrow flat ridge tops (LF4) with steep upper slopes (LF3) leading into long gentle lower slopes. The Triassic Sediments become dominated by narrow ridge tops with long upper slopes. There is a change in landscape

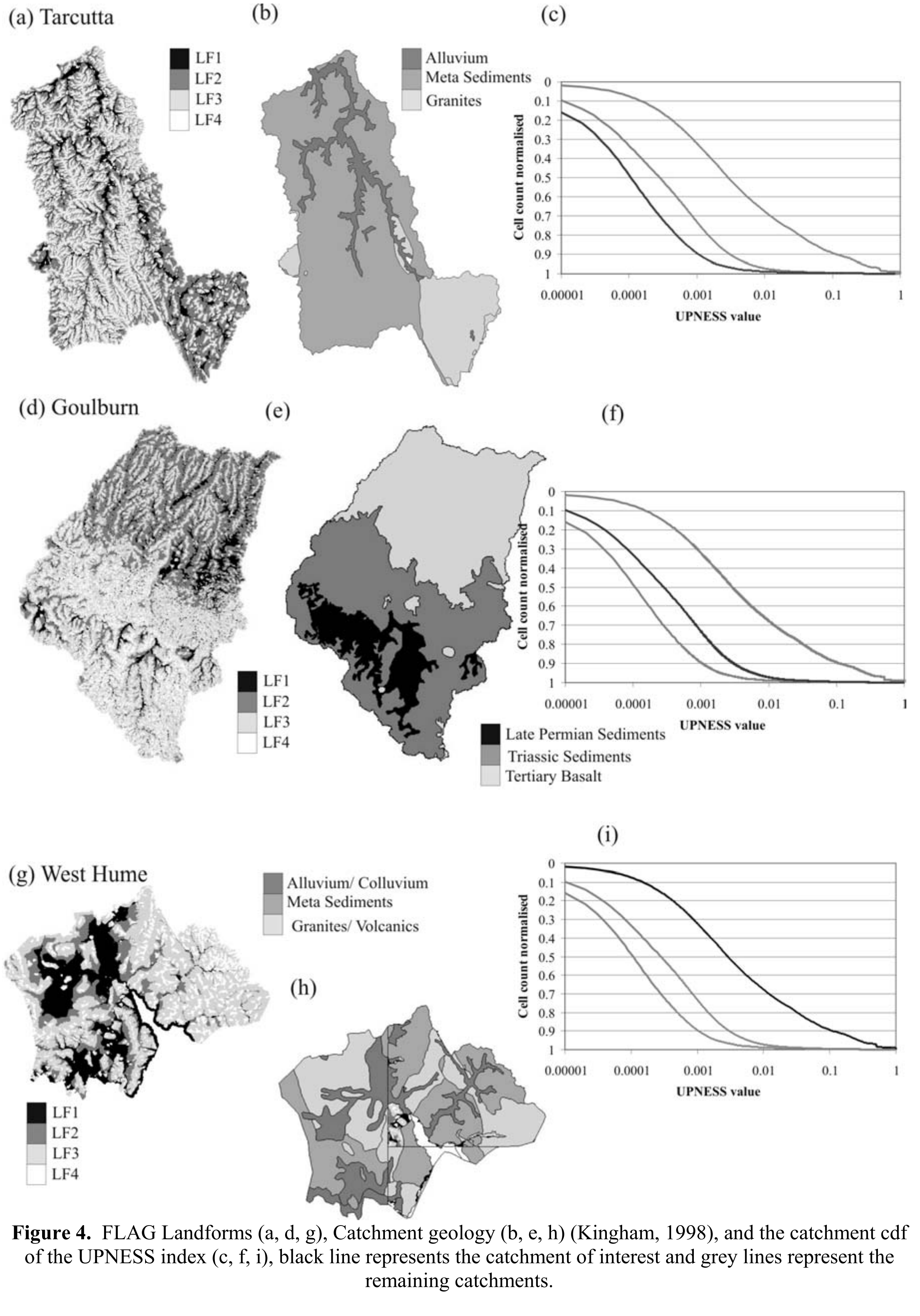

Figure 4. FLAG Landforms (a, d, g), Catchment geology (b, e, h) (Kingham, 1998), and the catchment cdf of the UPNESS index (c, f, i), black line represents the catchment of interest and grey lines represent the remaining catchments.

with the Late Permian Sediments that are more erodable leading to the narrow crests with long upper slopes and the development of small areas of lower slopes and alluvial flat landforms. The FLAG landforms index represents these landscape descriptions.

The shape of the UPNESS index cdf varies depending on the distribution of landforms found

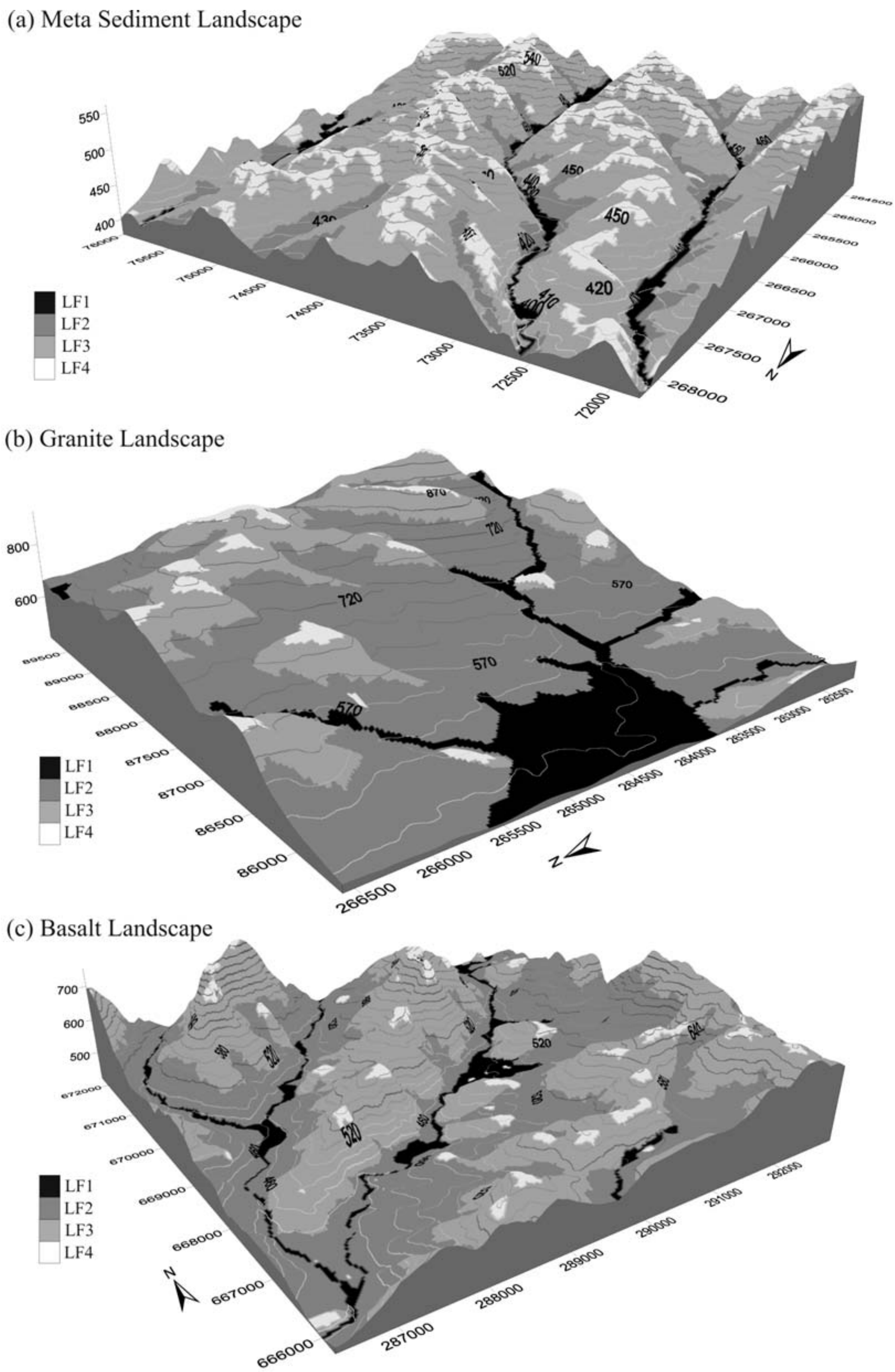

Figure 5. FLAG Landforms on different geologies at a hillslope scale showing how distribution and patterns reflect the geomorphic characteristics that shape the landforms of the landscape. Vertical exaggeration * 3.81

within a catchment. Steep upper slopes with few lower slopes or alluvial flats dominate the Tarcutta catchment. At an UPNESS value of about 0.001, the FLAG landform LF1 begins and the cdf distribution flattens out with a uniform slope (Figure 4c). The long flat landform LF1 indicates that only a small area of the alluvial and infilled valleys occur as the accumulation values increase towards 1. In contrast, the West Hume catchment (Figure 4i) is dominated by long upper slopes and the FLAG landforms index represents this with a gentle sloped landform LF4 and the landform LF1 also gently slopes down to a value of 1 indicating large areas of infilled valley deposits. Generally, catchments dominated by steep sloping toposequences will have a cdf plotting to the left of the chart and flatter toposequences to the right.

Figure 5 shows at a hillslope scale the FLAG landforms over three different geologies. On the Meta sediment geology (Figure 5a) the ridges and steep hillslopes dominate while on the Granite geology (Figure 5b) the long lower slopes of the undulating landscape occur and for the Basalt (Figure 5c), the short ridge tops followed be steep dominant upper slopes and long gentle lowers are shown.

4. CONCLUSIONS

An objective terrain analysis technique has been presented that enables landforms to be identified based on landscape toposequences. The technique has been applied using visual inspection of the cdf of the upness index on three different catchments. The FLAG landforms index closely represent major changes in the geology (which relates to landform due to different weathering and formation processes). Even though only 4 landform types are identified, the major geological changes are expressed by different patterns within the landscape caused by location and extent of these landforms.

The application of the method currently requires a cdf of the UPNESS index although parametric and non-parametric forms of the pdf are likely to be used in future work. However, the cdf will still be applied as different shapes of the cdf can be used to compare differences in the dominant landforms of catchments. The method presented could potentially be used for any accumulation index analogous to the FLAG UPNESS index.

5. ACKNOWLEDGMENTS

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