Proceedings of the International Conference on Environmental Changes in Karst Areas - I.G.U.- U.I.S.- Italy 15-27 Sept. 1991 ; Quaderni del Dipartimento di Geografia n. 13, 1991 - Università di Padova, pp.143-156

SOME MORPHOMETRIC AND ENVIRONMENTAL ASPECTS OF DOLINES IN BERICI HILLS (VICENZA, ITALY)

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ABSTRACT

G. K. W.: karst landscape, doline environments and forms, landscape modifications, vegetation
Geogr. K. W.: Italy, Veneto, Venetian Pre-Alps

The landscape of Berici Hills is deeply characterized by the presence of dolines; the characters of these karst landforms are linked to the natural environmental aspects as well as to the human presence ones. This research gives a general description of dolines in their morphometric, morpholigical, vegetational and soil use aspects; in addition it points out the relationships existing among morphometry, morphology, vegetation and soil use.

The purpose of this research is to analyze in detail the landscape with dolines of the southern part of Berici Hills. To this aim morphometric, morphological, vegetational aspects of dolines as well as aspects about the soil use have been considered. With the help of statistic methods, a general description of these landforms and of the environmental context in which they lie has been obtained. In addition the relationships existing among the different characters in every doline have been searched for.

The Berici Hills group is situated on the South of the town of Vicenza, separated by strips of plain from the close groups of mountains and hills; the group, nearly shaped as a lengthened parallelogram, stretches to the South for twenty kilometres. It appears like a table-land, unitary in some parts, cut in by large valleys in others. It has very steep slopes on the eastern side while on the western it degrades more gently to the plain.

Berici Hills are mostly formed by Eocene and Oligocene limestone: by consequence on their surface karst morphogenesis is active. In particular, because of the almost flat upper surface, the conditions are good for the formation of dolines; we find them very numerous on it till a density of twenty units for square kilometre.

Therefore dolines represent a very important element to determine the typical characters of Berici Hills landscape; they are linked both to the natural environmental aspects as also to the human presence ones.

The climate of table-land zones is generally milder than the surrounding plain's one, because the winter fogs don't reach the elevated areas and also because in Summer the temperature is lower.

In any case it can be noted that the local climates are deeply influenced by the slopes exposures; the temperature and humidity conditions of the zones with a northern exposure are decidedly different from the ones of the zones with a southern exposure.

It is possible to connect to these microclimatic differences the woody vegetational associations that we find on the Berici Hills.

On the warmer and dryer slopes the thermophile wood, the oak-grove with *Quercus pubescens* Willd. is present; it often appears like a sparse bush, with several typical shrub species, for example *Cotinus coggygria* Mill.(smoke tree), *Paliurus spina-christi* Mill. and *Rosa canina* L. (dog rose).

On the contrary, in temperature and humidity middle condition the mesophile wood, with *Ostrya carpinifolia* Scop. and *Fraxinus ornus* L. (manna-ash), is prevalent.

At the end, on the slopes with northern exposure we find a sub-association of mesophile wood with moderately microthermic characters, with *Castanea sativa* Mill. (chestnut), *Carpinus betulus* L. (horn-beam), *Quercus robur* L. (bay-oak), and, in the dampest localities, *Populus tremula* L. (trembling poplar).

It is necessary to take into consideration the fact that in the Berici Hills area the human presence has radically transformed the natural landscape. It can be noted , for example, that wood, which is almost always periodically cut, never occupies very wide areas; it generally covers only the very steep slopes and the most of the table-land zones are or were utilized for agriculture.

DATA COLLECTION

A sample of 129 dolines placed in the southern part of the table-land has been considered.

81 dolines have been object of on-the-field inspection; the morphological, vegetational and about use aspects have been directly observed.

For all the cases the morphometric parameters have been calculated with the help of the analysis of the topographic map (Regional Technical Map, on the scale of 1:10000 and 1:5000).

During the field research a card has been used in order to note the characters of each doline concerning:

- bottom morphology (flat, almost sublevel, or concave)
- slopes morphology (steepness, terraces and dry-wall, bare rock emergences)
- eventual presence of hydrological elements (water stagnation, cisterns, wells)
- vegetation covering the bottom and the slopes according to the exposure (North, South, East and West)
- soil use (distinguishing the bottom and the slopes).

With the help of the map, some data, concerning the following items, have been collected:

- position (UTM co-ordinates)
- altitude of the bottom, of the lowest rim and of the highest point of the catchment-basin pertaining to the doline; with these altitudes the highest and the lowest depths have been calculated.
- dimensions (doline's longest axis length and area, basin's longest axis length and area)
- the lengthening direction of the doline.

With all the data a table has been compiled (tab. 1); 42 variables for each doline have been studied.

Table (the key of the abbreviations table

	long.	lat.	b. alt.	l. r. alt.	h. alt.	d. l.	b. l.	l. dir.	d. area	b. area	l. depth 1	h. depth 1	shape 1	hidrol.	b. morph.	b. wall
1	8921	3047	177,3	184,0	232,9	145	460	32	10793	64215	6,70	55,60	2,053	•	concave	yes
2	8977	3053	221,2	229,5	234,3	105	170	66	7232	14291	8,30	13,10	2,624	•	flat	no
3	9043	3059	225,2	227,0	249,0	60	190	92	2101	12139	1,80	23,80	2,334	•	sublevel	yes
4	9043	3048	220,0	228,0	249,0	90	200	68	4987	20449	8,00	29,00	2,463	•	sublevel	yes
5	9064	2989	187,6	196,5	250,0	235	600	115	32120	149876	8,90	62,40	2,326	•	flat	yes
6	9050	2993	192,1	196,5	250,0	110	460	100	6284	64990	4,40	57,90	2,077	•	sublevel	yes
7	9333	3173	250,4	257,0	282,5	115	300	104	6842	29020	6,60	32,10	2,069	cist.	sublevel	yes
8	9321	3156	251,1	262,0	281,8	140	275	13	9458	33923	10,90	30,70	1,930	•	concave	no
9	9325	3176	254,6	257,0	280,0	72	195	120	2573	10397	2,40	25,40	1,985	•	sublevel	yes
10	9318	3179	260,1	262,0	280,0	40	170	151	1108	11019	1,90	19,90	2,770	•	concave	yes
11	9319	3186	266,2	266,5	282,4	35	130	103	864	6877	,30	16,20	2,821	•	flat	yes
12	9082	3043	198,7	204,5	250,0	170	420	170	10663	69572	5,80	51,30	1,476	•	concave	no
13	9091	3031	194,5	196,5	240,0	110	400	63	3253	36881	2,00	45,50	1,075	•	concave	no
14	9109	3024	197,7	206,8	248,1	235	550	178	27123	125698	9,10	50,40	1,965	•	concave	yes
15	9126	3058	225,7	226,5	262,9	80	350	141	3891	38119	,80	37,20	2,432	•	concave	no
16	9028	3063	234,6	238,0	249,0	70	185	96	2621	13689	3,40	14,40	2,140	•	flat	yes
17	9020	3075	234,8	240,0	260,7	75	170	97	2801	8493	5,20	25,90	1,992	•	sublevel	no
18	9135	3156	224,2	227,0	249,5	80	300	31	3409	19824	2,80	25,30	2,131	•	concave	no
19	9133	3175	212,1	224,9	248,4	240	460	148	18508	80473	12,80	36,30	1,285	•	sublevel	yes
20	9043	3039	226,7	233,0	250,0	80	175	150	4203	18757	6,30	23,30	2,627	•	flat	no
21	9129	2710	129,8	136,5	164,1	93	270	70	4967	17986	6,70	34,30	2,297	•	sublevel	no
22	9133	2713	137,0	139,0	148,8	60	160	0	2069	10274	2,00	11,80	2,299	•	concave	no
23	9103	2695	123,4	133,0	164,1	165	475	8	13173	44972	9,60	40,70	1,935	•	concave	no
24	9165	2663	125,1	127,2	154,9	100	300	9	5595	27174	2,10	29,80	2,238	•	concave	no
25	9272	2563	160,2	169,0	188,0	130	260	55	8128	30397	8,80	27,80	1,924	•	flat	no
26	9226	2533	125,8	129,5	158,5	70	370	87	2954	22283	3,70	32,70	2,411	•	concave	no
27	9141	2714	136,2	143,0	164,1	95	275	73	5869	20409	6,80	27,90	2,601	•	sublevel	no
28	9150	2704	147,3	147,9	164,1	50	225	161	1251	14877	,60	16,80	2,002	•	concave	no
29	9159	2703	146,5	146,9	164,1	55	300	148	1286	15704	,40	17,60	1,700	•	concave	no
30	9160	2696	142,3	146,9	164,1	90	350	10	4946	36936	4,60	21,80	2,442	stagn.	concave	no
31	9180	2664	125,8	132,5	172,0	135	530	55	9890	78744	6,70	46,20	2,171	stagn.	concave	no
32	9581	3426	334,2	334,8	353,5	45	175	128	791	13658	,60	19,30	1,562	•	sublevel	yes
33	9569	3433	312,3	322,5	351,2	120	240	19	9395	29730	10,20	38,90	2,610	•	sublevel	yes
34	9554	3421	318,0	322,3	351,2	205	330	118	12791	47968	4,30	33,20	1,217	•	sublevel	yes
35	9569	3449	314,0	318,0	351,2	65	210	85	2569	12204	4,00	37,20	2,432	•	flat	yes
36	9579	3450	307,7	309,5	341,7	65	240	175	2437	20418	1,80	34,00	2,307	•	sublevel	yes
37	9580	3452	299,2	303,0	334,0	140	240	161	4998	29797	3,80	34,80	1,020	•	flat	yes
38	9590	3449	308,7	313,0	368,5	135	450	85	6908	117215	4,30	59,80	1,516	•	concave	yes
39	9697	3197	353,2	358,0	373,3	65	160	53	2221	9810	4,80	20,10	2,103	•	sublevel	yes
40	9713	3184	343,5	359,1	395,1	340	530	145	30305	73124	15,60	51,60	1,049	•	concave	no
41	9718	3163	365,5	371,0	387,5	90	170	164	4145	10629	5,50	22,00	2,047	•	sublevel	yes
42	9700	3174	347,0	352,0	379,1	95	240	125	4852	24649	5,00	32,10	2,150	•	flat	no
43	9703	3180	350,5	352,0	364,0	60	190	156	2149	10086	1,50	13,50	2,388	•	flat	no
44	9691	3164	348,8	356,7	377,7	155	250	121	9006	28298	7,90	28,90	1,499	•	sublevel	yes
45	9668	3174	318,7	326,5	375,6	160	290	125	10785	46297	7,80	56,90	1,685	•	sublevel	no
46	9680	3188	327,0	330,0	369,0	100	260	127	4719	34115	3,00	42,00	1,888	•	concave	yes
47	9206	2822	168,2	177,2	199,3	190	340	37	11930	45001	9,00	31,10	1,322	•	concave	yes
48	9190	2814	163,5	167,0	199,3	120	300	123	7356	55344	3,50	35,80	2,043	well	flat	yes
49	9192	2807	160,7	167,0	190,0	110	320	27	6934	22260	6,30	29,30	2,292	•	concave	yes
50	9222	2811	172,1	186,0	200,9	135	300	17	12280	27771	13,90	28,80	2,695	cist.	concave	no
51	9233	2833	191,0	193,6	215,0	75	230	58	2158	20843	2,60	24,00	1,535	•	sublevel	yes
52	9224	2835	188,5	192,5	235,0	95	380	123	3503	20492	4,00	46,50	1,553	•	sublevel	no
53	9255	2838	212,3	214,5	224,0	60	160	85	2119	12808	2,20	11,70	2,354	•	concave	no
54	9246	2844	200,0	207,5	222,5	80	185	55	3579	16037	7,50	22,50	2,237	•	concave	no
55	9328	3496	277,5	282,0	298,6	87	160	60	4145	11644	4,50	21,10	2,191	•	sublevel	yes
56	9365	3480	264,0	269,0	310,7	100	300	97	4625	24152	5,00	46,70	1,850	•	sublevel	yes
57	9370	3473	271,0	274,0	285,0	50	165	157	1450	8678	3,00	14,00	2,320	•	concave	yes
58	9372	3510	291,1	295,5	305,0	65	110	62	2227	6889	4,40	13,86	2,108	•	concave	yes
59	9374	3506	294,5	295,5	310,7	60	125	67	1545	7234	1,00	16,20	1,717	•	concave	yes
60	9589	2768	216,5	227,5	240,8	93	270	150	5364	27116	11,00	24,30	2,481	•	flat	yes
61	9606	2791	200,7	206,5	232,0	90	270	174	5369	23484	5,80	31,30	2,651	•	sublevel	yes
62	9610	2781	190,6	198,8	240,8	110	480	96	6652	48617	8,20	50,20	2,199	stagn.	flat	yes
63	9590	2792	216,0	217,5	305,4	120	580	135	4092	66125	1,50	89,40	1,137	•	concave	yes
64	9564	2783	225,8	236,5	305,4	145	550	128	10422	50950	10,70	79,60	1,983	•	flat	yes
65	9109	2800	140,5	146,5	166,0	170	410	145	12390	39578	6,00	25,50	1,715	•	sublevel	yes
66	9100	2798	144,0	146,5	159,4	72	350	100	3119	14706	2,50	15,40	2,407	•	concave	no
67	9083	2798	137,7	142,0	159,4	95	260	35	5976	24780	4,30	21,70	2,649	•	flat	yes
68	9075	2792	134,6	138,0	152,1	85	280	13	4252	14591	3,40	17,50	2,354	•	sublevel	no
69	9067	2791	134,1	138,0	151,0	70	200	9	3640	11186	3,90	16,90	2,971	•	flat	yes
70	9067	2776	125,4	132,5	141,0	92	205	21	6128	18838	7,10	15,60	2,896	•	flat	no
71	9056	2775	130,0	132,5	136,7	60	130	37	1997	7160	2,50	6,70	2,219	•	sublevel	no
72	9077	2782	132,0	133,0	141,0	50	225	84	1452	9779	1,00	9,00	2,323	•	flat	no

Table

	b. veg.	b. use	N morph.	N terr.	N wall	N rock	N veg.	N use	E morph.	E terr.	E wall	E rock	E veg.
1	sowable	cultiv.	not incl.	no	no	no	cultiv.	cult.	steep	yes	yes	no	s. wild
2	s. wild	dump	m.-steep	no	no	no	mesoph.	wild	m.-steep	no	no	no	meso...
3	wild	wild	not incl.	no	no	yes	therm.	wood	not incl.	no	no	no	wild
4	wild	wild	not incl.	no	no	no	therm.	wood	not incl.	no	no	no	wild
5	grass	cultiv.	not incl.	yes	yes	no	therm.	wood	not incl.	yes	yes	no	cultiv.
6	grass	cultiv.	m.-steep	no	no	no	s. wild	wild	not incl.	no	no	no	therm.
7	sowable	cultiv.	steep	yes	yes	no	cultiv.	cult.	m.-steep	yes	yes	no	cultiv.
8	wild	wild	m.-steep	no	no	no	mesoph.	wood	steep	no	no	no	meso...
9	s. wild	wild	steep	no	no	no	wild	wild	m.-steep	no	no	no	meso...
10	wild	wild	m.-steep	yes	yes	no	wild	wild	m.-steep	no	no	no	meso...
11	grass	cultiv.	m.-steep	no	no	no	s. wild	wild	m.-steep	yes	yes	no	s. wild
12	sowable	cultiv.	m.-steep	no	yes	no	s. wild	wild	not incl.	no	no	no	cultiv.
13	grass	cultiv.	not incl.	no	yes	no	s. wild	wild	not incl.	no	no	no	cultiv.
14	vine	wild	not incl.	no	no	no	cultiv.	wild	not incl.	yes	no	no	cultiv.
15	grass	cultiv.	not incl.	no	no	no	cultiv.	cult.	not incl.	no	no	no	s. wild
16	s. wild	wild	m.-steep	yes	yes	yes	mesoph.	wood	not incl.	no	no	no	meso...
17	wild	wild	m.-steep	yes	no	no	s. wild	wild	m.-steep	no	no	no	s. wild
18	grass	cultiv.	not incl.	no	yes	no	mesoph.	wood	not incl.	no	no	no	s. wild
19	sowable	cultiv.	m.-steep	no	no	no	mesoph.	wood	m.-steep	no	no	no	meso...
20	grass	cultiv.	m.-steep	no	no	no	therm.	wood	m.-steep	no	no	no	meso...
21	grass	cultiv.	m.-steep	no	no	no	therm.	wood	m.-steep	no	no	no	meso...
22	vine	cultiv.	not incl.	no	no	no	cultiv.	cult.	not incl.	no	no	no	therm.
23	sowable	cultiv.	not incl.	no	no	no	cultiv.	cult.	m.-steep	no	yes	no	meso...
24	vine	cultiv.	m.-steep	no	yes	no	mesoph.	wood	not incl.	no	yes	no	cultiv.
25	sowable	cultiv.	m.-steep	no	no	no	therm.	wood	not incl.	no	no	no	meso...
26	vine	cultiv.	m.-steep	no	no	no	therm.	wood	not incl.	no	yes	no	s. wild
27	sowable	cultiv.	m.-steep	yes	yes	no	s. wild	wild	m.-steep	yes	yes	no	therm.
28	vine	cultiv.	not incl.	no	yes	yes	therm.	wood	not incl.	no	no	yes	therm.
29	vine	cultiv.	not incl.	no	no	no	cultiv.	cult.	m.-steep	no	no	no	therm.
30	veget.	cultiv.	not incl.	no	yes	no	therm.	wood	m.-steep	no	no	no	cultiv.
31	vine	cultiv.	m.-steep	no	no	no	therm.	wood	steep	no	no	no	therm.
32	sowable	cultiv.	m.-steep	yes	yes	no	therm.	wood	steep	no	no	no	meso...
33	sowable	cultiv.	steep	no	no	no	mesoph.	wood	steep	no	no	no	meso...
34	sowable	cultiv.	steep	no	no	no	therm.	wood	m.-steep	yes	no	no	meso...
35	s. wild	wild	m.-steep	no	no	no	mesoph.	wood	steep	no	no	no	meso...
36	sowable	cultiv.	m.-steep	no	no	no	therm.	wood	m.-steep	yes	yes	no	therm.
37	grass	cultiv.	m.-steep	yes	yes	no	cultiv.	cult.	m.-steep	yes	yes	no	cultiv.
38	grass	cultiv.	not incl.	no	yes	no	cultiv.	cult.	not incl.	yes	yes	no	cultiv.
39	sowable	cultiv.	m.-steep	yes	no	no	cultiv.	cult.	m.-steep	no	no	no	cultiv.
40	grass	cultiv.	m.-steep	yes	no	no	cultiv.	cult.	steep	no	yes	no	meso...
41	sowable	cultiv.	not incl.	no	no	no	cultiv.	cult.	steep	no	no	no	therm.
42	sowable	cultiv.	steep	no	yes	no	therm.	wood	steep	no	no	no	therm.
43	sowable	cultiv.	steep	yes	yes	no	cultiv.	cult.	m.-steep	no	no	no	therm.
44	grass	cultiv.	steep	no	no	no	therm.	wood	steep	no	no	no	meso...
45	sowable	cultiv.	not incl.	yes	no	no	cultiv.	cult.	m.-steep	yes	yes	no	s. wild
46	grass	cultiv.	steep	no	yes	yes	mesoph.	wood	m.-steep	yes	yes	no	cultiv.
47	sowable	cultiv.	not incl.	yes	yes	yes	cultiv.	cult.	m.-steep	yes	yes	yes	cultiv.
48	sowable	cultiv.	m.-steep	no	no	no	therm.	wood	steep	no	no	no	therm.
49	sowable	cultiv.	m.-steep	yes	yes	no	therm.	wood	m.-steep	yes	yes	no	therm.
50	vine	cultiv.	not incl.	no	no	no	cultiv.	cult.	m.-steep	yes	yes	no	cultiv.
51	sowable	cultiv.	m.-steep	no	no	no	therm.	wood	m.-steep	no	no	no	therm.
52	s. wild	wild	m.-steep	no	no	no	therm.	wood	not incl.	no	no	no	meso...
53	vine	cultiv.	not incl.	no	no	no	cultiv.	cult.	not incl.	no	no	no	cultiv.
54	s. wild	wild	m.-steep	no	no	yes	s. wild	wild	steep	no	no	yes	s. wild
55	s. wild	wild	m.-steep	no	no	yes	mesoph.	wood	m.-steep	no	no	no	microt.
56	grass	cultiv.	m.-steep	yes	yes	yes	cultiv.	cult.	m.-steep	yes	yes	no	cultiv.
57	veget.	cultiv.	m.-steep	no	no	no	cultiv.	cult.	m.-steep	no	no	no	cultiv.
58	s. wild	wild	m.-steep	no	no	no	s. wild	wild	not incl.	no	no	no	wild
59	vine	cultiv.	m.-steep	no	no	no	cultiv.	cult.	m.-steep	no	no	no	cultiv.
60	grass	cultiv.	m.-steep	no	no	no	therm.	wood	not incl.	no	no	no	therm.
61	grass	cultiv.	m.-steep	no	no	no	therm.	wood	m.-steep	no	no	no	s. wild
62	grass	cultiv.	m.-steep	yes	yes	no	cultiv.	cult.	not incl.	no	no	no	meso...
63	sowable	cultiv.	m.-steep	no	no	yes	mesoph.	wood	not incl.	no	no	no	cultiv.
64	grass	cultiv.	steep	yes	yes	no	s. wild	wild	steep	yes	yes	no	meso...
65	sowable	cultiv.	m.-steep	no	no	no	therm.	wood	m.-steep	no	no	no	therm.
66	sowable	cultiv.	not incl.	no	no	no	therm.	wood	not incl.	no	no	no	therm.
67	s. wild	wild	m.-steep	no	no	no	therm.	wood	steep	no	no	no	therm.
68	vine	cultiv.	steep	no	no	no	therm.	wood	m.-steep	no	no	no	meso...
69	sowable	cultiv.	steep	no	no	no	therm.	wood	m.-steep	no	no	no	meso...
70	sowable	cultiv.	m.-steep	yes	no	no	cultiv.	cult.	m.-steep	yes	no	no	cultiv.
71	vine	cultiv.	not incl.	no	no	yes	therm.	wood	not incl.	no	no	yes	therm.
72	vine	cultiv.	not incl.	no	no	no	therm.	wood	not incl.	no	no	yes	therm.

	E use	S morph.	S terr.	S wall	S rock	S veg.	S use	W morph.	W terr.	W wall	W rock	W veg.	W use	l. depth	h. depth	shape
1	wild	steep	no	no	no	meso...	wood	m.-steep	yes	no	no	cultiv.	cult.	6,7	55,6	2,053
2	wild	m.-steep	no	no	no	meso...	wild	m.-steep	no	no	no	mesoph.	wild	8,3	13,1	2,624
3	wild	not incl.	no	no	no	therm.	wood	m.-steep	no	no	no	therm.	wood	1,8	23,8	2,334
4	wild	not incl.	no	no	no	therm.	wood	m.-steep	no	no	no	therm.	wood	8,0	29,0	2,463
5	cult.	not incl.	no	no	no	meso...	wood	m.-steep	no	no	no	cultiv.	cult.	8,9	62,4	2,326
6	wood	steep	no	no	no	meso...	wood	not incl.	no	no	no	cultiv.	cult.	4,4	57,9	2,077
7	cult.	steep	no	yes	no	meso...	wood	m.-steep	no	yes	no	s. wild	wild	6,6	32,1	2,069
8	wood	m.-steep	no	yes	no	microt.	wood	steep	yes	yes	no	wild	wild	10,9	30,7	1,930
9	wood	m.-steep	no	yes	no	wild	wild	m.-steep	no	no	no	mesoph.	wood	2,4	25,4	1,985
10	wood	m.-steep	no	no	no	microt.	wood	m.-steep	yes	yes	no	s. wild	wild	1,9	19,9	2,770
11	wild	not incl.	no	no	no	s. wild	wild	m.-steep	yes	yes	no	s. wild	wild	,3	16,2	2,821
12	cult.	m.-steep	no	no	no	meso...	wood	not incl.	no	no	no	cultiv.	cult.	5,8	51,3	1,476
13	cult.	m.-steep	no	no	no	cultiv.	cult.	m.-steep	no	no	no	microt.	wood	2,0	45,5	1,075
14	wild	m.-steep	yes	yes	no	microt.	wood	not incl.	no	no	no	cultiv.	wild	9,1	50,4	1,965
15	wild	not incl.	no	no	no	s. wild	wild	not incl.	no	no	no	mesoph.	wood	,8	37,2	2,432
16	wood	steep	no	no	no	microt.	wood	m.-steep	no	no	no	mesoph.	wood	3,4	14,4	2,140
17	wild	steep	no	no	no	s. wild	dump	m.-steep	no	no	no	mesoph.	wood	5,2	25,9	1,992
18	wild	not incl.	no	no	no	microt.	wood	m.-steep	no	yes	no	s. wild	wild	2,8	25,3	2,131
19	wood	m.-steep	yes	no	no	microt.	wood	steep	no	no	no	microt.	wood	12,8	36,3	1,285
20	wood	m.-steep	no	no	no	microt.	wood	steep	no	no	no	mesoph.	wood	6,3	23,3	2,627
21	wood	m.-steep	no	no	no	meso...	wood	m.-steep	no	no	no	mesoph.	wood	6,7	34,3	2,297
22	wood	not incl.	no	no	no	cultiv.	cult.	not incl.	no	no	no	therm.	wood	2,0	11,8	2,299
23	wood	not incl.	no	no	no	s. wild	wild	not incl.	no	no	no	therm.	wood	9,6	40,7	1,935
24	cult.	not incl.	no	no	no	cultiv.	cult.	not incl.	no	no	no	cultiv.	cult.	2,1	29,8	2,238
25	wood	m.-steep	no	no	no	meso...	wood	not incl.	no	no	no	mesoph.	wood	8,8	27,8	1,924
26	wild	m.-steep	no	no	no	therm.	wood	not incl.	no	no	no	cultiv.	cult.	3,7	32,7	2,411
27	wood	m.-steep	no	no	no	microt.	wood	not incl.	no	no	no	microt.	wood	6,8	27,9	2,601
28	wood	m.-steep	no	no	no	therm.	wood	not incl.	no	no	no	therm.	wood	,6	16,8	2,002
29	wood	not incl.	no	no	no	therm.	wood	m.-steep	no	no	no	therm.	wood	,4	17,6	1,700
30	cult.	not incl.	no	no	no	cultiv.	cult.	m.-steep	no	no	no	wild	wild	4,6	21,8	2,442
31	wood	m.-steep	no	no	no	cultiv.	cult.	not incl.	no	yes	yes	therm.	wild	6,7	46,2	2,171
32	wood	m.-steep	no	no	no	microt.	wood	m.-steep	no	yes	no	microt.	wood	,6	19,3	1,562
33	wood	steep	no	no	no	meso...	wood	steep	no	no	no	mesoph.	wood	10,2	38,9	2,610
34	wood	not incl.	yes	no	no	microt.	wood	m.-steep	no	no	no	mesoph.	wood	4,3	33,2	1,217
35	wood	steep	no	no	no	microt.	wood	steep	no	no	no	mesoph.	wood	4,0	37,2	2,432
36	wood	steep	no	no	no	microt.	wood	steep	no	no	no	microt.	wood	1,8	34,0	2,307
37	cult.	m.-steep	no	no	no	microt.	wood	steep	no	no	no	mesoph.	wood	3,8	34,8	1,020
38	cult.	m.-steep	yes	yes	no	cultiv.	cult.	m.-steep	no	yes	no	mesoph.	wood	4,3	59,8	1,516
39	cult.	not incl.	no	no	no	cultiv.	cult.	m.-steep	yes	no	yes	mesoph.	wood	4,8	20,1	2,103
40	wood	m.-steep	yes	no	no	cultiv.	cult.	steep	yes	yes	no	mesoph.	wood	15,6	51,6	1,049
41	wood	m.-steep	no	no	no	meso...	wood	m.-steep	no	no	no	therm.	wood	5,5	22,0	2,047
42	wood	steep	no	no	no	meso...	wood	steep	no	no	no	therm.	wood	5,0	32,1	2,150
43	wood	m.-steep	no	no	no	meso...	wood	m.-steep	no	no	no	cultiv.	cult.	1,5	13,5	2,388
44	wood	m.-steep	yes	no	no	microt.	wood	steep	no	no	no	mesoph.	wood	7,9	28,9	1,499
45	wild	steep	no	no	no	microt.	wood	m.-steep	no	no	no	microt.	wood	7,8	56,9	1,685
46	cult.	steep	no	no	no	microt.	wood	m.-steep	no	no	no	cultiv.	cult.	3,0	42,0	1,888
47	cult.	not incl.	no	no	no	cultiv.	cult.	m.-steep	no	yes	no	therm.	wood	9,0	31,1	1,322
48	wood	m.-steep	no	no	no	microt.	wood	m.-steep	yes	no	no	mesoph.	wood	3,5	35,8	2,043
49	wood	m.-steep	yes	yes	no	cultiv.	cult.	m.-steep	yes	yes	no	cultiv.	cult.	6,3	29,3	2,292
50	cult.	steep	no	no	no	cultiv.	cult.	m.-steep	yes	yes	no	cultiv.	cult.	13,9	28,8	2,695
51	wood	not incl.	no	no	no	cultiv.	cult.	m.-steep	no	no	no	cultiv.	cult.	2,6	24,0	1,535
52	wood	m.-steep	no	no	no	microt.	wood	not incl.	no	no	no	mesoph.	wood	4,0	46,5	1,553
53	cult.	not incl.	no	no	no	cultiv.	cult.	not incl.	no	no	no	cultiv.	cult.	2,2	11,7	2,354
54	wild	m.-steep	no	no	yes	s. wild	wild	not incl.	no	yes	yes	s. wild	wild	7,5	22,5	2,237
55	wood	steep	no	no	no	microt.	wood	not incl.	no	no	no	therm.	wood	4,5	21,1	2,191
56	cult.	steep	yes	no	no	meso...	wood	m.-steep	no	no	no	cultiv.	cult.	5,0	46,7	1,850
57	cult.	m.-steep	no	no	no	cultiv.	cult.	m.-steep	yes	yes	no	cultiv.	cult.	3,0	14,0	2,320
58	wild	m.-steep	no	no	no	meso...	wood	not incl.	no	no	no	mesoph.	wood	4,4	13,9	2,108
59	cult.	steep	no	no	no	meso...	wood	m.-steep	yes	yes	no	cultiv.	cult.	1,0	16,2	1,717
60	wood	m.-steep	no	no	no	meso...	wood	m.-steep	no	no	no	mesoph.	wood	11,0	24,3	2,481
61	wild	steep	no	no	no	s. wild	dump	steep	no	no	no	s. wild	wild	5,8	31,3	2,651
62	wood	steep	no	no	no	meso...	wood	steep	yes	no	no	cultiv.	cult.	8,2	50,2	2,199
63	cult.	m.-steep	no	no	no	meso...	wood	not incl.	no	no	no	microt.	wood	1,5	89,4	1,137
64	wood	steep	no	no	no	microt.	wood	steep	yes	no	no	mesoph.	wood	10,7	79,6	1,983
65	wood	m.-steep	no	no	no	microt.	wood	m.-steep	no	no	no	microt.	wood	6,0	25,5	1,715
66	wood	not incl.	no	no	no	microt.	wood	not incl.	no	no	no	mesoph.	wood	2,5	15,4	2,407
67	wood	m.-steep	no	no	no	microt.	wood	not incl.	no	no	no	mesoph.	wood	4,3	21,7	2,649
68	wood	not incl.	no	no	no	meso...	wood	not incl.	no	no	no	therm.	wood	3,4	17,5	2,354
69	wood	not incl.	no	no	no	meso...	wood	m.-steep	no	no	no	mesoph.	wood	3,9	16,9	2,971
70	cult.	not incl.	no	no	no	meso...	wood	not incl.	yes	no	no	cultiv.	cult.	7,1	15,6	2,896
71	wood	not incl.	no	no	no	meso...	wood	not incl.	no	no	no	cultiv.	cult.	2,5	6,7	2,219
72	wood	not incl.	no	no	no	meso...	wood	not incl.	no	no	no	therm.	wood	1,0	9,0	2,323

Table

	long.	lat.	b. alt.	l. r. alt.	h. alt.	d. l.	b. l.	l. dir.	d. area	b. area	l. depth 1	h. depth 1	shape 1	hidrol.	b. morph.	b. wall
73	9109	2873	169,8	175,5	192,8	150	310	100	14150	43999	5,70	23,00	2,516	•	concave	yes
74	9123	2874	168,4	172,5	205,6	100	340	100	6478	30603	4,10	37,19	2,591	•	concave	no
75	9140	2873	161,8	169,8	207,2	110	500	152	8218	38587	8,00	45,40	2,717	•	flat	no
76	9242	2867	169,1	169,8	207,2	65	380	150	2061	24763	,70	38,10	1,951	•	flat	no
77	9128	2886	164,2	170,5	179,3	90	180	160	4973	13569	6,30	15,10	2,456	•	sublevel	yes
78	9687	3025	221,0	226,0	242,0	90	260	174	5648	19521	5,00	21,00	2,789	•	sublevel	yes
79	9679	3032	221,6	228,0	239,1	90	180	40	5115	14565	6,40	17,50	2,526	•	flat	yes
80	9667	3030	226,1	233,0	239,1	90	155	70	5503	9911	6,90	13,00	2,718	•	sublevel	yes
81	9667	3019	221,0	229,0	248,6	100	220	98	5267	22860	8,00	27,60	2,107	•	sublevel	yes
82	9183	2776	153,2	162,0	170,0	160	260	162	12800	28172	8,80	16,80	2,000	•	•	•
83	9196	2762	157,0	164,0	172,0	85	200	125	5359	17203	7,00	15,00	2,967	•	•	•
84	9204	2752	162,8	168,0	175,9	67	135	100	3145	10023	5,20	13,10	2,802	•	•	•
85	9192	2750	151,6	162,5	170,0	125	165	75	9111	14023	10,90	18,40	2,332	•	•	•
86	9177	2754	151,0	158,5	170,0	165	240	145	12460	28751	7,50	19,00	1,831	•	•	•
87	9175	2769	156,9	159,5	170,0	90	200	37	3106	9621	2,60	13,10	1,534	•	•	•
88	9170	2776	160,7	162,5	171,0	70	150	30	2699	12072	1,80	10,30	2,203	•	•	•
89	9160	2762	147,0	155,1	174,2	150	420	13	10980	46168	8,10	27,20	1,952	•	•	•
90	9146	2755	139,0	143,0	174,2	240	430	113	9062	64571	4,00	35,20	,629	•	•	•
91	9132	2764	140,4	143,0	174,2	140	380	165	7398	45475	2,60	33,80	1,510	•	•	•
92	9124	2782	146,4	151,0	171,3	175	300	153	12950	45233	4,60	24,90	1,691	•	•	•
93	9121	2766	143,5	147,0	155,5	60	140	95	2011	7648	3,50	12,00	2,234	•	•	•
94	9104	2755	127,8	138,0	155,5	160	350	75	12810	45421	10,20	27,70	2,002	•	•	•
95	9093	2763	124,4	135,3	150,0	125	270	60	11190	28633	10,90	25,60	2,865	•	•	•
96	9091	2780	128,7	129,5	157,1	110	280	145	4421	42114	,80	28,40	1,461	•	•	•
97	9085	2784	124,7	129,5	152,0	80	270	10	4404	25029	4,80	27,30	2,753	•	•	•
98	9075	2765	124,5	128,0	142,5	55	250	62	1960	19554	3,50	18,00	2,592	•	•	•
99	9067	2767	124,5	128,0	140,0	50	160	20	1804	8308	3,50	15,50	2,886	•	•	•
100	9064	2759	122,3	127,4	140,0	240	340	70	18350	46939	5,10	17,70	1,274	•	•	•
101	9045	2756	116,6	119,0	136,7	80	250	0	3669	26036	2,40	20,10	2,293	•	•	•
102	9039	2755	117,0	119,0	126,5	60	210	72	1942	13517	2,00	9,50	2,158	•	•	•
103	9041	2769	122,8	128,0	136,7	65	180	27	3086	14877	5,20	13,90	2,922	•	•	•
104	9035	2764	116,1	122,5	135,6	105	230	40	7297	17343	6,40	19,50	2,647	•	•	•
105	9036	2776	129,3	132,0	136,0	60	120	20	2143	6800	2,70	6,70	2,381	•	•	•
106	9028	2776	124,9	127,0	145,8	75	285	40	3436	20640	2,10	20,90	2,443	•	•	•
107	9024	2762	116,9	117,8	145,8	50	370	42	1075	18797	,90	28,90	1,720	•	•	•
108	9020	2753	111,1	114,5	124,3	70	225	130	2676	13733	3,40	13,20	2,184	•	•	•
109	9012	2759	109,7	111,5	145,8	80	470	167	3412	33091	1,80	36,10	2,132	•	•	•
110	9001	2760	105,4	106,5	137,0	48	300	150	704	16982	1,10	31,60	1,222	•	•	•
111	9072	2740	124,6	133,5	140,0	110	240	137	8662	19887	8,90	15,40	2,863	•	•	•
112	9090	2736	117,0	131,9	144,7	190	290	137	19216	43446	14,90	27,70	2,129	•	•	•
113	9113	2742	134,0	141,0	146,0	115	190	10	8173	14962	7,00	12,00	2,472	•	•	•
114	9130	2745	132,1	140,8	158,6	220	330	165	20366	58508	8,70	26,50	1,683	•	•	•
115	9086	2740	156,6	163,9	173,9	140	260	158	7028	24169	7,30	17,30	1,434	•	•	•
116	9201	2747	157,9	163,0	183,2	90	310	110	2742	17182	5,10	25,30	1,354	•	•	•
117	9196	2731	162,2	164,5	181,1	65	170	122	2497	13711	2,30	18,90	2,364	•	•	•
118	9200	2726	164,0	166,5	183,2	65	200	150	2942	15231	2,50	19,20	2,785	•	•	•
119	9193	2711	157,0	164,8	173,9	85	200	113	4189	17618	7,80	16,90	2,319	•	•	•
120	9177	2714	150,6	155,5	173,9	100	275	55	5833	33311	4,90	23,30	2,333	•	•	•
121	9176	2705	156,3	160,5	173,4	70	150	0	3637	13531	4,20	17,10	2,969	•	•	•
122	9166	2717	141,1	144,5	170,0	65	270	140	2868	17862	3,40	28,90	2,715	•	•	•
123	9161	2722	139,2	144,5	160,0	80	200	123	4259	17455	5,30	20,80	2,662	•	•	•
124	9165	2730	144,3	148,0	171,0	95	230	42	3947	24817	3,70	26,70	1,749	•	•	•
125	9154	2736	145,3	148,0	159,8	60	160	65	1635	13189	2,70	14,50	1,817	•	•	•
126	9139	2727	135,2	140,8	159,8	160	320	105	9035	35635	5,60	24,60	1,412	•	•	•
127	9111	2721	119,8	131,9	164,1	340	650	123	27540	104375	12,10	44,30	,953	•	•	•
128	9092	2717	123,5	132,5	141,2	90	170	83	5076	17357	9,00	17,70	2,507	•	•	•
129	9072	2723	116,5	127,0	138,2	140	260	64	11720	27429	10,50	21,70	2,392	•	•	•

Table 1e, and key of the abbreviations

	b. veg.	b. use	N morph.	N terr.	N wall	N rock	N veg.	N use	E morph.	E terr.	E wall	E rock	E veg.
73	sowable	cultiv.	not incl.	no	yes	no	cultiv.	cult.	not incl.	yes	yes	no	cultiv.
74	sowable	cultiv.	not incl.	no	no	no	therm.	wood	not incl.	no	no	no	meso...
75	grass	cultiv.	m.-steep	no	no	no	therm.	wood	steep	no	no	no	meso...
76	sowable	cultiv.	m.-steep	no	no	no	therm.	wood	steep	no	no	no	meso...
77	sowable	cultiv.	not incl.	no	no	yes	s. wild	wild	not incl.	no	no	no	therm.
78	vine	cultiv.	m.-steep	no	no	yes	s. wild	wild	m.-steep	no	no	no	cultiv.
79	grass	cultiv.	steep	no	no	no	therm.	wood	m.-steep	no	no	no	meso...
80	grass	cultiv.	steep	no	no	yes	therm.	wood	m.-steep	no	no	no	meso...
81	grass	cultiv.	m.-steep	no	no	yes	therm.	wood	m.-steep	no	no	no	meso...
82	•	•	•	•	•	•	•	•	•	•	•	•	•
83	•	•	•	•	•	•	•	•	•	•	•	•	•
84	•											•	•
85	•											•	•
86	•											•	•
87	•											•	•
88	•											•	•
89	•											•	•
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124	•											•	•
125	•											•	•
126	•											•	•
127	•											•	•
128	•											•	•
129	•											•	•

- long.: UTM longitude co-ordinate
- lat.: UTM latitude co-ordinate
- b. alt.: bottom altitude
- l. r. alt.: lowest rim altitude
- h. alt.: basin highest point altitude
- d. l.: doline longest axis length
- b. l.: basin longest axis length
- l. dir.: doline lengthening direction
- d. area: doline area
- b. area: basin area
- l. depth: lowest depth
- h. depth: highest depth
- shape: round shape index
- hydrol.: hydrological elements - well
  - cist.: cisterne
  - stagn.: water stagnation
- b. morph.: bottom morphology - flat
  - sublevel
  - concave
- b. wall: dry-wall on the bottom
- b. veg.: bottom vegetation - sowable
  - s. wild: wild with shrub
  - wild
  - vine
  - grass
  - vegetables
  - wood
- b. use: bottom use - cultiv.: cultivation
  - wood
  - dump
  - wild
- N (or E, S, W) morph.: North (or East, South, West) slope morphology - steep
  - m.-steep: middle-steep
  - not incl.: not very inclined
- N terraces: North slope terraces
- N wall: North slope dry-wall
- N rock: North slope bare rock emergences
- N veg.: North slope vegetation - therm.: termophile wood
  - mesoph.: mesophile wood
  - microt.: microthermic wood
- N use: North slope use - cult.: cultivation
  - wood
  - dump
  - wild

	E use	S morph.	S terr.	S wall	S rock	S veg.	S use	W morph.	W terr.	W wall	W rock	W veg.	W use	l. depth	h. depth	shape
73	cult.	not incl.	no	no	no	meso...	wood	not incl.	no	no	no	cultiv.	cult.	5,7	23,0	2,516
74	wood	m.-steep	no	no	no	meso...	wood	not incl.	no	no	no	cultiv.	cult.	4,1	37,2	2,591
75	wood	steep	no	no	yes	microt.	wood	not incl.	no	no	no	cultiv.	cult.	8,0	45,4	2,717
76	wood	steep	no	no	no	microt.	wood	steep	no	no	no	microt.	wood	,7	38,1	1,951
77	wood	not incl.	yes	no	no	cultiv.	cult.	m.-steep	no	no	no	mesoph.	wood	6,3	15,1	2,456
78	cult.	steep	no	no	no	cultiv.	cult.	m.-steep	yes	yes	no	cultiv.	cult.	5,0	21,0	2,789
79	wood	m.-steep	no	no	no	microt.	wood	m.-steep	no	no	no	mesoph.	wood	6,4	17,5	2,526
80	wood	m.-steep	no	no	no	meso...	wood	m.-steep	no	no	no	mesoph.	wood	6,9	13,0	2,718
81	wood	steep	no	no	no	microt.	wood	m.-steep	no	no	no	mesoph.	wood	8,0	27,6	2,107
82	•	•	•	•	•	•	•	•	•	•	•	•	•	8,8	16,8	2,000
83	•	•	•	•	•	•	•	•	•	•	•	•	•	7,0	15,0	2,967
84	•	•	•	•	•	•	•	•	•	•	•	•	•	5,2	13,1	2,802
85	•	•	•	•	•	•	•	•	•	•	•	•	•	10,9	18,4	2,332
86	•	•	•	•	•	•	•	•	•	•	•	•	•	7,5	19,0	1,831
87	•	•	•	•	•	•	•	•	•	•	•	•	•	2,6	13,1	1,534
88	•	•	•	•	•	•	•	•	•	•	•	•	•	1,8	10,3	2,203
89	•	•	•	•	•	•	•	•	•	•	•	•	•	8,1	27,2	1,952
90	•	•	•	•	•	•	•	•	•	•	•	•	•	4,0	35,2	,629
91	•	•	•	•	•	•	•	•	•	•	•	•	•	2,6	33,8	1,510
92	•	•	•	•	•	•	•	•	•	•	•	•	•	4,6	24,9	1,691
93	•	•	•	•	•	•	•	•	•	•	•	•	•	3,5	12,0	2,234
94	•	•	•	•	•	•	•	•	•	•	•	•	•	10,2	27,7	2,002
95	•	•	•	•	•	•	•	•	•	•	•	•	•	10,9	25,6	2,865
96	•	•	•	•	•	•	•	•	•	•	•	•	•	,8	28,4	1,461
97	•	•	•	•	•	•	•	•	•	•	•	•	•	4,8	27,3	2,753
98	•	•	•	•	•	•	•	•	•	•	•	•	•	3,5	18,0	2,592
99	•	•	•	•	•	•	•	•	•	•	•	•	•	3,5	15,5	2,886
100	•	•	•	•	•	•	•	•	•	•	•	•	•	5,1	17,7	1,274
101	•	•	•	•	•	•	•	•	•	•	•	•	•	2,4	20,1	2,293
102	•	•	•	•	•	•	•	•	•	•	•	•	•	2,0	9,5	2,158
103	•	•	•	•	•	•	•	•	•	•	•	•	•	5,2	13,9	2,922
104	•	•	•	•	•	•	•	•	•	•	•	•	•	6,4	19,5	2,647
105	•	•	•	•	•	•	•	•	•	•	•	•	•	2,7	6,7	2,381
106	•	•	•	•	•	•	•	•	•	•	•	•	•	2,1	20,9	2,443
107	•	•	•	•	•	•	•	•	•	•	•	•	•	,9	28,9	1,720
108	•	•	•	•	•	•	•	•	•	•	•	•	•	3,4	13,2	2,184
109	•	•	•	•	•	•	•	•	•	•	•	•	•	1,8	36,1	2,132
110	•	•	•	•	•	•	•	•	•	•	•	•	•	1,1	31,6	1,222
111	•	•	•	•	•	•	•	•	•	•	•	•	•	8,9	15,4	2,863
112	•	•	•	•	•	•	•	•	•	•	•	•	•	14,9	27,7	2,129
113	•	•	•	•	•	•	•	•	•	•	•	•	•	7,0	12,0	2,472
114	•	•	•	•	•	•	•	•	•	•	•	•	•	8,7	26,5	1,683
115	•	•	•	•	•	•	•	•	•	•	•	•	•	7,3	17,3	1,434
116	•	•	•	•	•	•	•	•	•	•	•	•	•	5,1	25,3	1,354
117	•	•	•	•	•	•	•	•	•	•	•	•	•	2,3	18,9	2,364
118	•	•	•	•	•	•	•	•	•	•	•	•	•	2,5	19,2	2,785
119	•	•	•	•	•	•	•	•	•	•	•	•	•	7,8	16,9	2,319
120	•	•	•	•	•	•	•	•	•	•	•	•	•	4,9	23,3	2,333
121	•	•	•	•	•	•	•	•	•	•	•	•	•	4,2	17,1	2,969
122	•	•	•	•	•	•	•	•	•	•	•	•	•	3,4	28,9	2,715
123	•	•	•	•	•	•	•	•	•	•	•	•	•	5,3	20,8	2,662
124	•	•	•	•	•	•	•	•	•	•	•	•	•	3,7	26,7	1,749
125	•	•	•	•	•	•	•	•	•	•	•	•	•	2,7	14,5	1,817
126	•	•	•	•	•	•	•	•	•	•	•	•	•	5,6	24,6	1,412
127	•	•	•	•	•	•	•	•	•	•	•	•	•	12,1	44,3	,953
128	•	•	•	•	•	•	•	•	•	•	•	•	•	9,0	17,7	2,507
129	•	•	•	•	•	•	•	•	•	•	•	•	•	10,5	21,7	2,392

DATA ELABORATION

The statistic analysis has been executed in two phases: in the first one the variables one by one have been considered and, from the frequency distributions, a general description of the dolines in their main characters has been obtained.

On the other hand, in the second phase the principal components analysis has been used in order to search for the relationships existing among the variables; this statistic method allows to point out some factors which gather and explain more variables linked each others.

For example the connection among the variables concerning the doline dimensions is interpreted by a "dimension-factor", the connection between the topographic position and the bottom altitude is interpreted by a "position- factor".

Moreover these factors allowed also the correlation with the disconnected variables (not numerically expressible), not included in the principal components analysis.

In fact, arranging the dolines according to the " dimension-factor" five classes have been considered (small dolines, middle-small, middle, middle-large, large); in each class the frequency distributions of the variables we wanted to correlate have been observed.

The same has been done with the "position-factor", and this fact allowed to observe the changing of the dolines characters in the different parts of the table-land.

RESULTS

Dolines' description

The most of the observed dolines has medium-small dimensions, with longest axis length between 35 m and 340 m, and an average value of 107.4 m; the basin longest axis length is between 110 m and 650 m, average value is 278.4 m.

Tab. 2. Frequency distribution for the variables concerning the bottom

morphology	flat	21	25,9%
	sublevel	29	35,8%
	concave	31	38,3%
dry-wall presence	yes	46	56,8%
	no	35	43,2%
vegetation	wild	5	6,2%
	shrub wild	9	11,1%
	wood	0	0%
	grass	22	27,2%
	vine	14	17,3%
	vegetables	2	2,5%
	sowable	29	35,8%
soil use	cultivation	66	81,5%
	wood	0	0%
	dump	1	1,2%
	wild	14	17,3%

Observing the lowest depth, the average is 5.3 m, the minimum 0.3 m and the maximum 15.6 m. Therefore, to the generally small dimensions, also a small depth corresponds. It can be even noted that also the wider dolines (that can be considered uvalas) are generally not very deep.

The doline bottom (tab. 2) is farmed in the 81.5% of the cases, with sowable cultivation (35.8%), grass (27.2%) or vine (17.3%).

It is never filled by wood, but it is wild for the 17.3%; this condition commonly is caused by the cultivation's abandonment, as it can be noted by the presence of vegetal species connected with the anthropic participation (vine, fruit-trees, cover or lucerne).

The cultivations per cent is very high if we consider that it is a hilly area - with low population density and with a few scattered inhabited nucleus - and that the doline bottom is quite small. As a consequence it is difficult to use the modern agricultural equipments.

To this frequent human utilization the high per cent (56.8%) of dolines with dry-wall around the bottom (at the slopes base) is connected. The dry-wall has two functions linked to the bottom cultivation: on one hand it "supports" the slopes by limiting the movement of materials (stones, colluvium) to the bottom; on the other it allows to use the stones that are removed from the cultivable area.

The dolines slopes are steep (more than 40% incline) in the 20.07% of the cases, middle-steep (between 20% and 40%) in the 47.85% and not very sloping (less than 20%) in the 32.1%.

Terraces are present on the 18.8% of the slopes, dry-walls on the 20.07%; bare rock emergences are noticed in 7.42% of the cases.

The slopes are covered most of all by wood (60.05%), and only in lower per cent by cultivations (24.72%) and by wild vegetation (13.87%).

Looking in particular at the North slope (tab. 3), exposed to the South, the condition of warm and dry microclimate is pointed out.

In fact the thermophile wood is present in the 42% of the cases and the mesophile one in the 13.6%, while the microthermic wood is completely absent.

There is a high per cent of cultivations (28.4%), of terraces (22.2%) and of dry-walls (28.4%); therefore the North slope is widely exploited by man.

Also bare rock emergences are frequently present (17.3%): this is because the thermophile wood appears often as a spare bush with scanty arboreal vegetation and the washing away is deeper on this warmer and dryer slope.

The South slope (tab.3) is in opposite condition: the scarce exposition to the sun determines a cool and humid microclimate, most of all if the doline is deep.

The microthermic wood is prevalent (33.3%) followed by the mesophile one (32.1%), and the termophile wood is present only in a very low per cent (6.2%).

The South slope is cultivated only in the 19.8% of the cases and also the per cent of terraces, of dry-walls and of bare rock emergences is very low.

The East and West slopes are in intermediate condition, perhaps with a deeper similarity of the East slope to the North one and of the West slope to the South one.

CORRELATIONS AMONG VARIABLES

Morphometric variables

Two matters in particular comes out from the principal components analysis based on the morphometric data:

Tab. 3. Frequency distribution for the variables concerning the slopes

		North slope		South slope	
morphology	steep	13	16%	22	27,2%
	middle steep	43	53,1%	35	43,2%
	not very sloping	25	30,9%	24	29,6%
terraces	yes	18	22,2%	9	11,1%
	no	63	77,8%	72	88,9%
dry-wall	yes	23	28,4%	6	7,4%
	no	58	71,6%	75	92,6
bare rock	yes	14	17,3%	2	2,5%
	no	67	82,7%	79	97,5%
vegetation	thermophile wood	34	42%	5	6,2%
	mesophile wood	11	13,6%	26	32,1%
	microthermic wood	0	0%	27	33,3%
	wild	2	2,5%	1	1,2%
	shrub wild	11	13,6%	6	7,4%
	cultivation	23	28,4%	16	19,8%
soil use	cultivation	22	27,2%	16	19,8%
	wood	44	54,3%	57	70,4%
	dump	0	0%	2	2,5%
	wild	15	18,5%	6	7,4%

- The topographic position is strongly linked to the bottom altitude; however it is known that the southern table-land of Berici Hills degrades toward South-West: therefore the dolines of the northern and eastern zones have the highest altitudes, and the dolines of the southern and western zones have the lowest altitudes.

- There is a strong link among data concerning doline dimensions excepted the lowest depth; in fact it is not always true that he largest dolines are also the deepest. Moreover there isn't whole dependence of the doline dimension on the basin one.

Introducing in the analysis a variable concerning the doline shape it results that the small dolines have often a nearly round shape, while the larger ones frequently draw away from it.

Dolines morphology

Using the process of division in classes according to the factors of the principal components analysis, some considerations on the dolines morphology have been expressed.

It results for example, that the small dolines more frequently present flat bottom while in the large and middle-large ones the concave shape is prevalent (tab. 4).

Tab. 4. Bottom morphology in relationship with dimension-factor

	class 1 small		class 2		class 3		class 4			
flat	7	43,75%	4	25%	1	5,88%	6	37,25%	3	18,7
sublevel	4	25%	9	56,25%	8	47,16%	3	18,75%	5	31,2
concave	5	31,25%	3	18,75%	8	47,06%	7	43,75%	8	50%

Tab. 5. Slopes morphology in relationship with position-factor
NORTH SLOPE

	class 1 high altitude		class 2		class 3		class 4		class 5 low altitude	
steep	6	37,5%	5	31,25%	0	0%	1	6,25%	1	6,25%
middle-steep	9	56,25%	9	56,25%	12	70,59%	8	50%	5	31,25%
not very inclined	1	6,25%	2	12,5%	5	29,41%	7	43,75%	10	62,5%

steep	7	43,75%	8	50%	3	17,65%	1	6,25%	3	18,75%
middle-steep	7	43,75%	8	50%	8	47,06%	9	56,25%	3	18,75%
not very inclined	2	12,5%	0	0%	6	35,29%	6	37,5%	10	62,5%

The correlation with "position -factor" is more interesting: it comes out that the slopes of the dolines situated on the high altitudes are usually steep or middle steep, while in the class pertinent to the low altitudes not very incline slopes are decidedly prevalent (tab. 5).

Moreover, looking at the morphology of the bottom, it appears more frequently flat or sublevel at the high altitude and concave at the low ones (tab. 6).

We can come to the conclusion that the dolines morphology is different according to the zone; this diversity is connected with a difference of lithological substratum on which the karst process acts.

In fact in the northern and eastern zones the prevalent kind of rock is an Oligocene back reef limestone; on the other hand at South and West we find the Priabona Formation with Eocene marly limestone. On this lithological type, with higher per cent of terrigenous elements, the relief modelling defines smoother and softer shapes, with not very sharp slope changing.

The real connection between bottom and slopes morphology has been also tested. The dolines with concave bottom present in prevalence not very inclined slopes and almost never steep slopes; on the other hand, when the bottom is flat or sublevel very often the slopes are steep or middle-steep (tab. 7).

As a further confirmation of the morphological differences existing, it can be noted that the dry-wall (as a slope support) is almost absent at the low altitude, while it is present in more than the 80% of the cases at the high and middle-high altitudes. In fact the dry-wall loses its function of support if the slopes are not very inclined.

Tab. 6. Bottom morphology in relationship with position-factor

	class 1 high altitude		class 2		class 3		class 4		class 5 low altitude	
flat	4	25%	2	12,5%	8	47,06%	4	25%	3	18,75%
sublevel	9	56,25%	9	56,25%	4	23,53%	4	25%	3	18,75%
concave	3	18,75%	5	31,25%	5	29,41%	8	50%	10	62,5%

Tab. 7. Slopes morphology in relationship with bottom morphology
NORTH SLOPE

	flat bottom		sublevel bottom		concave bottom	
steep	5	23,81%	7	24,14%	1	3,23%
middle-steep	14	66,67%	16	55,17%	13,	41,94%
not very inclined	2	9,52%	6	20,69%	17	54,84%

SOUTH SLOPE

	flat bottom		sublevel bottom		concave bottom	
steep	7	33,33%	11	37,93%	4	12,9%
middle-steep	9	42,86%	10	34,48%	10	51,61%
not very inclined	5	23,81%	8	27,59%	11	35,48%

Vegetation

With the same process of division in classes the correlations between vegetation of the doline bottom and dimensions and between vegetation and position have been observed.

It results that the bottom appears uncultivated only in the classes of small and medium dolines, while in the large dolines grass and sowable cultivation are prevalent. Small dolines have quite often the bottom farmed with vine (tab. 8).

Moreover it is evident that vine is a peculiarity of dolines situated on low altitude and in the southern and western zones and that it is almost absent at high altitude; in fact vine prefers zones with warm and dry climate. On the other hand, at high altitude, grass is mostly present (tab. 9).

CONCLUSIONS

The landscape of Berici table-land is deeply characterized by the presence of dolines: in fact, in the inner zones, the karst basins alternate to more or less elevated ridges, to cols between a doline and another and to not very large nearly flat areas;

It has been also observed that the peculiarities of this landscape are deeply determined by presence of man who has occupied all parts suitable for cultivation.

In the present circumstances it would be harmful to eliminate as well as to reduce

Tab. 8. Bottom vegetation in relationship with dimension-factor

	class 1 small		class 2		class 3		class 4		class 5 large	
wild	3	18,75%	7	43,75%	3	17,65%	1	6,25%	0	0%
grass	3	18,75%	2	12,5%	4	23,53%	7	43,75%	6	37,5%
vine	5	31,25%	2	12,5%	3	17,65%	2	12,5%	2	12,5%
vegetables	1	6,25%	0	0%	1	5,88%	0	0%	0	0%
sowable	4	25%	5	31,25%	6	35,29%	6	37,5%	8	50%

Tab. 9. Bottom vegetation in relationship with position-factor

	class 1 high altitude		class 2		class 3		class 4		class 5 low altitude	
wild	1	6,25%	6	37,5%	3	17,65%	4	25%	0	0%
grass	5	31,25%	6	37,5%	6	35,29%	4	25%	1	6,25%
vine	1	6,25%	1	6,25%	0	0%	5	31,25%	7	43,75%
vegetables	0	0%	1	6,25%	0	0%	0	0%	1	6,25%
sowable	9	56,25%	2	12,5%	8	47,06%	3	18,75%	7	43,75%

this presence since a balance has been established that otherwise would be broken.

In fact where cultivations are abandoned there are conditions of deep environmental deterioration, also because the woody vegetation requires a long time to settle.

Therefore it is necessary to support agricultural practices that don't deform the landscape, but contribute to determine the peculiar characters.

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KARST MANAGEMENT ISSUES IN NEW SOUTH WALES, AUSTRALIA

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ABSTRACT

G.K.W. :human impact, planning, cave tourism, mining, management
Geogr. K.W. : Australia, New South Wales

Increased interest in tourism and recreational caving in New South Wales have caused various environmental problems in karst areas in New South Wales. There are also conflicts between mining and conservation groups. New management strategies are evolving, but matters are in an interesting state of flux, with commercial pressures affecting government attitudes. However plans of management are now being considered for some of the major cave systems, which should result in long-term improvements.

INTRODUCTION

Many changes have occurred in the past few years in the management of karst and cave systems in New South Wales (Figure 1), and attitudes about conservation and tourism are in a state of flux.

There are seven cave systems in New South Wales open to tourists: they are Jenolan, Wombeyan, Abercrombie, Wellington, Yarrangobilly, Bungonia, Borenore and Wee Jasper (Figure 2). Of these Bungonia has limited guided access, Borenore is self-guided with laid paths only, and Wee Jasper is publicly owned but leased to a private operator.

Jenolan is by far the most visited tourist cave system, followed by Wombeyan and Wellington. Road access to Jenolan and Wombeyan (both impounded karsts) is quite difficult and poses considerable problems for cave management and conservation.

Important systems which are used to a varying degree for recreational caving are Bungonia, Wee Jasper, Colong, Tuglow, Wyanbene, Borenore, and Timor (Figures 2 & 3), Osborne and Branagan (1989). Recreational caving at tourist cave localities and at Cooleman, Cliefden and Walli is more strictly regulated. Recreational caving poses considerable, but various, conservation and management problems which still have to be addressed.

Cave systems also occur in, or adjacent to working limestone quarries at Portland, Kandos, Charbon, Attunga and Yessabah (Figures 2 & 3). Legal proceedings are in progress concerning conservation and leasing arguments at Yessabah.

Some, but not all of these cave systems, occur within the State National Parks system, which has but a single officer devoted to karst management. Those systems not within the National Parks are variously administered by the State's Departments of Lands or occur on private property.

In 1989 the Jenolan, Wombeyan and Abercrombie systems were placed under a single independent (government) management, while the accommodation at Jenolan and Wellington was passed from government control to private operation.

Cave guides, tourist cave managers, and resource managers and others involved in karst management find a focus for their interests in the Australasian Cave and Karst Management Association (A.C.K.M.A.) which has an expanding membership in New South Wales.

The peak body for both recreational caving and cave science in Australia is the Australian Speleological Federation (A.S.F), a federation of societies which is affiliated with the U.I.S. Unlike other Australian states where there are only a few (1-3) speleological societies, the organised caving community in N.S.W. is characterised by a proliferation of societies.

IMPACT OF TOURISM

The effect of tourism on cave systems can take many forms. Most cause deterioration of the natural environment, and there have been various attempts to reduce the impact of tourism, while making the environment more attractive to visitors.

Major issues within the tourist caves are: - air quality, lint accumulation , lampenflora, cleaning and lighting.

Natural accumulation of carbon dioxide occurs in some N.S.W. caves and is an important issue at Wellington Caves (Osborne, 1991), where toxic levels are occasionally found in one tourist cave. There is also concern about the effect of exhaled carbon dioxide on speleothems in cave systems with high rates of visitation, such as Jenolan. There is yet insufficient data on air quality in tourist caves in N.S.W. to allow informed decisions on carrying-capacities to be made.

Accumulation of lint from clothes has been a significant problem at Jenolan Caves. Steam and high pressure water cleaning have removed large amounts of lint deposited in the past, but a long-term solution has yet to be devised.

Lampenflora has been a problem in some tourist caves, but has been controlled by changes in lighting usage and use of bleach solutions. Self-guided caves, such as the Fig Tree Cave at Wombeyan, have been particularly susceptible to this problem as a result of continuous operating track lights. Timers and infa-red activated switches have recently been installed in an effort to alleviate this problem.

High pressure water cleaning has been used extensively at Jenolan Caves and to a lesser degree at other systems. The long term effects of this are unknown and there are questions as to the effect of cleaning on natural mud deposits and on the stability of breakdown piles.

Various types of electrical lighting systems are in use in N.S.W. tourist caves, with some systems operating on reduced voltage (110 V) and others working on the Australian standard voltage (240V). Much of the wiring in the caves is becoming old and major re-wires will soon be required. Major electrical works are now under way at Yarrangobilly, the work being carried out by an electrical contractor with speleological experience who is specialising in cave wiring.

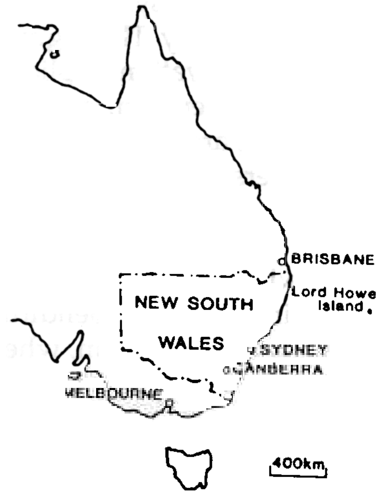

Fig. 1. Eastern Australia, showing New South Wales.

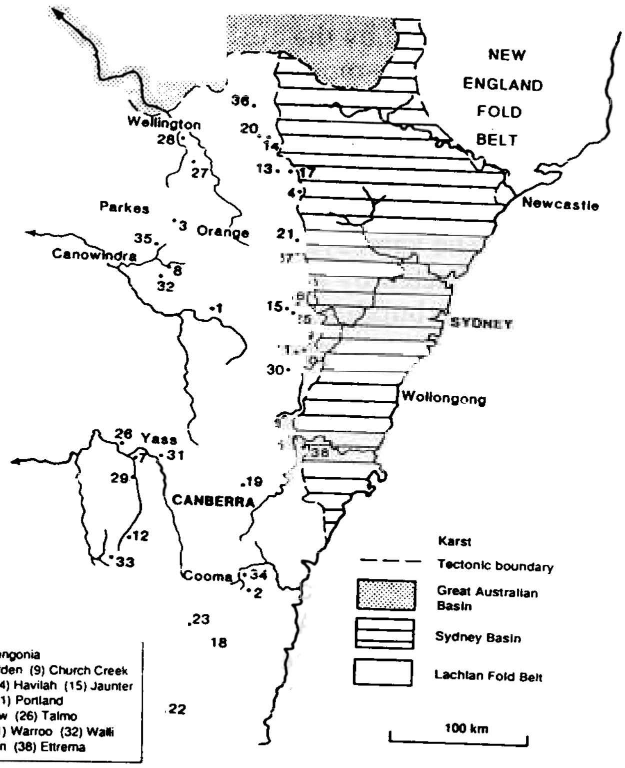

Fig. 2. Karsts of the Lachlan Fold Belt.

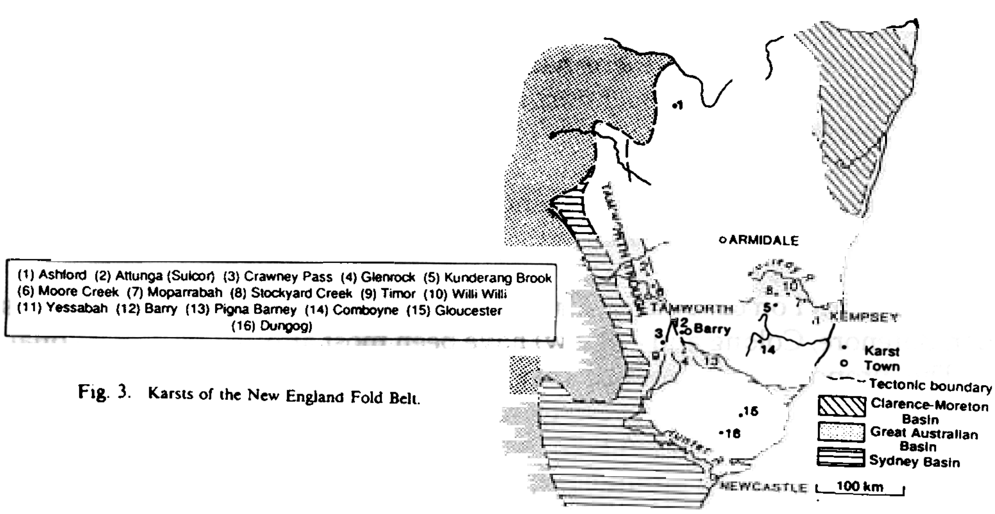

Fig. 3. Karsts of the New England Fold Belt.

Self-guided tours are available at Yarrangobilly (signposted), at Wombeyan (recorded, using new digital recorders), at Jenolan and Borenore, the latter two in "open" arch areas. A self guided tour is now being considered for Abercrombie.

Adventure tours into "non-tourist" parts of the tourist cave systems are now being offered by the officials at Jenolan , Wombeyan and Yarangobilly. These give more insights to the more adventurous tourists, but have obvious conservation implications.

Vehicular traffic poses special air pollution problems at Jenolan, as access to parking and accommodation is via the Grand Arch, where there are the main entrances to the guided tour caves and where large web-building spiders live on the roof of the Arch.

The karst systems at Jenolan, Wombeyan, Wellington and Yarrangobilly have all been affected by general problems associated with increased tourism- such as sewage disposal, building on karst, road stability, runoff and silting. Major expenditure on environmentally-friendly sewerage systems is a high priority at Wombeyan, where the tourist development is upstream of the main caves, and at Wellington where sewage is currently disposed of in evaporating ponds adjacent to the caves.

RECREATIONAL CAVING

Recreational caving continues to be a significant activity. The Australian Speleological Federation (A.S.F.) has 15 member societies and 9 associated organisations in N.S.W. Although member societies have considerable status and exclusive access to a number of cave areas, including the major tourist cave areas, their membership only represents a small part of the recreational caving community.

The Scout Association is by far the largest single recreational caving organisation, followed probably by other organised youth groups. Surveys carried out at Bungonia, however, suggest that most recreational cavers are unaffiliated with any formal organisation.

In the past ten years there has been spectacular increase in the number of commercial adventure tour operators offering caving as an activity to paying (inexperienced) customers.

Since A.S.F. clubs have preferential or exclusive access to a number of cave areas, the impact of the majority of recreational cavers (Scouts, other youth groups, unaffiliated cavers and professional adventure tour operators) has been restricted to a few cave systems where there is

little control on cave entry. Thus Bungonia and Wee Jasper (and to a lesser extent Timor, Borenore, Colong and Tuglow) have been most affected by recreational caving.

The proposal to introduce cave classification systems, which would classify certain caves as "reference caves" to which entry would be restricted, has become a controversial issue within A.S.F. societies. Some members have supported the proposal on conservation grounds, while others have mounted concerted opposition to any proposal which will restrict the entry of A.S.F. society members to caves on public property.

Cavers of all descriptions have become more conservation-minded than in the past, but their impact on the cave systems is now viewed more seriously (Spate, 1989).

MINING

There has been a significant history of disputes between conservationists and miners over the future of limestone deposits in New South Wales. This has largely occurred because the deposits which were most attractive to miners; large, easily-mined high grade deposits, are those in which significant cave systems are developed.

There are three karst areas in New South Wales were disputes are now in progress about limestone mining and karst conservation. The most significant dispute concerns the Yessabah karst (Osborne & Branagan 1989) where an individual caver is taking legal action against the granting of a mining lease in a cavernous area within a caves reserve, adjacent to significant surface karst features, and caves which are important to the life cycle of a number of species of bat. The final outcome of this action, which will go to court in June 1991, has yet to be determined.

Mining issues also exist at Wombeyan Caves where large-scale mining for high purity marble occurs in cavernous limestone upstream of the tourist cave complex. Concern has been expressed about water pollution form the mine and the destruction of caves containing vertebrate fossils.

Small scale quarrying of marble for dimension stone also occurs at Wombeyan in quarry leases within the caves reserve. How this activity can be reconciled with the purpose of the reserve is an issue which will need to be addressed in the reserve's Plan of Management, now being prepared (see below).

At Bungonia there has been some recent activity in a long-standing dispute about the effect of the large South Marulan Quarry. This quarry operates adjacent to Bungonia Gorge, a significant limestone canyon, and in direct view of a scenic lookout, Bungonia Lookdown. The current issue concerns not only the aesthetic appearance of the quarry, but also whether quarry waste has spilled into adjacent public land.

MANAGEMENT OF KARST AREAS

Karst areas in New South Wales occur in freehold (private) land and in Crown (public) land administered by a number of different authorities. The seven tourist cave localities and many of the significant non-tourist cavernous karsts occur in Crown Land. By far the majority of cavernous karst areas in the State are found in lands administered either by the National Parks and Wildlife Service (N.P.W.S.) or by the Department of Lands.

National Parks and Wildlife Service

The National Parks and Wildlife Service is responsible for the State's National Park System and for the protection of wildlife, Aboriginal and historic sites. A significant number of cavernous karsts, including Yarrangobilly Caves, a developed, guided tourist cave system, occur within National Parks.

The N.P.W.S has legislative power to control scientific research and recreational caving activities in the caves within its lands. The degree of practical control on recreational caving in these areas is, however, quite variable, due to staff and financial constraints and the remoteness of some areas from centres of administration.

Bungonia Caves, where there is much recreational caving, is administered for the N.P.W.S. by a Trust which includes representatives of recreational caving interests.

The N.P.W.S. employs Mr A.P. Spate as Investigations Officer-Karst whose role is to provide professional advice on karst management.

Department of Lands

The majority of Crown Land in New South Wales is administered by the Department of Lands. This includes land reserved for a variety of special purposes which is usually administered through Trusts, bodies of persons appointed to manage the land in accordance with the reasons for its reservation, rather than directly by the Department. Trusts have varying degrees of financial independence and are responsible for the "care, control and management" of the land.

Jenolan, Wombeyan and Abercrombie Caves, three of the major tourist caves in the State are administered for the Lands Department by the Jenolan Caves Reserve Trust, which is the largest single tourist cave operator in the State. The Trust is advised by a Scientific Committee and a Speleological Committee and employs Mr E. Holland as a specialist adviser on karst management.

Wellington Caves are administered by the Wellington Shire Council (a Local Government Authority) acting as Trustees to the Department of Lands. The Council has appointed an Advisory Committee which includes a number of karst specialists to advise it on the management of the caves.

Many other karst areas e.g. Borenore, Wee Jasper, Moore Creek, are administered for the Lands Department by Trusts.

Karst on Private Land

A number of significant cavernous karsts in New South Wales occur on private land. Some of these, e.g. Cliefden and Walli, are extremely well-managed by concerned landholders, who have come to private arrangements with speleological societies to gate cave entrances and control access. Other karst areas on private land have been significantly degraded by unsympathetic management.

Planning legislation allows Local Government authorities to offer some protection to karst areas on private land by controlling development, subdivision and possibly agricultural practices. As there has been little urban development on karst in New South Wales, Local Government has had minimal experience in controlling building and other engineering works on karst. New tourist developments on private land adjacent to Wellngton Caves have raised the issue of what types of site investigation should be required prior to granting permission for building.

Recent legislation will allow the State Government to dedicate underground Reserves and Wilderness Areas, while leaving the ground-surface and top few metres of land in private ownership. This is seen as a means of protecting the environment of cave systems currently on freehold land. It is not yet clear, however, how this legislation will work in practice.

Plans of Management

Legislation requires that Plans of Management are prepared for Crown Lands administered by the National Parks and Wildlife Service and the Department of Lands. Plans of management are intended to describe the resource to be managed and provide management guide-lines for its conservation and development.

Detailed management strategies have been developed for the management of the Yarrangobillly and Cooleman Plains karst areas in the Kosciusko National Park. Less sophisticated guide-lines are given for karst areas in the management plans of other

National Parks.

Of the karst areas administered by the Department of Lands, Jenolan Caves has the most comprehensive management plan, produced in 1988. The Plan, which includes a volume of specialist papers describing the resources at the caves, has been somewhat overtaken by administrative changes at Jenolan Caves and is now in need of revision. A Plan of Management and detailed resource study (Anderson, 1991) has recently been prepared for Wellington Caves. Management Plans for the Abercrombie, Borenore, Moore Creek and Wombeyan karst areas are currently in various stages of preparation.

HERITAGE STATUS

A number of karst areas in New South Wales have been recognised as being of heritage significance by being listed in the Register of the National Estate kept by the Australian Heritage Commission (a Commonwealth Government authority). These areas have been listed for a number of reasons in addition to their significance as karst. Many are listed as geological sites (Osborne, 1989,1990) due to significant fossils either in the limestone or in cave deposits. Others, e.g. Yessabah, are considered significant for their vegetation or fauna.

Although listing offers little in the way of legal protection to the karsts it has proved to be an important tool in influencing public opinion and political debate about the management of karst areas.

Currently there is public and political debate about the possible nomination of the Blue Mountains as a World Heritage Area. Any such nomination is likely to include Jenolan Caves, an area which some members of the speleological community have considered for some time to be of World Heritage significance.

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KARST AND SOILS, DEVELOPED ON LIMESTONES IN VIETNAM

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ABSTRACT

G.K.W. : soils, landuse, soil dynamic, vegetation
Geogr. K. W.: Vietnam

In Vietnam, karst belong to the tropical type (occurring in South-East Asian karst zone) and occupies an area of nearly 50.000 km^2, i.e. about 1/6 of the natural territory of the country, not concerning uncovered karst.

Karst formations in Vietnam are mostly limestones of Cambrian (Early and late), Ordovician-Silurian, Devonian (Eifen-Givetian, Frasnian), Carbon-Permian, Triassic ages and some marbled limestones of Cambrian and younger ages.

Givetian limestones are frequently covered by a thick ferralitic soils layer with forests, whereas on the Frassian limestones often occur naked karst with slopes and rocky ridges.

Triassic limestones are of Norian (late Triassic) and especially Ladian (Middle Triassic) stages, having various colours from light to sombre grey. They comprise light siliceous and black bituminous limestones.

As seen from the map of the karst distribution in Vietnam, on the platforms and its outskirts are occurring only Precambrian, Ordovician, Silurian and Devonian carbonaceous rocks with widespread residual karst relieves, whereas on the geosynclines in Permian and Triassis carbonaceous rocks with younger karst relieves.

In Vietnam the earliest karst formation begun at the end of the Devonian era (nearly 270 millions years from now) and the latest at the end of the Triassic era (160 millions years from now). Karst have been formed mostly on the mountains, while on the plains they occupy inconsiderable areas. The naked and old karst are most widespread.

On the soils, developed on the fertile limestones one can cultivate various valuable plants, such as maize, cotton, soy-bean, tobacco etc. In the forests, developed on the limestones soils there are many kinds of precious trees, such as Chukrasia tabularia, Liquidamba formosana, Castanen mollissims etc. The karst plateaus usually have big absolute heights. In the coastal karst zones the landscapes are very wonderful. One can find there a lot of extraordinary caves, adoring the tourists from the various corners of the world.

The square of the ferralitic soils, formed on limestones is about 383.000 ha, i. e. 1,2% of the total natural territory of the country. Although the square is not so big, the role of the ferralitic soils, developed on limestones is very important to the country economy. Owing to the complexity of the processes of karst formation in Vietnam,

Table I. Elements of **water balance and moisture** pressure of the Red-brown ferralitic soils, developed on limestones (Plateau Son-la)

Depths, Elements of water balance	1973	1974												Total Avarage*
	30.XII	30.I	30.II	30.III	30.IV	30.V	30.VI	30.VII	30.VIII	30.IX	30.X	30.XI	30.XII	
Soil moisture storage, mm														
0-50 cm	125	140	125	125	160	170	175	160	150	145	130	125	120	145
50-100 cm	165	170	150	170	180	190	205	190	180	170	170	165	160	175
0-100 cm	290	310	275	315	340	360	380	350	330	315	300	290	280	320
D SMS	+20	-35	+40	+25	+20	+20	-50	-20	-15	-15	-10	-10		-30
Rainfall (R)	20	5	47	42	109	468	360	343	20	33	23	0		1490
E+F+f= R- DSMS	0	40	7	17	80	448	410	363	35	68	33	10		1520
E_0	61,8	71,3	98,0	106,9	106,7	50,8	62,5	57,6	64,3	61,7	56,8	52,6		851
$E+F+f/E_0$	0	0,56	0,07	0,16	0,83	8,82	6,56	6,30	0,54	1,10	0,58	0,19		1,786
$C_h = R/E_0$	0,32	0,07	0,48	0,39	1,02	9,21	5,76	5,95	0,31	0,86	0,40	0,00		1,750
$R-E_0 = F+f$	-	-	-	-	2,30	418,8	297,5	285,0	-	-	-	-		1003
Soil moisture, mm														
	25	28	25	29	32	34	35	32	30	29	26	25	24	29*
	33		30	34	36	38	41	38	36	34	34	33	32	35*
	22		19	28	-		-		-		22	22	22	22,5*
Pressure of the soil moisture, atmosphère (P)														
0-50 cm	-9,0	-4,0	-9,0	-3,0	-1,3	-0,7	-0,5	-1,3	-2,0	-3,0	-7,0	-9,0	-13,0	-4,5*
50-100 cm	-2,3	-1,9	-6,0	-1,9	-1,2	-0,75	-0,35	-0,75	-1,2	-1,9	-1,9	-2,3	-3,0	-1,9*
0-20 cm	-30,0	-30,0	-80,0	-4,0	-	-	-	-	-	-	-30,0	-30,0	-30,0	

Annotation: SMS - Soil moisture storage; R - Rainfall; E - Evaporation; E_0 - Evapotranspiration Potential; F - Filtration; f - flow (surface + subsurface); C_h - Coefficient of humidification (moistening).

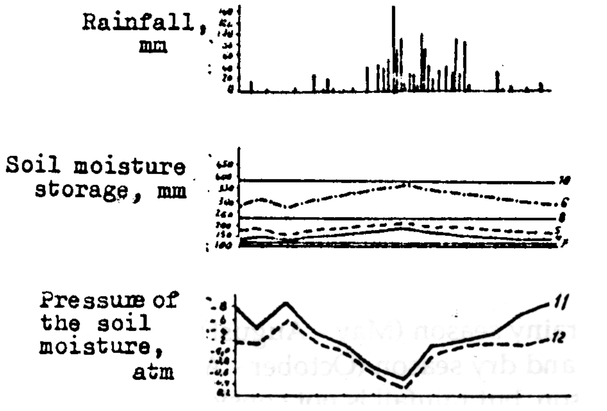

Fig. 1 Meteorological conditions in Karst Area Plateau Son-la and water regime's elements of the Red-brown ferralitic soil on limestones.
Legend: 1. Rainfall, mm; 2. Air temperature, 3 °C. Relative air humidity, %.
Soil moisture storage in the depths: 4. 0-50 cm; 5. 50-100 cm; 6. 0-100 cm;
Soil moisture storage which corresponds with wilting moisture in the depths: 7. 0-50 cm; 8. 0-100 cm;
Soil moisture storage which corresponds with field moisture capacity in the depths: 9. 0-50 cm; 10. 0-100 cm;
Pressure of the soil moisture
(P= atmosphere) 11. 0-50 cm; 12. 50-100 cm.

different kind of ferralitic soils are formed on limestones, such as:

1. Brownish-red ferralitic soils
2. Reddish-brown ferralitic soils Ferasol Rhodic
3. Yellowish-red ferralitic soils
4. Black earth soils (Vertisol) developed on lime materials
5. Calcisols, i. e. soils with calcium carbonate accumulation.

The soils on limestones is formed under influence of the next factors:

1. Quantity of calcium, freed from parent rocks.
2. Quantity of calcium, brought from limestones in the high mountains or from higher relieves.
3. Ability of flora to reserve calcium.
4. Ability of depresions to store calcium.
5. Quantity of calcium washed.

Because of the complicated relations of these factors different types of soils can meet on limestones. For example, at the bottom of limestone mountains and slopes, one can find brownish-red neutral soils; farther from the bottom acids soils; in the low, moist places-yellow and less acid soils; in the rather dry and humus-rich places-brown soils; in the depressions-black humus-rich soils.

The soils, developed on limestones are fertile. Nevertheless, they have some negative character, such as: 1. Division and dispersion of soils owing to complicated relieves. 2. Lack of moisture during dry season. 3. Depth of soil layer is very changeable, the same as acidity, humus, washing level, soil moisture and other chemico-physical properties.

We have studied genetical, chemico-physical properties of soils, developed on limestones. Soil analysis is determined by the popular methods. Many profiles have been studied in different places, but in the framework of this paper we are to present only the dynamics of soil moisture and water regime and some chemical properties of the Reddish-brown ferralitic soils, developed on limestones in the karst areas Son la - Moc chau. Soil moisture were determined by drilling. A sample of the soils is collected after every 10 cm until the depth of 100 cm or 150 cm.

Being in the North-Western Vietnam, plateau Son la - Moc chau is the biggest and most typical karst area of the country. This karst area is 180 km in length and 25 km in width and composed mainly of Ladian (Middle Triassic) limestones with some thin strata of Eifen-Givetian (Middle Devonian) and Early Carbonferous limestones. The depth of Ladian limestones is rather considerable. The Reddish-brown ferralitic soils, formed on limestones is widespread in this area.

Research works were carried out on slopes with declivity 7-10°. Next remarks can be made from the results of study on the water regime of soils on Son-la karst area, which showed on table No I and fig. 1.

1. Two seasons can be distinguished: rainy season (May - August) with the greatest rain quantity in June, equal to 468 mm and dry season (October - April). Unlike to the other areas, it rains here during dry season, but rainfall is not considerable, varying from 5 to 53 mm.

Because of the dry wind, blowing from the west evapotranspiration potential reaches 98-107 mm in March - May. In the whole year rainfall is equal 1500 mm, evapotranspiration potential - 850 mm; relatively coefficient of moistening during the whole rainy season varies from 1,02 to 9,21; during dry season - from 0,86 to 0,07; year average - 1,75.

2. Soil moisture storage in the layer 0-100 cm vibrates from 330 to 380 mm during rainy period and from 275 to 315 mm during dry period. As seen from fig. 1 from October to March (next year) moisture lack is very considerable because soil moisture storage in the layer 0-50 cm during these months is almost as wilting moisture.

During the period from June to December the change of soil moisture storage is negative, because during this time evapotranspiration potential is very great and rainfall - very low.

3. Difference between total rainfall per month and change of soil moisture storage is a sum of total water loss by soil evaporation, transpiration, filtration and surface flow.

Moisture storage of soil developed on limestones is always less than that of soils developed on argillaceous slates in despite of identical climate conditions.

Difference between total rainfall and change of soil moisture storage in June and August reaches 363 - 448 mm, while evaporation only vibrates from 50,8 to 62,5 mm. Thus total water loss is very high, reaching 300 - 400 mm per month due to surface flow. Filtration is not considerable, perhaps owing to decrease of soil porosity under influence of calcium cations swelling. According to data by Dr. Bui Quang Toan soil washing in this area reaches 276 tons per ha when soil surface is uncovered. Our research shows that main reason, causing soil washing is surface flow. Therefore search for suitable measures to cover soils, to hammer surface flow and washing is one of the most important task to protect this fertile limestone karst plateau.

The ratio between total water loss and evapotranspiration potential reaches very high value, especially during rainy season (6,3-8,8) and decreases to 0-0,58 during dry season.

4. Soil moisture and soil moisture pressure varies greatly, depending on climate conditions. During rainy period capillary pressure varies from - 0,5 to - 0,7 atm in the upper layer and from - 0,35 to - 0,8 atm in the layer 50-100 cm. During dry period this value diminishes, total moisture pressure vibrates from - 2 to - 9 atm in the layer 0-50 cm and from - 1,2 to - 6 atm in the layer 50-100 cm. Exclusively the total moisture pressure in the arable layer reaches - 30 atm, even - 80 atm on 30 th February during dry season.

Table 2. Total compositions (in the colloidal clay, %) of Reddish-brown ferralitic soils developed on limestones (Absolute altitude < 300 m)

INDEX	DEPTHS, cm			
	0-20	20-40	40-60	60-80
SiO_2	19,7	27,9	24,5	30,8
Al_2O_3	22,59	30,46	30,42	38,52
Fe_2O_3	10,00	16,80	18,80	21,20
CaO	0,49	1,13	0,56	0,42
MgO	1,52	2,78	3,30	-
MnO	0,50	0,10	0,21	0,21
SiO_2/Al_2O_3	1,48	1,55	1,36	1,35
SiO_2/R_2O_3	1,15	1,15	0,98	1,00
Clay fraction (< 0,001 mm)	6,40	16,40	20,50	34,00

So, available soil moisture in the arable layer is absent during the whole six months. Consequentially in order to ensure generation, growth and high productivity of plants it is necessary to apply suitable measures to get optimum water regime, fore-most - obstacle surface flow, store soil moisture for plants during dry season.

In humid tropical soils generally quantity of Al_2O_3 is more than that of Fe_2O_3. The ratios SiO_2/R_2O_3 (in colloidal clay) show that the less this ratio the higher ferralitization intensity (see table 2).

As seen from the data on total compositions (table 2) weathering level (ferralitization intensity) of soils is high, where ratio SiO_2/Al_2O_3 varies from 1,35 to 1,55 and SiO_2/R_2O_3 from 0,98 to 1,15.

The clay tenor (i.e. Clay fraction< 0,001 mm) in the layer 20-40 cm is equal to 16,4 %, especially in the layer 0-20 cm - only 6,4 %, showing that soils are intensively washed.

The data on chemical compositions of soils, developed on limestones (table 3) show difference of chemical properties of soils formed on the same limestones but at different places and depths, under various flora covers, concretely:

1. Acidity of soils vibrates in a great interval: pH_{KCl} is equal 4,1-6,8. The most acid soils, where pH_{KCl}= 4,1-4,4 occur in profiles ML.1 and MS.1 (Deeper arable layer).

2. The least fertile is soil, occurring on barrens (profile BY.2). The total humus here varies only in interval 0,63-0,70, while this value reaches 4,2% at depth 0-10 cm (in profile MS.1) or 4,5% in profile SL.100. The total compositions N, P_2O_5, K_2O are pure and very pure. Clay tenor, i.e. fraction < 0,001 mm only varies from 7,4 to 10% for the whole profile.

Concerning total P_2O_5 of Northern Vietnam soils, according to Wohltmann (1940) one can divide them into: very fertile soils P_2O_5 < 0,20%; fertile 0,10-0,20%; not fertile 0,06%. Thus, total P_2O_5 soils, developed on limestones is good with the exception of profile BY.2 (Barren) and arable layer of profile ML.1 (Cassava).

Table 3. Chemical properties of Brownish-red ferralitic soils developed on limestones in Vietnam. (Data by Le Thay Bat).

No of profile	Depth of sampling, cm	pH KCl	Acidity hydrolytic meq/100 g soil	Total composition, % from absolute dry soil				Nutrient mobility mg/100 g soil		Cation exchange meq/100 g soil			C/N	Absorbing capacity meq/100 g soil	Clay <0,001 mm %
				Humus	N	P_2O_5	K_2O	P_2O_5	K_2O	Ca^{++}	Mg^{++}	H^+			
				Plateau Son la, Absolute altitude 1.100 m, Declivity 25° Cluster											
SL 100	0-10	6,4	1,4	4,50	0,28	0,22	0,90	1,6	11,0	14,0	6,0	0,5	9	26,0	19,6
	25-35	5,8	2,6	1,17	0,12	0,18	0,80	2,3	4,0	5,6	4,0	0,2	6	18	28,0
	60-70	5,5	2,3	1,11	0,09	0,18	0,80	1,4	3,0	5,6	4,0	0,2	7	15,8	18,2
				Phien ban, Bac-yen Plateau Son-la, Absolute altitude 1000 m, Declivity 7-10 °, Barren											
BY.2	0-10	6,0	1,4	0,65	0,09	0,06	0,10	1,7	9,0	12,8	9,0	0,2	4	24,8	8,4
	40-50	5,5	2,5	0,70	0,10	0,05	0,70	0,3	9,5	10,0	12,0	0,3	4	18,0	7,4
	70-80	5,8	1,9	0,60	0,08	0,08	0,70	7,5	7,0	14,0	10,0	1,0	5	21,3	10,0
	90-100	6,8	0,9	0,63	0,07	0,13	0,10	9,7	6,0	4,3	2,8	0,5	5	16,0	8,8
				Hui phuong, Phu yen Absolute altitude 500 m, Declivity 15-25°											
BY.2	0-10	5,2	2,0	2,17	0,22	0,15	1,40	2,7	16,0	10,0	2,5	0,5	6	19,0	21,2
	35-45	5,3	3,1	1,91	0,21	0,16	1,50	1,8	10,8	10,8	2,4	0,4	5	16,0	24,0
	60-70	5,4	1,8	1,69	0,21	0,22	1,40	3,2	7,0	10,0	3,2	0,3	4	13,0	26,2
				Itong, Muong la Plateau Son-la, Absolute altitude 500 m, Declivity 8-15°, Cassava											
ML.1	0-10	5,1	4,0	1,66	0,19	0,02	-	2,1	16,0	12,0	7,6	1,2	9	23,0	19,6
	50-60	4,4	4,8	1,64	0,11	0,18	-	0,5	5,0	11,2	5,6	0,4	9	23,0	14,0
	90-100	4,3	4,4	1,22	0,07	0,13	-	0,3	5,0	12,0	6,0	0,5	10	23,9	22,0
				Co-noi, Mai son, Plateau Son-la, Absolute 500 m, Declivity 8-15°, Fruit-tree											
MS.	0-10	5,3	4,0	4,20	0,27	0,15	0,08	1,0	40,0	16,0	6,4	0,2		23,9	30,2
	35-45	4,2	6,5	1,80	0,16	0,06	0,80	0,2	10,0	6,4	5,9	0,8		21,3	43,6
	80-90	4,1	6,2	1,40	0,15	0,05	0,90	0,1	9,0	6,4	3,3	2,1		27,1	54,8

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Proceedings of the International Conference on Environmental Changes in Karst Areas - I.G.U.- U.I.S.- Italy 15-27 Sept. 1991 ; Quaderni del Dipartimento di Geografia n. 13, 1991 - Università di Padova, pp. 173-175

A PROPOSAL: STUDY OF SINKHOLES AS A POINT-SOURCE CONTAMINATION IN KARST TERRAIN

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ABSTRACT

G.K.W.: human impact, pollution of water

INTRODUCTION

In covered karst terrain, a number of physical and chemical geological processes interact to produce gradual erosion of limestone and its overburden with the result often being the development of sinkholes. Those sinkholes can be opened to the surface as a vertical shaft or they can be filled with sand and clay materials resulting in the formation of surface depressions. In both cases they serve as source of water supply and ground water pollution (Sincliar, 1985). The vertical penetration of sinkholes interrupts the lateral continuity of the overburdens, induces changes in the hydraulic conditions of a local flow pathway also in chemical components in ground water. These chemical changes are the result of mixing of surface water with aquifer water through the sinkhole windows, although they may be plug temporally.

PURPOSE OF THE STUDY

Nonpoint source contamination is a world-wide phenomenon that is very often the result of agriculture practices. Point-source contamination is generally defined as a single pollutant source such as landfill, a septic tank, or an underground oil tank. Sinkholes acting as potential point-sources of contamination needs to be confirmed. The chemical reactions of ground water within sinkholes are unique and very rapid and often produce catastrophic changes. These reactions can be temporarily suspended as a result of plugging. The velocity of flow within sinkhole shafts could be tens to hundreds of times higher than flow within the micro-fractures (Figure 1). The sinkholes not only introduce contaminated surface waters into the aquifer directly, but also enhance the nonpoint source contaminants at a point to degrading the water quality.

The purpose of this study is to determine haw point source and localized chemical reactions reflect active sinkholes' area. Additionally, it will characterize the differences in the relationships between sinkhole area and non-sinkhole area with water qualities of aquifer system. It attempts to answer the question of why and how they differ. The result will be used to construct a sinkhole-water quality model for the prediction of water quality in similar sinkhole terrains and for predicting potential sinkholes by water input.

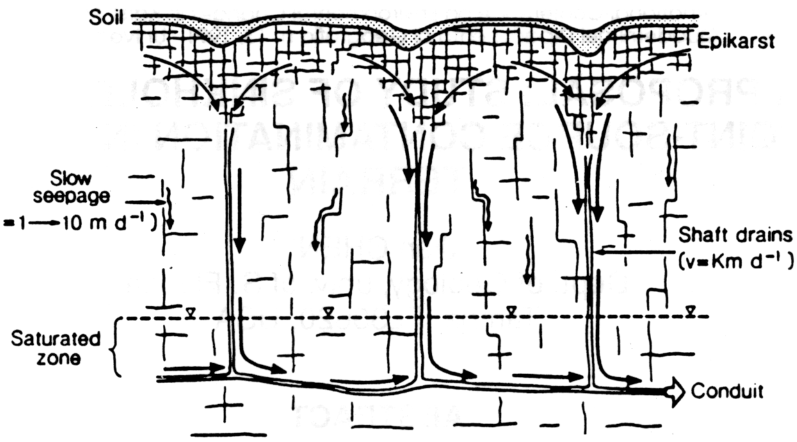

Fig. 1 Cartoon contrasting the difference of flow between sinkhole shaft and micro-fractures (Edwards & Smart, 1989)

PREVIOUS WORK

Numerous studies on the potential contamination from sinkholes has been done by Quinlan & Ewers (1977); Crawford (1985); Stewart (1987); Trommer (1987); Edwards & Smart, (1989). The research examined the role of sinkholes as potential sites for ground water pollution by using tracing techniques and routine chemical analysis. Rapid migration of pollutants through the sinkholes directly into the aquifer was addressed. A more specific study was Trommer's (1987). His research results came from each of five sinkholes in west-central Florida during October 1984 to September 1985. Some pollutants were detected in those sinkholes. However, because of the lack of systematic and spatial data collection from the sinkholes, the previous studies were limited to single chemical component changes through time at a sinkhole or sinkhole spring site (Stewart 1987). The relationship between chemical reactions and variations of water quality in aquifer system and how it reflects a area of active sinkhole development is a gap that this study intends to fill.

OBJECTIVES

General objectives of this study are processing the water quality and sinkholes data and, numerical interpretation of these data with geological concernment, which include:

1. Use of available water quality data and prepared chemical programs such as WATEQ and PHREEQE to determine the variations in chemical composition, dominant ions and reaction pathways in surface and ground water. WATEQ will be used to analyze the state of chemical composition and activities of ions over a period of time in

different sinkhole areas. Expectedly the time period over which water quality analysis will be done will include sinkhole formation. Selective analyses may be applied to characterize the distinctions between water quality in the sinkhole and non-sinkhole areas. PHREEQE will be used to computing the mass balance to analyze the origin of significant parameters reflecting sinkholes with surface water hydrology, and hydro-stratigraphy.

2. Use of available sinkhole data to construct a contour map of sinkhole density for correlation analysis with water quality data to draw their spatial relationship.

3. Analysis of hydraulic and geologic conditions to understand the variations of driven force of ground-water flow and medium characteristics, which control the movement of pollutants trough the sinkhole and non-sinkhole area.

4. To interpret the analyzed water quality and sinkhole data combine with geological, hydrogeochemical conditions to identify a numerical model consistent with the regional geology.

5. To generate a geochemical model that relates point-source contamination to the sinkholes.

This is going to be a graduate thesis study under the direction of professors of the University of South Florida. Suggestions and commends are certainly welcomed, and could be sent to Chen Jian, Geology Dept., Univ. of Florida, Tampa, FL33620, USA.

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MINING VERSUS KARST HYDROGEOLOGY: VACLAV GRAPHITE MINE NEAR BLIZNA, SOUTH BOHEMIA, CZECHOSLOVAKIA

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ABSTRACT

G.K.W.: hydrology, human impact, minig, natural hazards
R.K.W.: Czechoslovakia, South Bohemia, Sumava foothills

Catastrophic inrushes of karst water into graphite mine Vaclav caused: (1) damages on mining equipment, (2) substantial change of hydrogeological and hydrological situation (direction of groundwater flow, piezometric level, gradual deepening and widening of depression cone). Large karst caverns forming system in crystalline limestones were emptied during mining operations. In the present time, static reserves from karst system are drained yielding drink water of top quality.

INTRODUCTION

The interaction of karst and karst hydrology with mining of the Blizna graphite deposit is a classical example of poor knowledge and understanding of karst/poleokarst and related phenomena. General underestimate or ignoration of specific characteristics of karst by civil and minig engineers, sometimes even geologists, result from this point and have led to "unforeseen" floods and catastrophes in mines (e.g. Glazek and Szynkiewicz 1979).

Mine floods have been occurring in the Vaclav Mine since 1954. Their damaging effects, however, were relatively small. Although, karst nature of some floods was evident, no prevention of the natural hazard had been organized. Only two catastrophic floods in January and February 1983 with present water volume of about 4000 m^3 and 900 to 100 m^3 of 1985 caused reaction. Floods made substantial damages on mining equipment. The volume of water inflow to the 3rd mine level during 13 days after the second flood was estimated to more than 40000 m^3. Since the time, all mining operations follow detailed drilling prospection.

The present state of hydrogeology of the Vaclav mine and its broader vicinity, with all relations and consequences, results from the disturbation of the natural equilibrium established during the evolution of karst system. The process of gallery/adit driving, mine dewatering and water floods dramatically changed and drastically disturbed the natural equilibrium, i.e. the stationary state of the karst. Present outflow in karst and surrounding fissure or porous aquifers (directions, yields, mineralizations etc.) can not be connected, in any case, with conditions operating during karst evolution phase. The present state reflects continual adaptation of hydraulic, hydrologic, hydrochemical system and other elements of the hydrogeological structure to the situa-

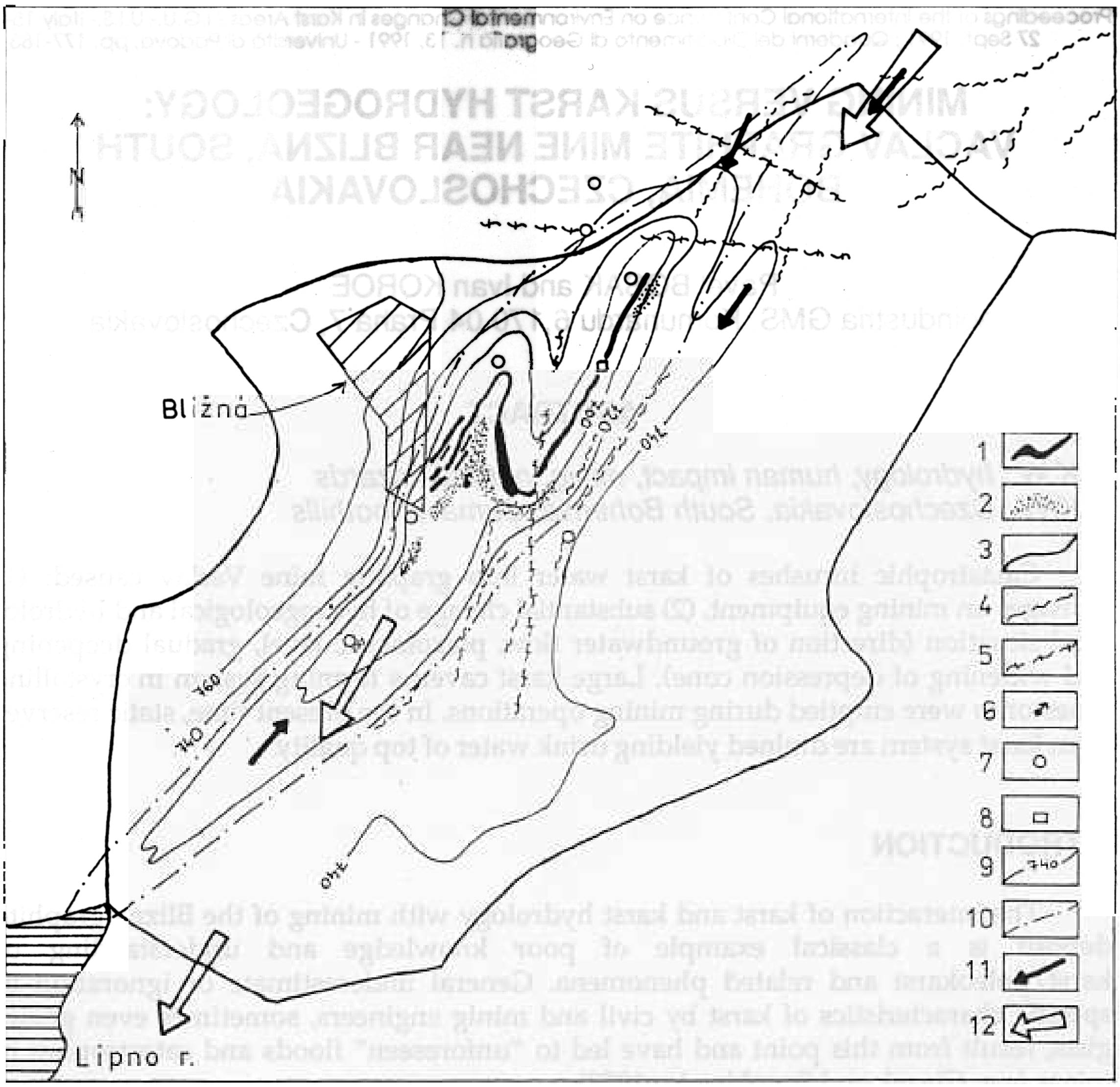

Figure 1. Schematic hydrogeological map of area

1. graphite-bearing horizon, 2. karstified underlying limestones, 3. limits of drainage basin, 4. conductive zones (geophysical indication), 6. karst spring at the 3rd mine level, 7. boreholes (on the surface and some of important underground ones), 8. pumping station (mine shaft), 9. hydroizopiezes (to the end of January 1991), 10. boundaries of hydrogeological structures influenced by mine dewatering, 11. present direction of groundwater flow, 12. supposed direction of main groundwater flow before mine was dewatered.

tion changed.

Blizna graphite field with the Vaclav Mine is situated on the left bank of huge artificial Lipno reservoir in the original valley of the Vlatava River. The region belongs to the Sumava foothills with local altitudes of 725 m a. s. l. (reservoir water level) up to about 870 m a.s.l. The Vaclav Mine is developed in 3 levels with water adits below the 3rd level. Water inrushes occured on the 2nd and 3rd levels, i.e. 38 to 65 m below the surface and 10 to 45 m below the water level in the Lipno reservoir (distant only 1200 m from the mine; Fig. 1).

GEOLOGY

South Bohemian graphite mines are founded in lithologically variable metamorphic sequences (Cesky Krumlov branchleozoic). The unit is composed mostly of biotitic gneisses with horizons of graphite-bearing rocks, limestones, erlans, aplites and lamprophyres. The area of the Vaclav Mine is strongly folded into brachyform structure with detailed internal folding and steeply inclined beds. The region is highly faulted, sometimes with mylonitized zones. Normal faults and thrust faults, sometimes with district horizontal element, limit tectonic blocks of different order with specific hydrogeological situation. Graphite body and other varied lithologies show boudinage pointing up original inhomogeneity of strata and secondary tectonic disruptions (folding and faulting).

Crystalline limestones (marbles), dominantly dolomite-calcitic, are developed in two horizons. They are separated by the graphite deposit associated with other non Karst rocks of highly variable thickness (metres to tens of metres). Limestones are therefore signed as overlying and underlying.

GEOMORPHOLOGY

Geomorphological evolution of the area was complex and is relatively poorly known. All rocks are highly weathered to the depths of 20 to 40 m, along lithological boundaries (e.g. limestone/gneiss) up to 65 m as proved by features on the 3rd mine level. Deep kaolinic-lateritic weathering led to the formation of smoothly undulating surface of the basal etchplain surface. Hills are formed on more resistant lithologies (limestones, amphibolities etc.). Weathering products are composed of clayey-silty-sandy variegated eluvium, often highly micaceous. According to correlate sediments from adjacent regions, weathering culminated in Eocene-? Lower Oligocene. Weathered surface was planated, wide and flat-bottom Vltava valley -so-called Vltavice furrow-incised the pediment during Upper Karpathian and Lower Badenian (Malkovsky 1979). Outflow was directed to southeast into the system of Alpine Molasse Basins (Kincl 1930). The furrow is structurally controled by regional NNE-SSW (Lhenice Graben), NW-SE and WNW-ESE trending fault zones. Hydrologic function and old outflow direction of the furrow were interrupted at the end of Miocene (Sarmatian) and in Pliocene when block movements reflected the Alpine Orogeny. At this time, the region was dissected by system of faults causing present step-like character of pediment (Fig. 2). Quaternary period brought regional uplift of the Sumava region with deep river back erosion and cryogenic processes (planation, pedimentation, permafrost activity).

KARST

Karst forms differ in overlying and underlying limestone horizons. Karst in overlying horizon can be characterized as contact type developed along lithological contact/transition or tectonic contact of limestones and non karst rocks. Karstified zones are up to several metres wide and first hundreds of metres long with irregular lithologically controled openings, small cavities and tubes, anastomoses and products or collapsed rock blocks. This karst type is sometimes water-bearing.

Karst in underlying horizon is represented by large free and colmated or water filled caverns discovered at the 3 rd mine level (690 m a.s.l.). Caves are less or more steeply inclined tubes with diameter of 4 to 7 m reaching level of about 712 a.s.l. (cave roof at 718 a.s.l.), i.e. the 2nd mine level. In upper part of caves, horizontal to subhoatic morphology with vadose entrenchments in horizontal segments (small vadose canyons). One cavern is partly collapsed, probably as a consequence of previous permafrost disturbation (Panos and Pucalka 1989). Water filled caverns, discovered by protective drilling, had water level at the 2nd mine level, where small springs occured.

Karstogenetic model

Karst in underlying limestone horizon was developed in phreatic conditions. Phreatic loop-bypass cavern morphology can indicate the batyphreatic environment comparable with the 2nd stage of "Four Stage" model of Ford and Ewers (1978). Aquiclude properties of graphite-bearing deposit level caused the artesian cofinement in underlying limestone with hydraulic and hydrochemical environment of the batyphreatic type and architecture. Therefore, the caveforming process should not be strictly connected with high depths under the surface. Cave formation could propagate in relatively dynamic zone of shallow phreatic conditions, as upposed by Panos and Pucalka (1989,1990). This presumption is supported by not elevated temperature of karst spring on the 3rd mine level. Acquiclude effect of graphite-bearing level explains also the general difference between karst developed in underlying and overlying limestones.

Caverns discovered at the 3rd mine level are part of large cave system originated in conditions of concentrated groundwater inflow and free outflow in karst aquifer. Concentrated groundwater flow could result from: (1) drainage function of carbonate lenses with hydraulic connection to fissure aquifers of non karst lithologies, and/or (29 lithologic and /or hydraulic connection of carbonate horizon in deep geological structure. Both possibilities make the catchment basin as well as the sufficient hydraulic head more spread and distinct. Infiltration of precipitation or surface water is supposed through the system of karst porosity (s.l.) or along fault zones.

One problematic question remained: character and place of groundwater flow followed main structural trend (from NE to SW; Fig. 1). According to geological maps and other data, limestones and a majority of other varied lithologies pinch out to SW. Then, the artesian karst aquifer drained under the pressure into: (a) fissure system in overlying strata and to the surface; (b) regional structural zones (" Graben) by fissure system and along the zone into springs in closer or broader vicinity, and (c) permeable weathered superficial zone (Fig. 2).

Based on obtained data supposed facts, we propose two stage model of the origin of the cavern system in underlying limestones. *P h r e a t i c stage* was connected with period of high precipitation and infiltration rates. Such period can be detected in Eocene-Oligocene. Karstogenesis in phreatic conditions took place during the end

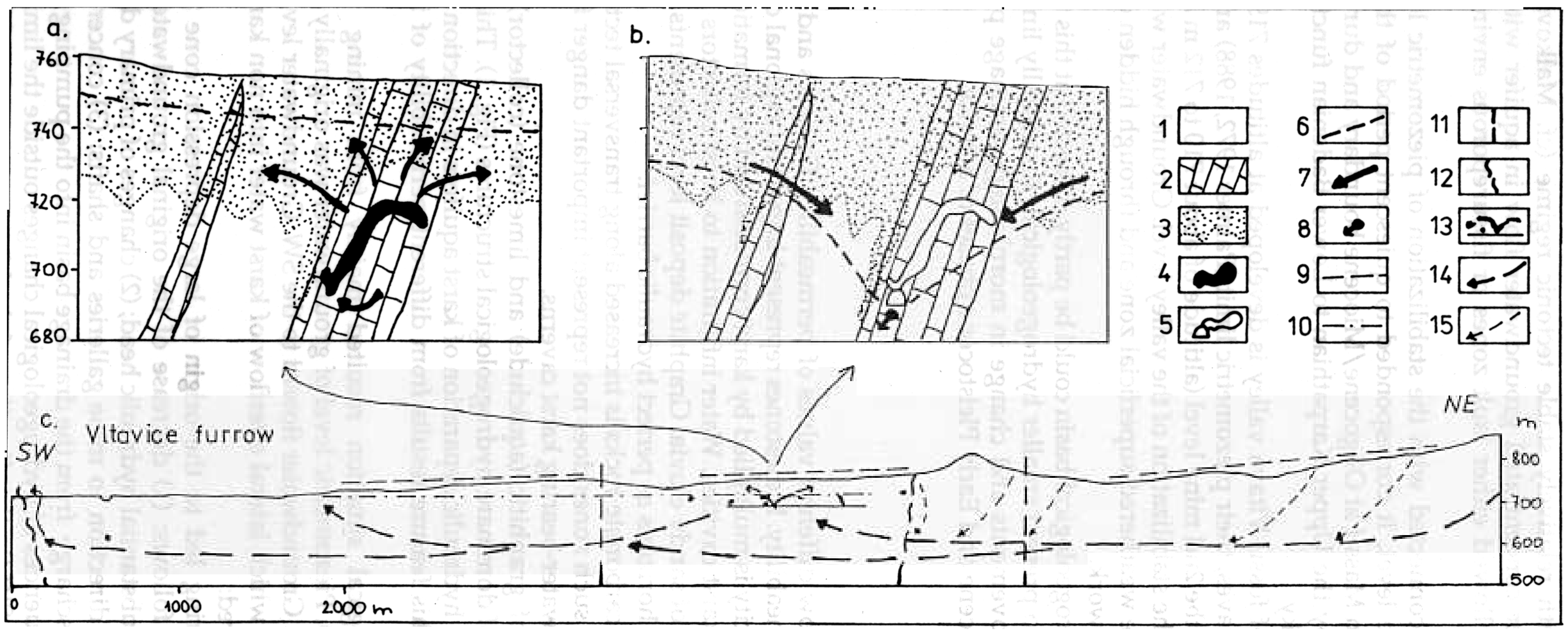

Figure 2. Schematic sections of the Blizna deposit. Section a and b highly schematized cross-sections with only roughly indicated geology (not to scale), section c is schematic geomorphological and hydrogeological section (scales are indicated) a and b: 1. non karst rocks, 2. limestones, 3. weathered zone, 4. water filled caves, 5. mine gallery and dewatered caves, 6. groundwater level, 7. groundwater flow directions, 8. karst spring; c: 9. pediment, 10. level of the bottom of the Vltavice furrow, 11. supposed lines of pediment displacement, 12. faults, 13. karst caverns with the 3rd mine level, 14. main circulation paths of groundwater during phreatic stage of cavern development, 15. inflow directions to karst aquifer.

phases of weathering with relatively stable tectonic regime (cf. Malkovsky 1979). Karstification acted under concentrated groundwater flow in aquifer with artesian confinement. Drainage followed either fault zones or fissureporous environment in overlaying formations.

V a d o s e stage is connected with the stabilization of piezometric level, most probably of regional base level. It corresponded to quiescent period of the tectonic evolution of the Bohemian Massif at Oligocene/Miocene boundary and during Lower Miocene evidenced e.g. by the Upper Karpathian to Lower Badenian function of the Vltavice furrow (Malkovsky

1979). The bottom of fossil Vltava valley is developed at altitudes 715 to 702 m a.s.l. Vadose elements in caves, their piezometric limit (Palmer 1972, 1988) and concentration of contact karst at the 2nd mine level (altitude of about 710 to 712 m a.s.l.) indicate the connection with the stabilization of the valley level. Groundwater was drained from karst aquifer into the weathered superficial zone and through hidden or covered springs into the valley network.

Originally large hydrogeological basin could be partly dissected at this time. Final dissection of the basin into present smaller hydrogeological, structurally limited units resulted from tectonic movements and change in morphology, drainage pattern etc. during Late Miocene, Pliocene and Early Pleistocene phases of activity.

HYDROGEOLOGY

Crystalline rocks show different values of permeability. Gneisses and amphibolites have low fissure permeability. Limestones represent important regional collector in which accumulation capacity is multiplied by karst corrosion and by formation of large system of water-bearing karst cavities. Water infiltration to karst collectors is enabled also by high permeability of sandy eluvia. Graphite deposit level represents aquiclude separating both limestone horizons as perfect hydraulic barrier.

Permeability of non carbonate rocks is increased along transversal tectonic lines. Accumulation capacity of such zones does not represent important danger for mining operations as is noted for water-bearing karst caverns.

The NE-SW trend of graphitic (aquiclude) and limestone (collector) horizons determines the direction of dominant hydrogeological structures (Fig. 1). This situation causes partial or complete hydraulic separation of karst aquifers in direction perpendicular to the schistosity. This feature results from different permeability of individual lithologies.

Present hydrogeological situation resulted mainly from mining influences (exploitation, dewatering). Piezometric level of groundwater was originally situated 5 to 10 m below the surface. Groundwater flowed to the SW. Groundwater level reached the weathering mantle in which lateral overflow of karst water into non karst lithologies (and vice versa) occured:

Water pumping during led to the origin of large depression cone and other characteristic features as follows: (1) decrease of the original groundwater level in about 45 m and origin of substantial hydraulic head; (2) changes of primary direction of groundwater flow in the direction to mine galleries and shafts; (3) concentration of nearly all underground discharge from the drainage basin into the pumping station on the 3rd mine level; (4) influences of hydrogeological changes outside the limits of drainage basin, namely to the SW (in the direction of the Lipno reservoir) and also to the

SE, and (5) the extent of the depression cone is not stabilized now due to continuing mining operations.

The genesis and laws of the groundwater circulation have been solved by numerous water analyses, measurements of water level and inflow. Present total inflow is 27 $l.s^{-1}$, one half coming from karst caverns. The problem of the origin of karst water from karst spring in underlying limestone horizon has been compiled by two conceptions. The first considers the inflow from large karst system inside and outside the discharge basin. The second theory suppose important inflow by water infiltration (through weathering mantle and/or fissure systems in non karst rocks) from the Lipno reservoir. Tritium and oxygen isotope analyses did not contributed to solution of the problem. Karst spring yields now excellent drink water low in all kinds of impurities (as nitrates etc.). Nevertheless, contemporaneous exploitation of graphite and utilization of drink water is ruled out by Czechoslovak hygienic standards.

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