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Transitional relation exploration for the typical loess geomorphologic types based on the slope spectrum characteristics

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Abstract

Based on the Chinese Geomorphologic Database at 1 : 1 000 000 scales, the distribution of the typical loess geomorphologic types, such as the loess tableland, loess ridge and loess knoll is acquired in the Loess Plateau of China; then, based on the SRTM (shuttle radar topography mission)-DEM data and topographic analysis methods, the slope spectrums are computed for the typical loess geomorphologic types and their sub-types; through achieving the tendency line of the slope spectrum and analyzing the slope spectrum characteristics of the loess typical geomorphologic types, the transitional relationships are explored: (1) the general rule is: the loess tableland transits to the loess ridge, and then transits to the loess knoll; (2) the specific relationship for the subtypes is: in the loess tableland, from the loess terrace to the complete tableland, then to the residual tableland, and finally to the beam tableland; in the loess ridge, from the oblique ridge to the knoll ridge; the final types is the loess knoll.

1 Introduction

Topography is formed through relief-generation processes (such as uplift and stream incision) and slope-driven denudation processes, so the resulting topographic slopes can gives clues for these processes, and many topographic studies are carried out using slope distributions to explore these processes (Wolinsky and Pratson, 2005). For example, early studies focused on the hill slope profiles and modal characteristics slopes (Strahler, 1956; Carson, 1971; Anderson et al., 1980); then, latter studies had mainly attempt to use slope statistics from natural and simulated digital elevation models (DEMs) to relate it to geomorphologic processes (Burbank, 1992; Roering et al., 1999; Iwahashi et al., 2001); finally, recent studies mainly takes slope as an important topographic factor for characterizing, and automatic classifying the landform types (Crevenna et al., 2005; Bue and Stepinski, 2006; Tang and Li, 2008).

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This research takes the Loess Plateau of China as an experimental area, which attracts world attention in geographic research because of its unique geomorphologic features. In Loess Plateau, slope spectrum index is applied in studying the loess geomorphology (Tang et al., 2008). Slope spectrum, as a microscopic terrain index, can reveal the macro-geomorphologic features, which makes it a valuable topographic index in geomorphologic research (Tang et al., 2005).

In previous researches, the loess geomorphology can be classified and characterized by using the slope spectrum index (Li et al., 2007; Wang et al., 2008; Zhou et al., 2010). The achievement of the Chinese Geomorphologic Database (CGD) at 1 : 1 000 000 scales provides the distribution of the loess geomorphologic types (Cheng et al., 2011a); as to the slope spectrum index, it can be computed based on the digital elevation model (DEM) data, which is the shuttle radar topography mission (SRTM) data in this research.

Hence, this research aims to analyze the characteristics of the slope spectrums of the typical loess geomorphologic types using CGD and SRTM-DEM data, and then explore the transitional relationships among the types and their sub-types based on the slope characteristics changing rules.

2 Study area and Data sources

2.1 Study area

This research selects the Loess Plateau of China as the study area. Located in the upper and middle reaches of Yellow River, Loess Plateau is in the west side of Taihang Mountain, the east side of Qinghai–Tibet Plateau, the north side of Qinling Mountain and the south side of Mongolia Plateau. Loess Plateau is one of the four largest plateaus in China, which distributes the widest and deepest loess in the world, so as to form the most typical loess geomorphology. Loess geomorphology has close relation with soil erosion, which is the one of the most serious problems for ecological and environmental safety in the Loess Plateau. So the research to the loess geomorphology has both scientific significance and economic importance.

2.2 Data sources

The main data sources used in this research are the CGD at 1 : 1 000 000 scales and the SRTM-DEM data.

The CGD data at 1 : 1 000 000 scales was achieved by using remote sensing visual interpretation and geographic information system methods from multi-source data, such as remote sensing images, SRTM3-DEM data, published geomorphologic maps, geologic data, and geographic base data and so on (Cheng et al., 2011a). This data is the source data to compile the 1 : 1 000 000 set of geomorphologic atlas of China (Li et al., 2009) and can be divided into seven layers: relief and altitude, genesis, sub-genesis, morphology, micro-morphology, slope and aspect, material and lithology (Cheng et al., 2011b). In this research, the fourth layer – morphology and the fifth layer – micro-morphology are used to acquire the distribution of the typical loess geomorphologic types and their sub-types.

The SRTM-DEM data is the SRTM3-DEM data, which has 3″ spatial resolution (SRTM3) and is processed by the Consortium for Spatial Information of the Consultative Group for International Agricultural Research. It can provide continuous elevation surface information and wide coverage (60° N–56° S), so it has been used in many research fields. In this research, the SRTM3-DEM data is the 4th version data, and it is used to compute the slope spectrums for the typical loess geomorphologic types and their subtypes.

3 Methodology

Based on the CGD data, the distribution of the typical loess geomorphologic types and their sub-types are acquired; then, the slope spectrums are computed for these

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geomorphologic types using SRTM3-DEM data and the topographic analysis method; finally, the characteristics of the slope spectrum are quantitative analyzed, such as the tendency line, the regression equation and its corresponding R^2.

3.1 Acquisition of the distribution of the typical loess geomorphologic types and their subtypes

The typical loess geomorphology types are loess tableland, loess ridge and loess knoll. According to the CGD data, the distribution of the typical loess geomorphologic types is acquired. The areas of the three types are 6.52×10^4 km^2, 9.12×10^4 km^2 and 1.91×10^4 km^2.

The transitional rule among typical loess geomorphologic types is widely acknowledged as: from loess tableland to loess ridge and finally to loess knoll (Sang et al., 2007). Hence, in this research, the transitional rules of the subtypes of typical loess geomorphology are paid more attention.

Considering the distribution areas and situations of the typical loess geomorphology types, the loess tableland is divided into four subtypes: loess terrace, complete tableland, residual tableland and beam tableland; the loess ridge is divided into oblique ridge and knoll ridge; and the loess knoll is not divided further. From the CDG data, the distribution of the subtypes of the typical loess geomorphology can be acquired and shown in Fig. 1.

Figure 1 shows the distribution of the typical loess geomorphology: loess table mainly distributes in the northern part of Xi'an City and eastern part of the Lanzhou City; besides, there exist spares distribution around Taiyuan City. Loess ridge has the greatest area, which mainly distributes in the eastern part of Lanzhou City and western part of Taiyuan City. Loess knoll has the least area, which distributes in the western part of Taiyuan City, the northern part of Xi'an City, and around the Lanzhou City.

The acquisition of the distribution of the typical loess geomorphology provides the chance to compute the slope spectrum index for every type.

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3.2 Slope spectrum computation for the typical loess geomorphologic types and their subtypes

Based on SRTM3-DEM data and topographic analysis method, the slope is computed for the whole Loess Plateau; then, the slope is classified with the interval of 3°, which is applicable in slope spectrum researches (Zhu and Li, 2009); overlapped with the classified slope data and the distribution data of typical loess geomorphologic types, the slope distribution status are acquired for all the types; through numerical statistics, the slope spectrum index is achieved for every type.

3.3 Quantitative analysis for the slope spectrum

Using the Excel software, the slope spectrums of the typical loess geomorphologic types are quantitatively analyzed.

Through several experiments, the tendency line for the slope spectrum is firstly acquired; in order to keep high similarity, the function of polynomial regression with four powers is chosen for the tendency prediction; in this condition, the R^2 is above than 0.99.

4 Results

4.1 The slope spectrum analysis for the typical loess geomorphologic types

Based on the distribution boundary of the typical loess geomorphologic types, SRTM-DEM data and the slope spectrum computation method, the slope distribution status for the typical loess geomorphologic types are computed as shown in Table 1.

In Table 1, according to the 3° slope interval, the areal distribution percentage of the three loess geomorphologic types – loess tableland, loess ridge and loess knoll are computed and listed.

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According to the computed results of Table 1, the slope spectrum indexes for the typical loess geomorphologic types are acquired as shown in Fig. 2.

Table 1 and Fig. 2 show: loess tableland mainly distributes in 0–9° slope area, especially in 0–3° interval; loess ridge and loess knoll both mainly distributes in 3–15° slope area, especially in 6–12° interval. Hence, the slope spectrum index for the loess ridge is similar to that for the loess knoll; the loess ridge is a little steeper than loess knoll. As to the loess table, it is much flatter than other two types; so it has distinct slope spectrum characteristics compared to loess ridge and loess knoll.

4.2 The slope spectrum analysis for the subtypes of the loess tableland

The sub-types of the loess tableland are loess terrace, complete tableland, residual tableland and beam tableland. Based on the distribution status of these subtypes, SRTM-DEM data and the slope spectrum computation method, the slope distribution with 3° interval is computed for these subtypes as shown in Table 2.

Table 2 gives the slope percentage distribution of these subtypes of the loess tableland. Based on Table 2, the slope spectrum is computed as shown in Fig. 3.

Table 2 and Fig. 3 show: loess terrace mainly distributes in the 0–6° slope area, especially in 0–3° slope area, which is the flattest subtype of the loess tableland; complete tableland mainly distributes in the 0–9° slope area, especially in 0–3° slope area, which is similar to the whole loess tableland; residual tableland and beam tableland are steep and similar, they both almost evenly distribute in the 0–21° slope area, and the slope spectrums for the two subtypes are similar to that for the loess ridge.

4.3 The slope spectrum analysis for the subtypes of the loess ridge

The subtypes of the loess ridge are oblique ridge and knoll ridge. The slope distribution status for the two subtypes is computed in Table 3.

Based on Table 3, the slope spectrum for the oblique ridge and knoll ridge are computed in Fig. 4.

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From Table 3 and Fig. 4 we can see: oblique ridge and knoll ridge both mainly distributes in the 3–18° slope area, and the slope spectrum characteristics for the two subtypes are similar; oblique ridge is a little steeper than the knoll ridge; compared to oblique ridge, the slope for the knoll ridge is more similar to that for the loess knoll.

4.4 Quantitative analysis for the slope spectrums

In order to make quantitative analysis to the slope spectrums, the tendency lines of the slope spectrums are chosen; then, the regression equation and R^2 are tested for every slope spectrum. Taking the loess tableland as an example, the tendency line, regression equation and R^2 are achieved as shown in Fig. 5.

Figure 5 shows the status of the slope spectrum for the loess tableland: the regression equation chooses the polynomial function with four powers, and the R^2 is 0.9938, above than 0.99, so the tendency line has relatively close to the slope spectrum histograms.

Through experiment, the regression equations for other loess geomorphologic types and their sub-types can also use the equation for the loess tableland, only the parameters should be changed. Based on the experiments, the regressions equations and their corresponding R^2 are achieved for all the loess geomorphologic types and their subtypes, which are shown in Table 4.

Form Table 4 we can see: the R^2 for every type is above than 0.99, so the regression equations are very close to the slope spectrum histograms; then, the slope spectrum characteristics of these geomorphologic types can be analyzed from the regression equations; hence, the relationship among the geomorphologic types can be speculated from these regression equations.

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4.5 Transitional relationship exploration for the typical loess geomorphologic types

Based on the tendency lines and regression equations of the slope spectrums, the transitional order of the loess geomorphologic types is: in the loess tableland, with the slope from flat to steep, the subtypes transit from loess terrace to complete tableland, then to residual tableland and finally to beam tableland; in the loess ridge, the subtypes transit from oblique ridge to knoll ridge. Hence, the transitional relationship among the typical loess geomorphologic types is achieved as shown in Fig. 5.

Figure 5 is generally according to the transitional rule of the typical geomorphologic types: from loess tableland to loess ridge, and finally transits to the loess knoll. As to the subtypes, the slope change rule is adopted, so every subtype transit according to the elevating slope.

5 Discussions

5.1 Innovations

Based on DEM data and the topographic analysis methods, slope spectrum is usually used in landform analysis, landform classification and geomorphologic classification in previous research (Iwahashi et al., 2001; Tang and Li, 2008; Tang et al., 2008).

In this research, the geomorphologic boundary is determined in advance using visual interpretation and multi-source data, such as remote sensing images and DEM data and so on (Cheng et al., 2011a, b). The accurate boundary of the loess geomorphologic types provides much more precise results for slope spectrum characteristic analysis; moreover, the transitional relationship among the typical loess geomorphologic types is explored based on the slope spectrum characteristic analysis, especially for the subtypes. Hence, this research gives a way to deeply study the relationship among the loess geomorphologic types.

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5.2 Prospects

The future research can be improved in the following aspects:

(1) In this research, the boundary of the geomorphologic types is determined by multi-sources data; whereas the slope spectrum characteristics are analyzed based on the DEM data. If the boundary can be revised using DEM data, the slope spectrum analysis could have better results.

(2) Topographic analysis mainly uses the slope spectrum in this research. In the future, more topographic indexes will be used to acquire more reasonable results.

(3) The transitional relation among geomorphologic types is explored in this research. In the future, the relation can be explored for every geomorphologic type. Through analyzing the difference of the same geomorphologic type in different region, the threshold values of the topographic indexes among the geomorphologic types can be found, so as to acquire the fundamental difference among the geomorphologic types.

6 Conclusion

The results can be acquired in the following:

(1) The slope spectrum of the typical loess geomorphologic types and their sub-types are acquired by using the GCD data and DEM data; then, based on the tendency line, regression equation and R^2, the slope spectrum characteristics are quantitatively analyzed, which provides a way to achieve the relations among the loess geomorphologic types.

(2) The transitional relations among the typical loess geomorphologic types and their sub-types are: in general, for the typical loess geomorphologic types, from loess tableland to loess ridge and finally to loess hill; in specific, for the subtypes of the loess tableland, from loess terrace to complete terrace, and then to the residual tableland and finally to beam tableland; as to the loess ridge, from oblique ridge to knoll ridge.

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Table 1. Distribution status of the slope intervals for the typical loess geomorphologic types.

slope interval (°)	loess tableland percentage (%)	grid number	loess ridge percentage (%)	grid number	loess knoll percentage (%)	grid number
0–3	39	3 481 883	6	728 129	7	195 155
3–6	18	1 608 957	15	1 832 410	16	422 065
6–9	12	1 054 711	19	2 333 408	20	511 864
9–12	9	805 219	18	2 253 837	19	490 007
12–15	7	647 609	15	1 896 942	15	401 575
15–18	6	509 414	11	1 408 602	11	281 653
18–21	4	365 281	8	952 910	6	168 136
21–24	3	229 533	5	571 302	3	84 814
24–27	1	121 041	2	287 704	1	34 178
27–30	1	52 343	1	120 561	0	10 974
30–33	0	18 310	0	41 779	0	2870
33–36	0	5269	0	11 749	0	579
36–39	0	1415	0	2543	0	103
39–42	0	324	0	577	0	28
42–45	0	98	0	160	0	6
45–48	0	15	0	52	0	1
48–51	0	0	0	11		
51–54	0	1	0	1		
total	100	8 901 423	100	12 442 677	100	2 604 008

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Table 2. Distribution status of the slope intervals for the subtypes of the loess tableland.

slope interval (°)	loess terrace percentage (%)	grid number	complete tableland percentage (%)	grid number	residual tableland percentage (%)	grid number	beam tableland percentage (%)	grid number
0–3	65	1 713 075	41	1 568 793	10	36 401	8	163 851
3–6	20	516 158	19	737 272	15	56 426	15	297 644
6–9	8	211 427	12	467 274	15	58 501	16	316 833
9–12	4	100 710	9	342 276	15	55 785	15	306 259
12–15	2	51 825	7	258 675	14	51 875	14	285 322
15–18	1	27 116	5	194 177	12	44 530	12	243 966
18–21	1	13 296	4	135 348	9	34 529	9	182 496
21–24	0	6507	2	83 790	6	22 236	6	117 388
24–27	0	2992	1	43 770	3	11 469	3	63 067
27–30	0	1433	0	18 460	1	4503	1	28 140
30–33	0	598	0	5728	0	1466	1	10 578
33–36	0	226	0	1315	0	291	0	3470
36–39	0	76	0	240	0	31	0	1084
39–42	0	23	0	20	0	1	0	285
42–45	0	11	0	1			0	85
45–48	0	2					0	13
48–51	0	0						
51–54	0	1						
total	100	2 645 476	100	3 857 139	100	378 044	100	2 020 481

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Table 3. Distribution status of the slope intervals for the subtypes of the loess ridge.

slope interval (°)	oblique ridge percentage (%)	grid number	knoll ridge percentage (%)	grid number
0–3	5	302 457	6	423 662
3–6	13	729 610	16	1 102 216
6–9	17	942 728	20	1 390 490
9–12	18	985 107	18	1 268 763
12–15	16	885 598	15	1 011 807
15–18	12	678 737	11	730 640
18–21	8	469 594	7	483 916
21–24	5	293 507	4	278 244
24–27	3	153 879	2	134 075
27–30	1	66 960	1	53 610
30–33	0	24 294	0	17 478
33–36	0	7270	0	4478
36–39	0	1653	0	884
39–42	0	428	0	149
42–45	0	136	0	29
45–48	0	45	0	7
48–51	0	10	0	1
51–54	0	1		
total	100	5 542 014	100	6 900 449

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Table 4. Regression equations and R^2 of the tendency lines of the slope spectrums for the typical loess geomorphologic types and their sub-types.

typical types	regression equation	R^2	Sub-types	regression equation	R^2
loess tableland	$y = 0.0459x^4 - 1.1829x^3 + 10.889x^2 - 43.658x + 72.35$	0.9938	loess terrace	$y = 0.3213x^4 - 6.2439x^3 + 44.358x^2 - 138.1x + 164.16$	0.9984
			complete tableland	$y = 0.0896x^4 - 1.9542x^3 + 15.503x^2 - 54.716x + 81.52$	0.9982
			residual tableland	$y = -0.0048x^4 + 0.172x^3 - 2.2317x^2 + 9.7599x + 2.24$	0.9932
			beam tableland	$y = -0.0040x^4 + 0.1762x^3 - 2.5001x^2 + 11.59x - 0.77$	0.9939
loess ridge	$y = -0.0136x^4 + 0.4618x^3 - 5.3695x^2 + 22.402x - 11.74$	0.9994	oblique ridge	$y = -0.0034x^4 + 0.212x^3 - 3.3564x^2 + 16.68x - 8.19$	0.9987
			knoll ridge	$y = -0.0219x^4 + 0.6629x^3 - 6.992x^2 + 27.028x - 14.65$	0.9987
loess knoll	$y = -0.0083x^4 + 0.3742x^3 - 4.9253x^2 + 21.235x - 9.24$	0.9997			

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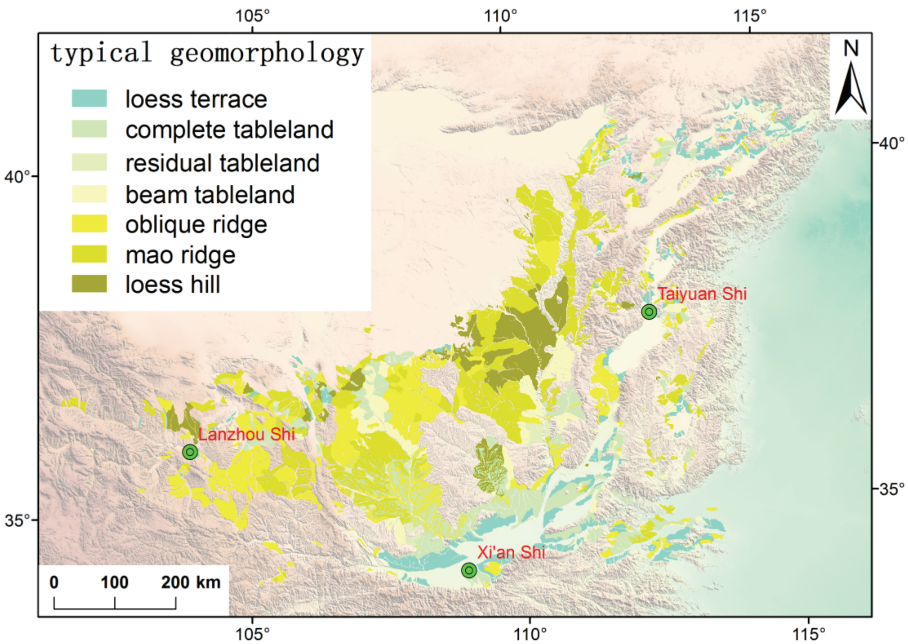

Fig. 1. Typical loess geomorphology distribution in the Loess Plateau.

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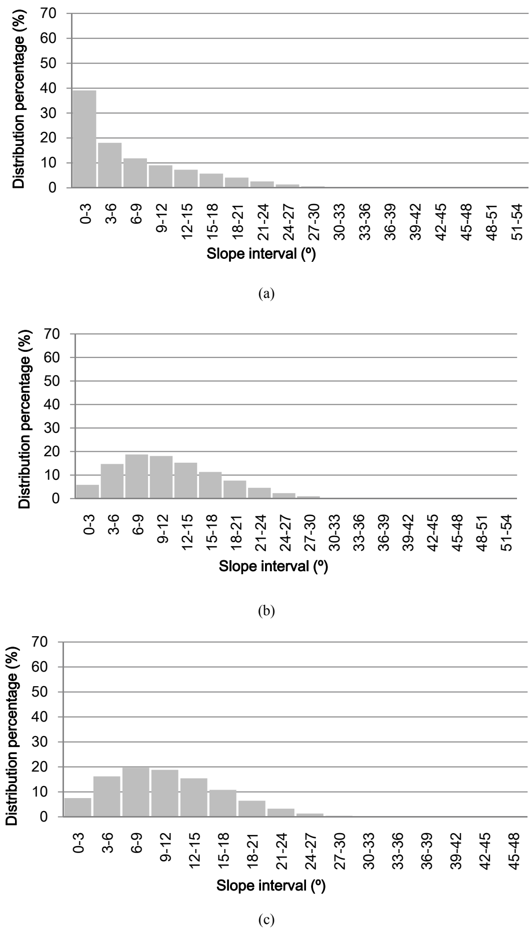

Fig. 2. Slope spectrum of the typical loess geomorphologic types. Panel **(a)** loess tableland; Panel **(b)** loess ridge; Panel **(c)** loess knoll.

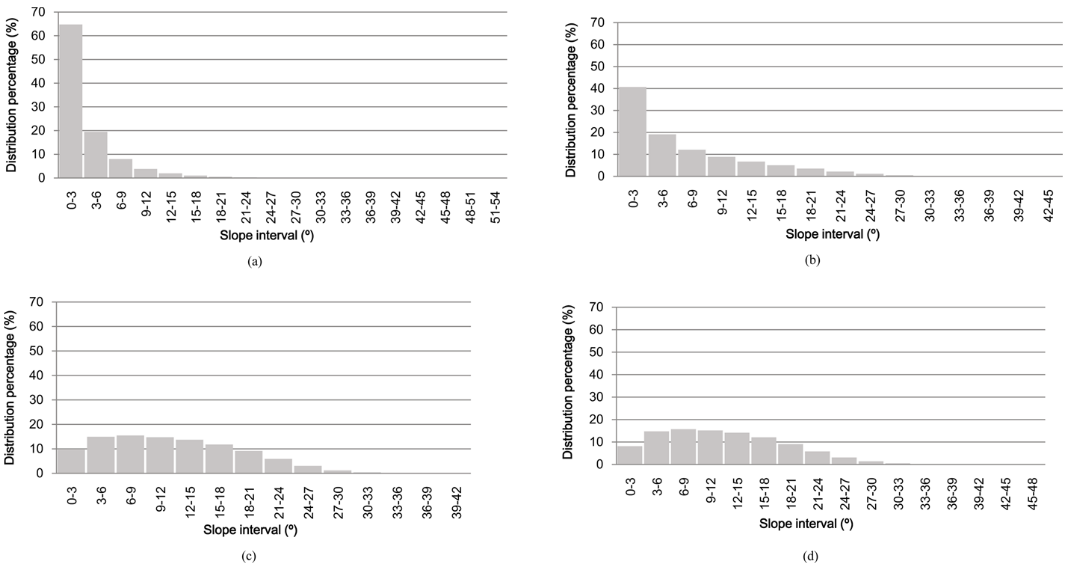

Fig. 3. Slope spectrum for the subtypes of the loess tableand. Panel **(a)** loess terrace; Panel **(b)** complete tableland; Panel **(c)** residual tableland; Panel **(d)** beam tableland.

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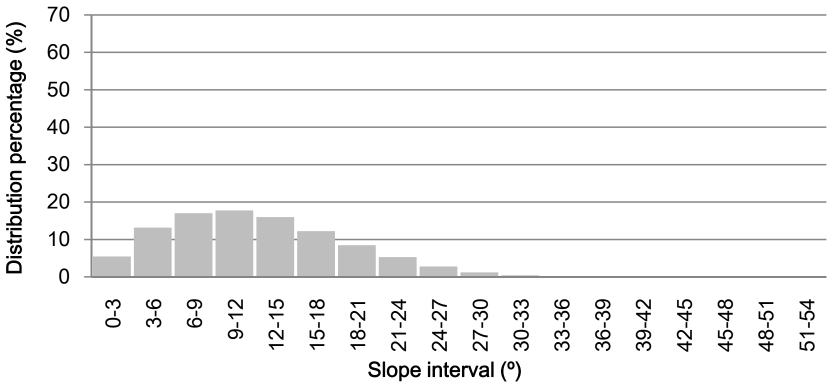
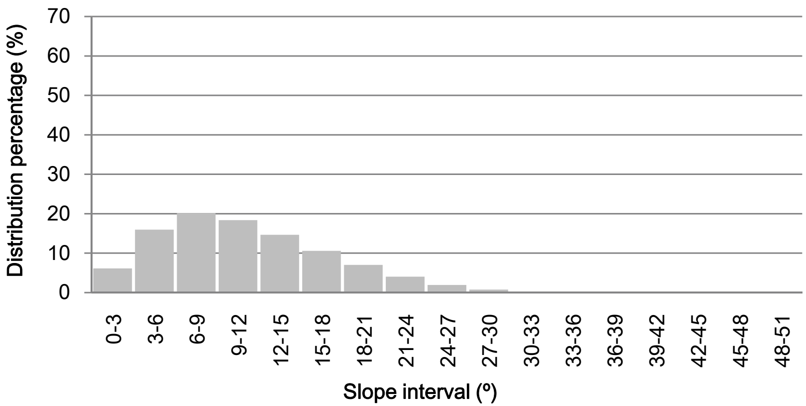


(a)



(b)

Fig. 4. Slope spectrum for the subtypes of the loess ridge. Panel **(a)** oblique ridge; Panel **(b)** knoll ridge.

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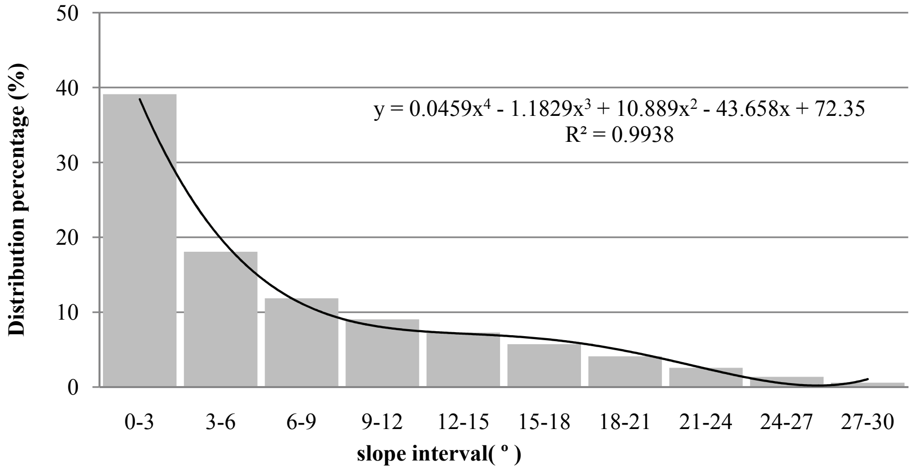

Fig. 5. Tendency line, regression equation and R^2 for the slope spectrum of the loess tableland.

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Typical loess geomorphologic types

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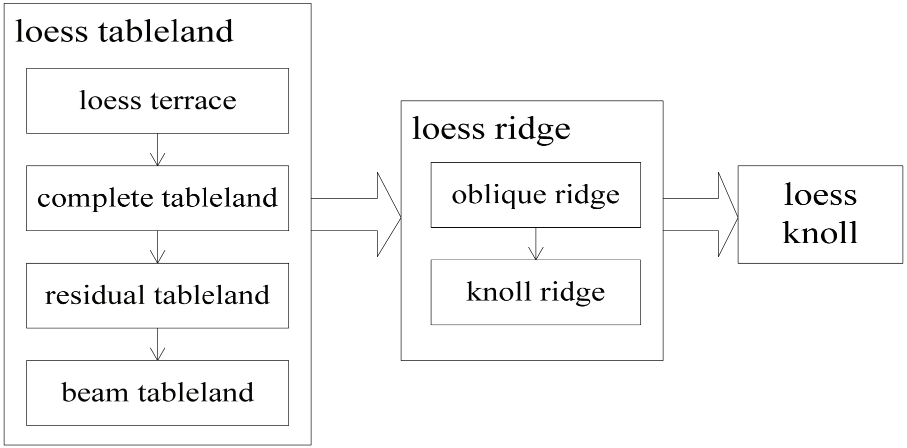

Fig. 6. Transitional relationship among typical loess geomorphology.