Secció de Sòls

Delegació Territorial de Catalunya

Guia de camp

TRANSCATALÒNIA 2016
Comarca del Berguedà

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SÍNTESI DEL PROGRAMA

- Cal Rosal. Terrasses del Llobregat
- Queralt. Vistes del Baix Berguedà
- Vallcebre. Sòls al·luvials.
- Estudis hidrològics a les conques de Vallcebre. *Carles Balasch*
- Estudi de sòls en àrees de restauració de mines a cel obert. *Rosa M. Poch*
- Els sòls i les transformacions de la zona de coll de Pradell afectades per la mineria a cel obert. *Miquel Aran*
- Saldes. Sòls sobre vessants col·luvials del Pedraforca.

1 Índex

2 Introducció

2.1 Localització

El Berguedà es troba al nord de la província de Barcelona, entre les comarques del Bages, Osona, el Ripollès, la Cerdanya, l'Alt Urgell i el Ripollès. És una comarca allargada de nord a sud, des del Pirineu Oriental fins Depressió Central.

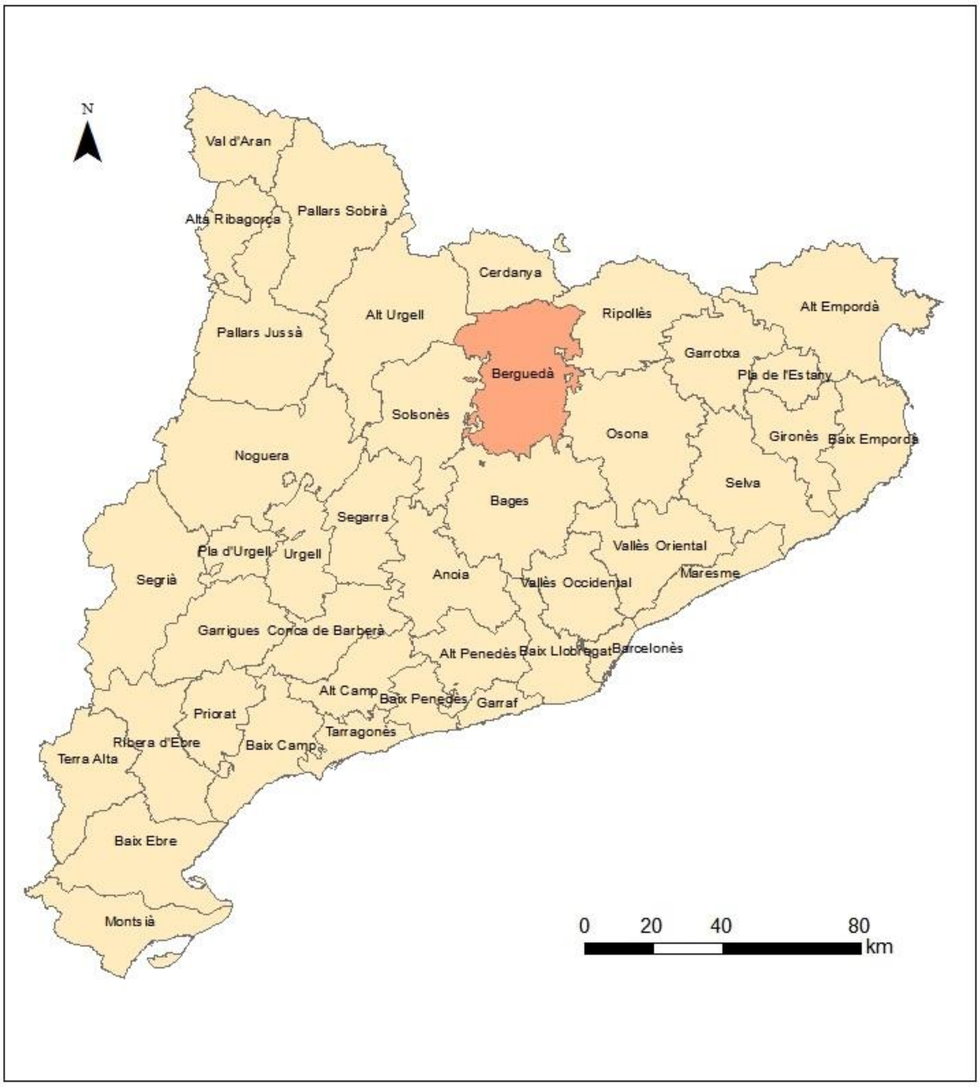


Figura 2.1.1. Situació de la comarca del Berguedà en un mapa comarcal de Catalunya.

La comarca del Berguedà està dividida en 31 municipis. La població del Berguedà l'any 2009 era de 41.000 habitants, 16.000 dels quals a Berga, la seva capital.

Figura 2.1.2. Municipis de la comarca del Berguedà

2.2 Usos del sòl

La comarca del Berguedà presenta una superfície cartografiable d'unes 118.640 ha. Segons les estadístiques oficials de distribució del territori de Catalunya, aquesta superfície presenta el següents usos:

Agrícola: 18.100 ha
Forestal: 99.000 ha
Miscel·lanis: 1.640 ha

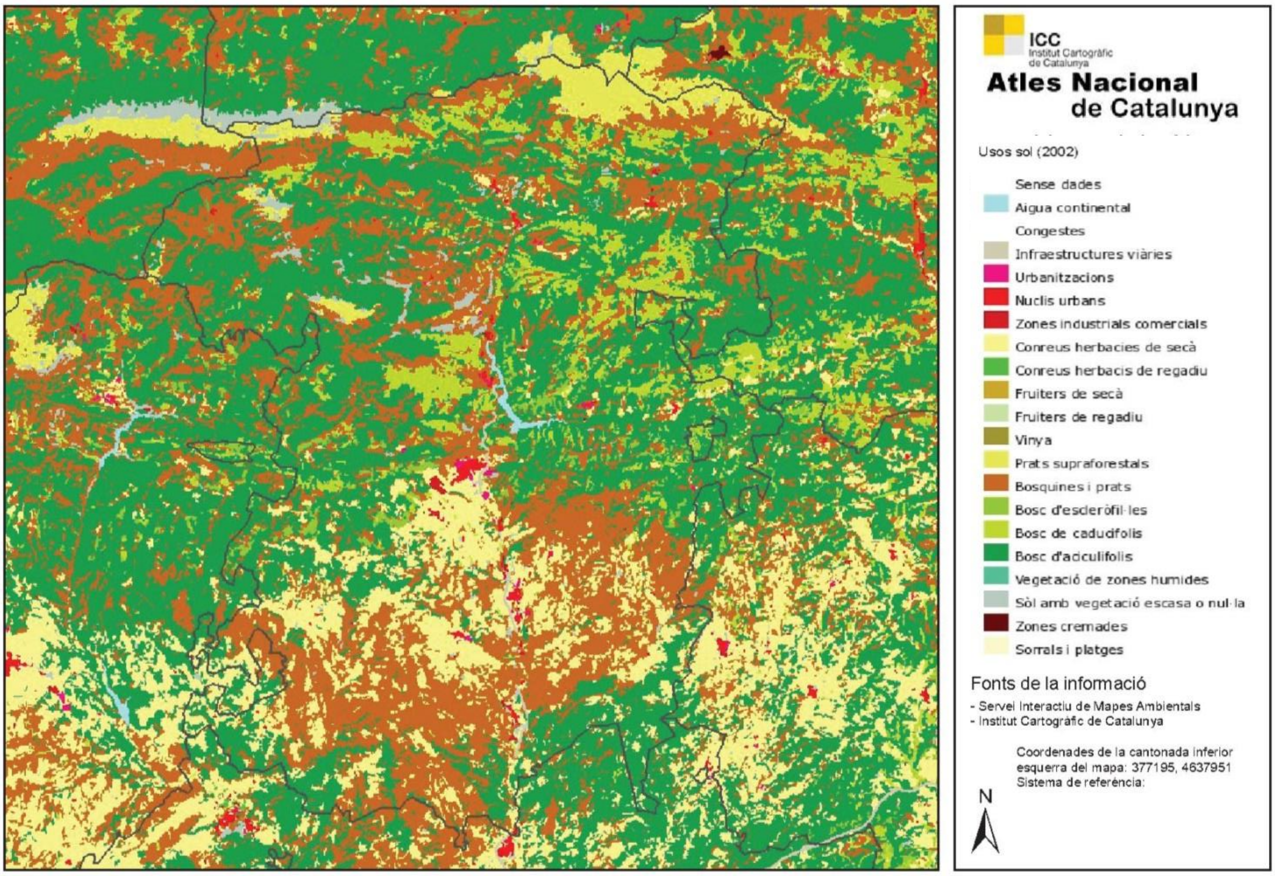


Figura 2.2. Usos del sòl. (Font: Institut Cartogràfic i Geològic de Catalunya)

La zona agrícola del Berguedà està dedicada bàsicament a la producció de cereal i farratge. A l'àrea de més al sud s'hi sembren cereals d'hivern i a la zona central, propera a Berga, s'hi cultiven més farratges i cereal d'estiu.

En l'àmbit forestal és molt variada. Al sud s'hi troben boscos de pinassa (*Pinus nigra*). A gran part del sud del Berguedà, el mapa d'usos del sòl i indica bosquines i prats. Aquesta superfícies és l'afectada pels importants incendis de l'any 1994. Cap al centre i nord del Berguedà s'hi troba pineda de pi roig (*Pinus silvestris*), amb fagedes *(Fagus* *sylvatica*) a les obagues (orientació N). En zones elevades (a partir de 1800 m) s'hi troben prats i pi negre (*Pinus Uncinata*).

2.3 Clima

El clima de la comarca del Berguedà, segons el Servei Meteorològic de Catalunya, és Mediterrani, de tipus Pirinenc i Prepirinenc a la meitat nord de la comarca i continental subhumit a la meitat sud.

Les temperatures mitjanes anuals, al Baix Berguedà es troben entre 10 i 13 ºC (Fig. 2.3.1). L'àrea muntanyosa de l'Alt Berguedà té un gradient de temperatura decreixent amb l'augment de l'altitud. A partir d'uns 1700 m la temperatura mitjana anual és d'uns 7 ºC.

En les precipitacions, hi ha un gradient de sud a nord de la comarca que van de 650 – 700 mm a l'àrea sud de la comarca fins a superar els 1000 mm als punts alts de l'Alt Berguedà. El règim de precipitacions a la comarca és ben contrastat. Mentre que al sud del Baix Berguedà els estius són secs i calorosos, a l'Alt Berguedà les precipitacions estivals sovintegen i en algunes localitzacions l'estiu és l'època de l'any més plujosa.

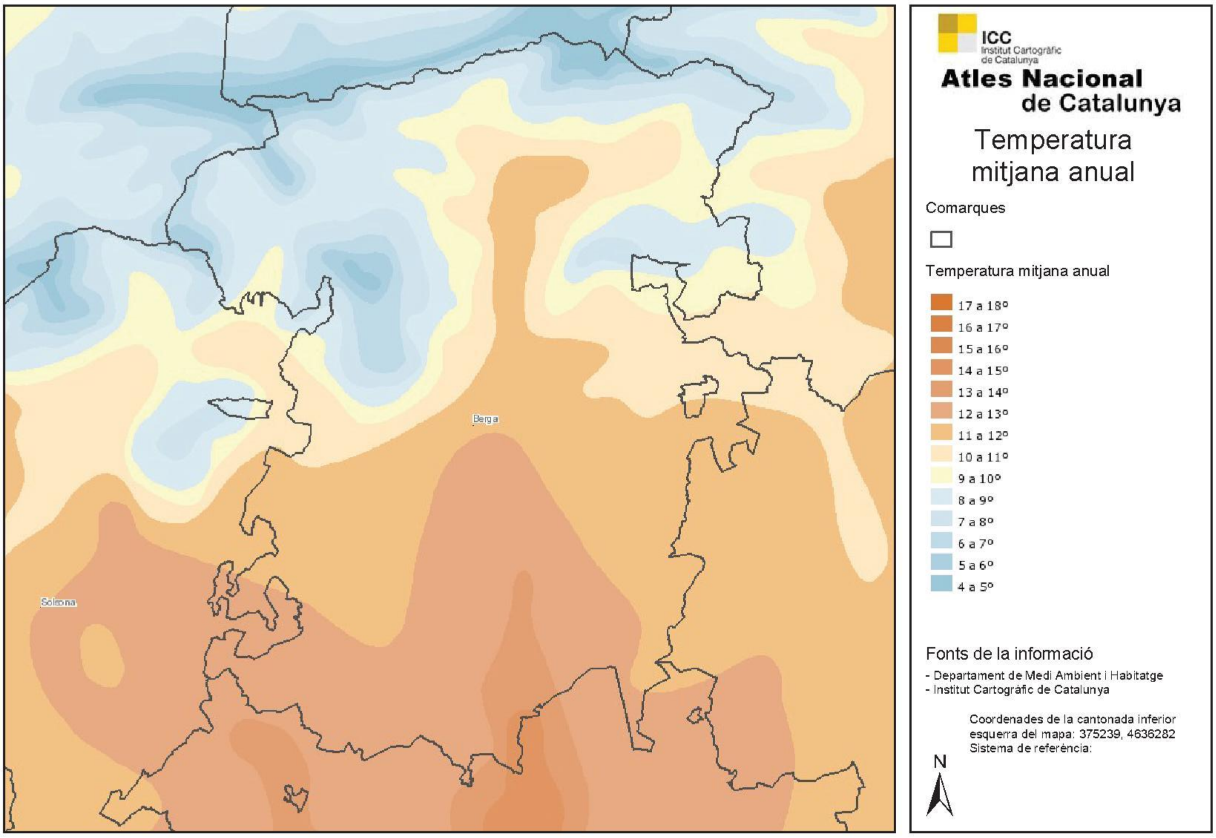


Figura 2.3.1. Temperatura mitjana anual de la comarca del Berguedà. Font. ICGC.

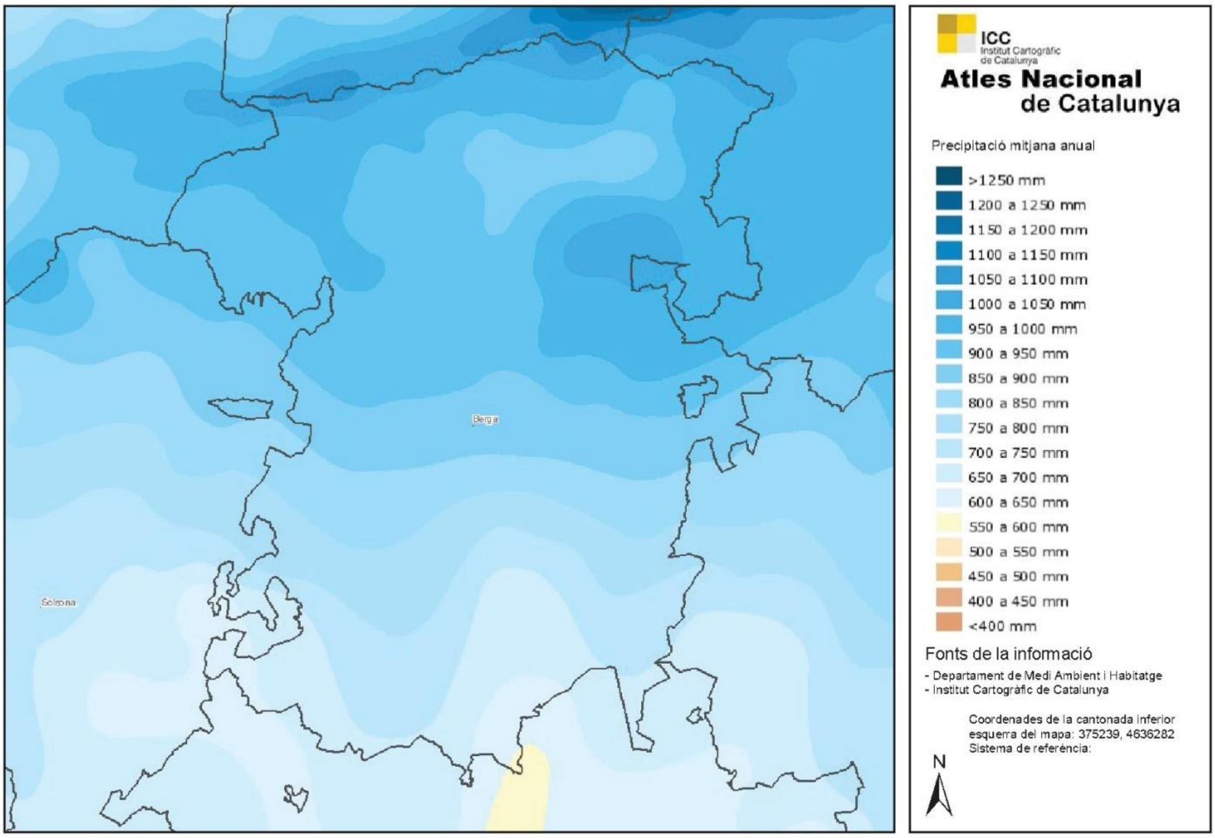


Figura 2.3.2. Pluviometria anual de la comarca del Berguedà. Font. ICGC.

Tot seguit es fa una breu caracterització mitjançant diagrames ombrotèrmics de diverses estacions meteorològiques del Servei Meteorològic de Catalunya a la comarca del Berguedà, situades a Gisclareny i la Quar.

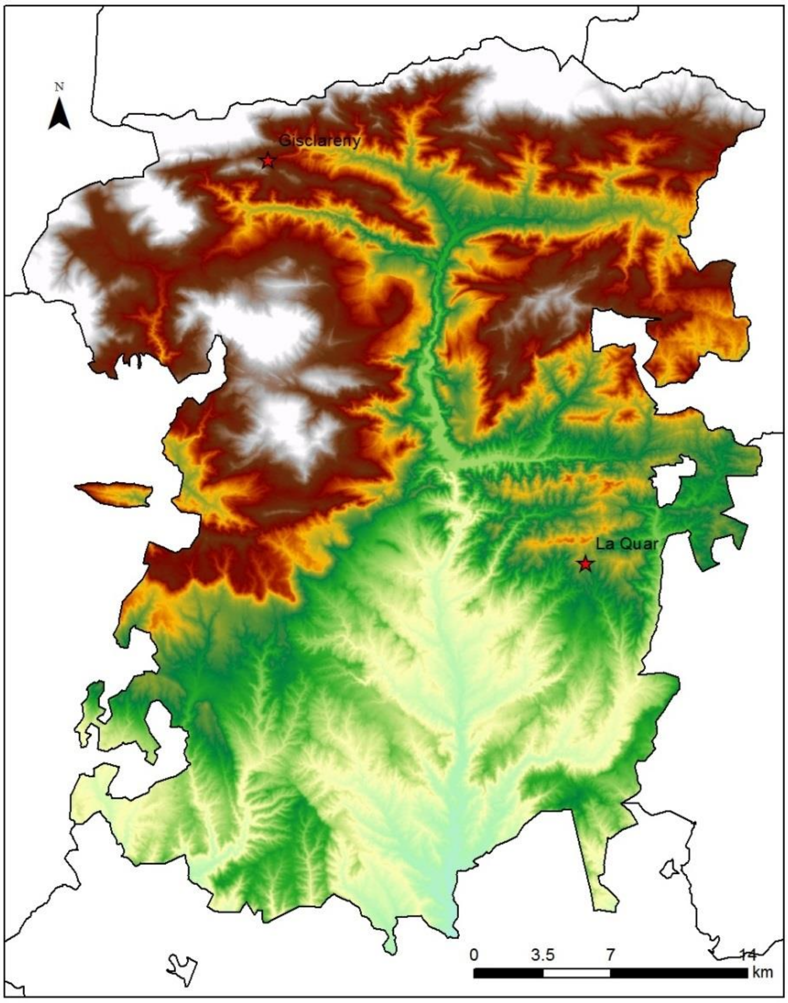
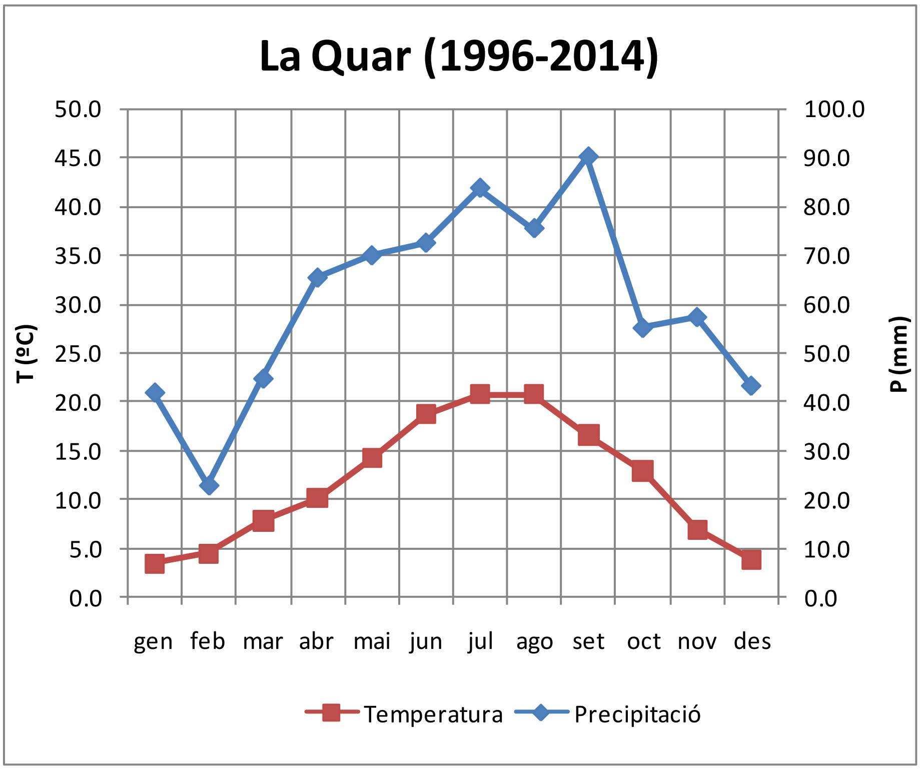


Figura 2.3.3. Situació de les estacions del SMC estudiades.

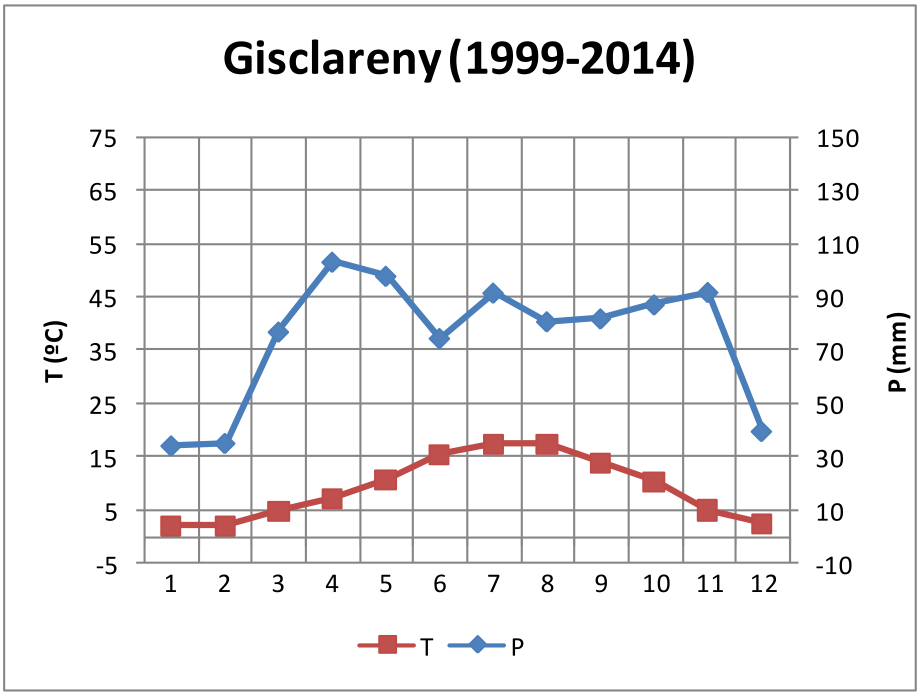


Altitud: 873 m

UTM X: 414270 m
UTM Y: 4659419 m

P mitjana anual: 721 mm

T mitjana anual: 11,6 ºC



Altitud: 1386 m

UTM X: 398005 m
UTM Y: 4680120 m

P mitjana anual: 898 mm

T mitjana anual: 9,1 ºC

2.4 Règims de temperatura i humitat del sòl

El règim de temperatura segons el sistema de classificació de Soil Taxonomy s'ha considerat Mèsic al Baix Berguedà i a les cotes baixes de l'Alt Berguedà. A partir de 1800 m a la cara sud i 1700 a la cara nord, el règim de temperatura és **cryíc**. Segons el sistema de classificació de règims de temperatura de la Soil Taxonomy (SSS, 2006), si hi ha presència d'un horitzó orgànic (O), les àrees amb règim cryíc passarien a tenir un règim de frígid.

Considerant les dades climàtiques, es poden establir diverses zones diferenciades pel què fa al règim d'humitat.

A l'àrea del sud del Baix Berguedà, en contacte amb la comarca del Bages, es considera que el règim d'humitat al sòl és **Xèric**. En canvi, el règim d'humitat a l'Alt Berguedà s'ha considerat **Údic**. Entre aquestes dues zones, hi ha tot una franja on el règim d'humitat s'ha considerat **Ústic**. El règim Ústic es defineix per ser un règim d'humitat limitat, però amb condicions favorables per al creixement de les plantes (SSS, 2006). Aquesta àrea intermitja rep precipitacions significatives a l'estiu, qüestió que la diferencia de la major part d'àrees interiors i costaneres de Catalunya, que tenen un dèficit de precipitacions evident durant els mesos estivals (règim Xèric).

A les zones altes de l'Alt Berguedà (>1800 m), amb major precipitació, el regim d'humitat es pot classificar com a **Perúdic**.

Per tal de delimitar els règims d'humitat i temperatura s'ha realitzat a partir de les unitats cartogràfiques. D'aquesta forma s'eviten duplicitats en els tipus de sòls semblants.

La xarxa de drenatge, que transcorre per diferents règims d'humitat, s'ha cartografiat com a Xèric/Ústic.

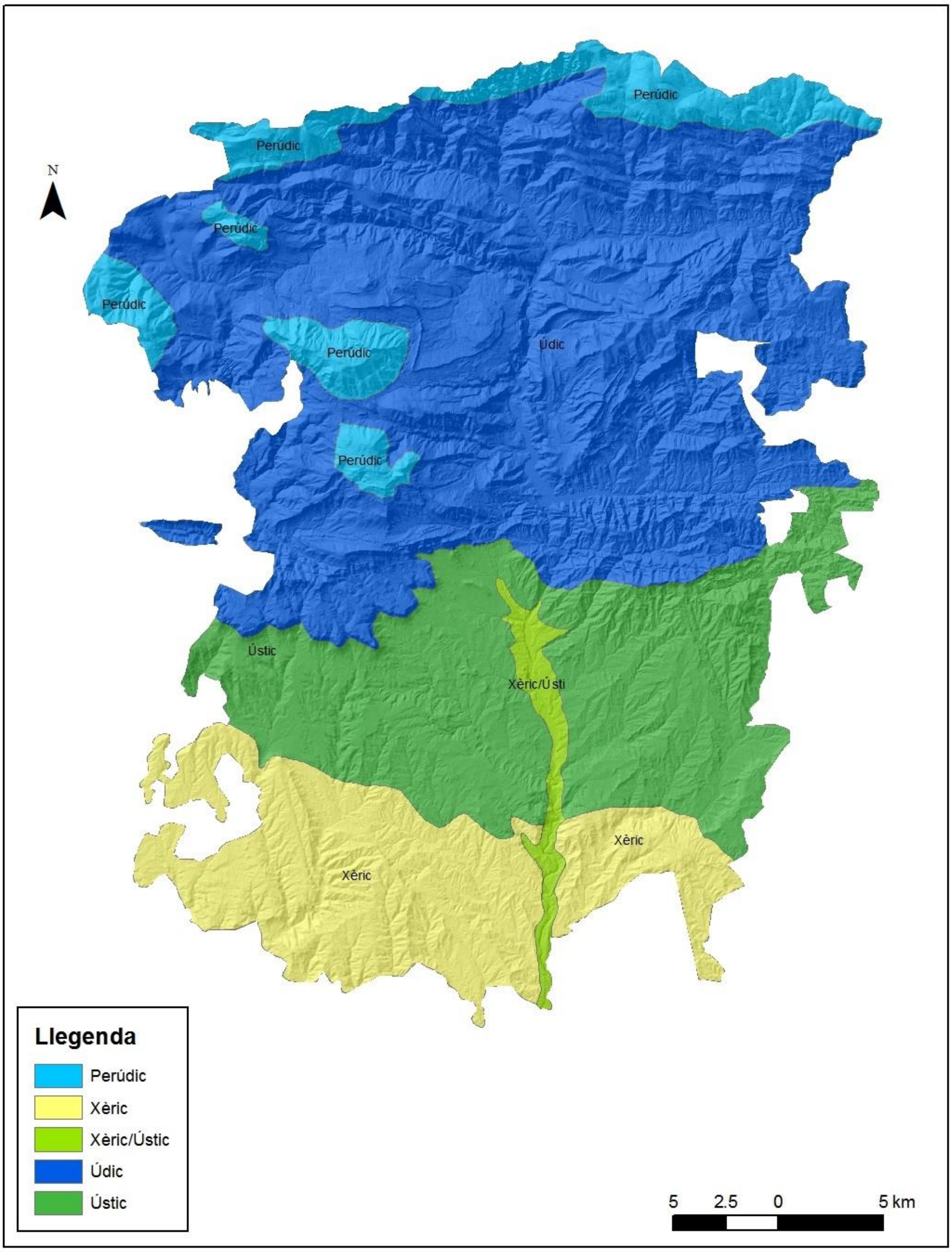


Figura 2.4.1. Règims d'humitat a la comarca del Berguedà

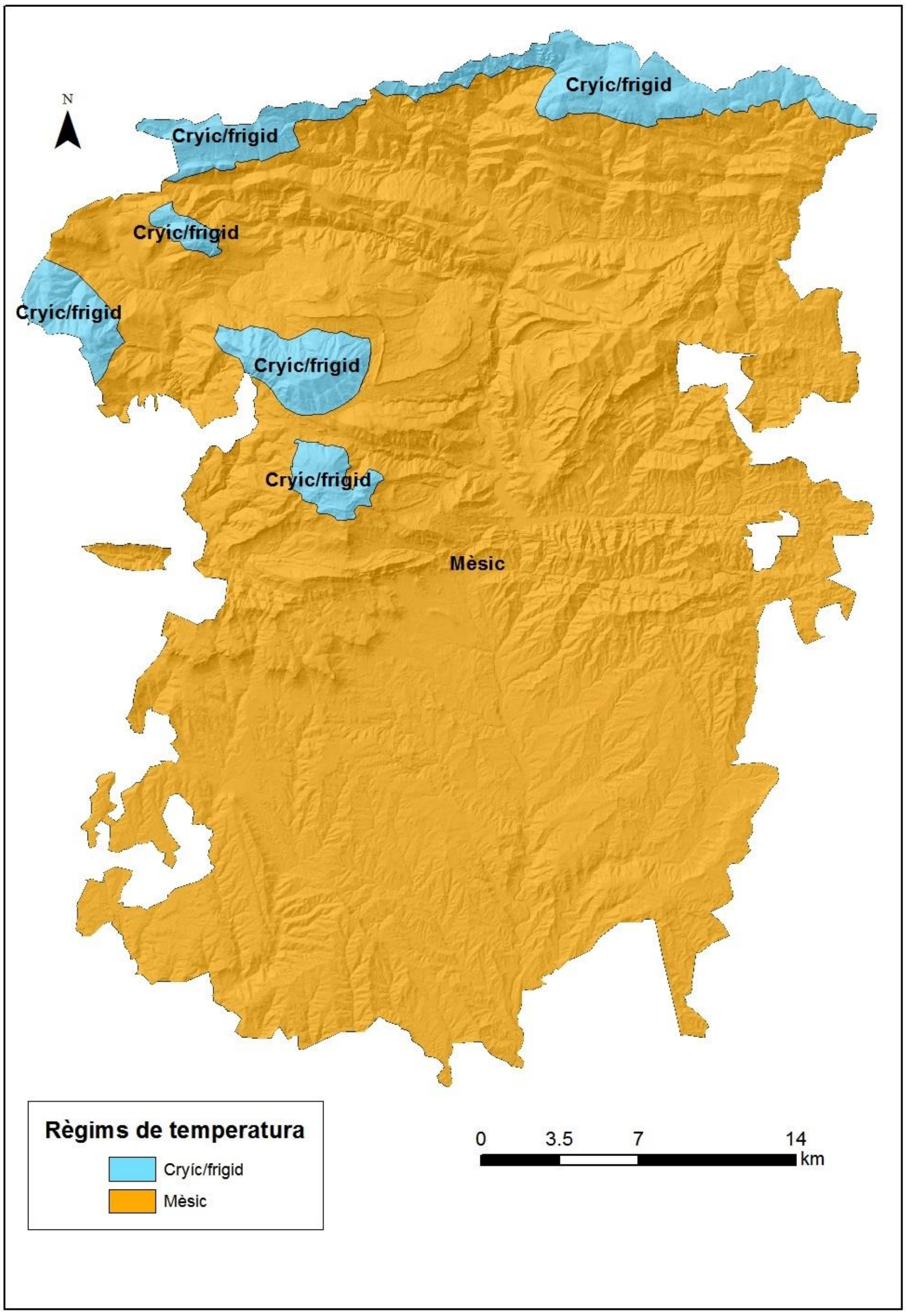


Figura 2.4.2. Règims de temperatura a la comarca del Berguedà

2.5 Geologia i litologia

L'esquema geològic del Berguedà mostra els diversos temps geològics que es troben a la zona:

- Cenozoic.
    - Quaternari: Bàsicament representats a les terrasses del riu Llobregat
    - Paleogen: Ocupa gran part del Berguedà Sud (Oligocè) i àrees importants del l'Alt Berguedà (Eocè)
- Cenozoic/mesozoic:
    - Facies Garumnià: Zones de Vallcebre, Castellar del Riu i Malanyeu.
- Mesozoic: Alt Berguedà, Àrees muntanyoses dels Rasos de Peguera, Ensija i Pedraforca.
- Paleozoic: Extrem nord de la comarca. Coll de Pal

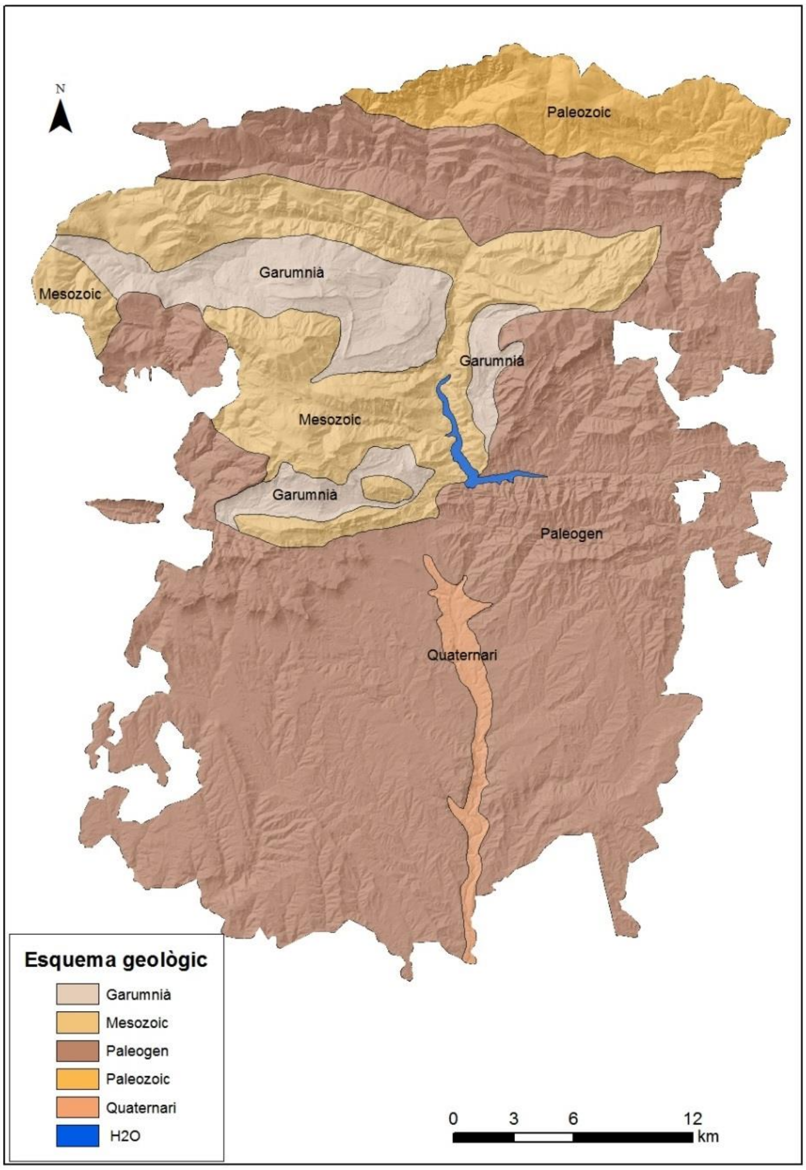


Figura 2.5.1. Esquema geològic de la comarca del Berguedà

La comarca del Berguedà morfològicament es divideix en tres grans àrees:

- Conca de l'Ebre (Baix Berguedà)
- Prepirineus
- Pirineu Oriental

La zona del Baix Berguedà està formada per materials del Paleògen (Eocè i Oligocè). Aquests estan lleugerament plegats a l'Anticlinal de Puig-Reig i la Sinclinal de Prats. Els materials que s'hi poden trobar bàsicament són estrats de lutites i gresos. Cap a la zona nord del Baix Berguedà, els gresos cada vegada són de gra més gruixut i fins i tot s'hi poden trobar estrats de conglomerat.

L'àrea Prepirinenca té una gran complexitat. Hi apareixen plegaments combinats amb mantells de corriment del Pirineu Oriental. En aquesta àrea s'hi pot trobar una gran diversitat de materials i edats. Un breu resum dels materials que s'hi poden trobar són:

- Margues grises i calcàries (Eocè) al mantell del Cadí.
- Calcàries i margues (Cretaci): Àrea que comprèn les zones del Pedraforca, Catllaràs, Ensija, Serra del Verd i Rasos de Peguera.
- Lutites i calcàries (Garumnià): Vallcebre, Castellar del Riu, Malanyeu.
- Conglomerats (Eocè-Oligocè): Catllaràs, Capolat i Llinars.

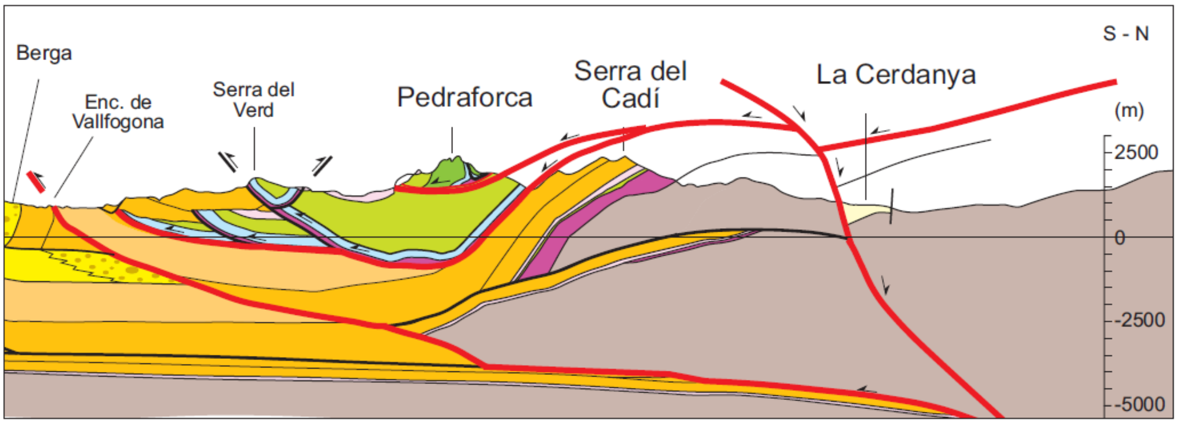


Figura 2.5.2. Tall geològic simplificat de l'Àrea Prepirinenca. (Font: Martinez, A., Tudela M. (2013))

Al Pirineu Oriental, hi afloren diversos tipus de materials Paleozoics, entre els que destaquen calcàries metamorfitzades i esquistos (no carbonatades) i en la zona de Castellar de n'Hug, gresos i lutites vulcanoclàstiques.

S’ha confeccionat un mapa de litologies adaptat a l’elaboració del mapa de sòls 1:250.000, on es poden observar els diferents materials originaris que es poden trobar a cada zona (Figura 2.5.2)

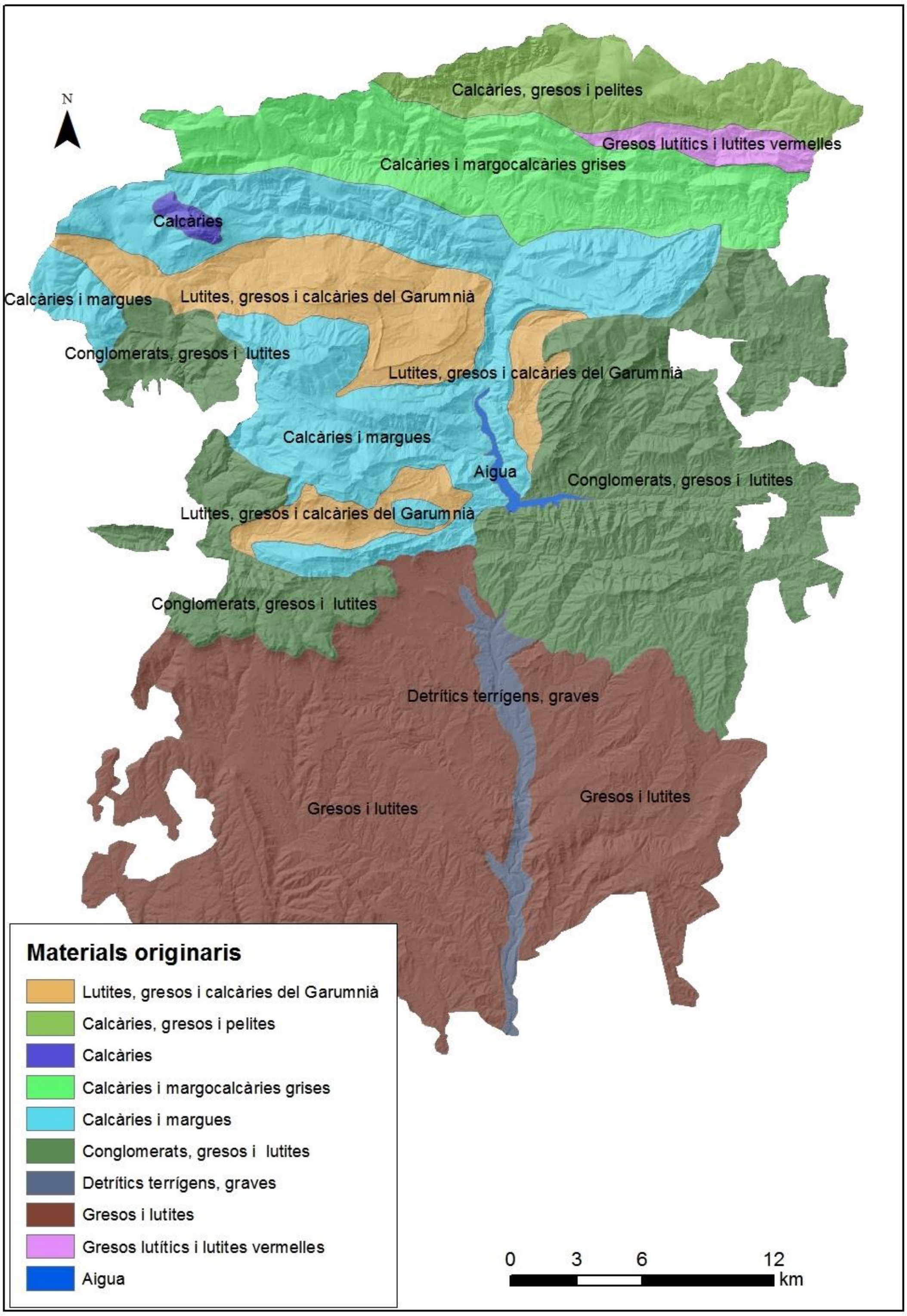


Figura 2.5.2. Mapa dels materials originaris de la comarca del Berguedà

2.6 Xarxa hidrogràfica

El drenatge del Berguedà es caracteritza per tenir una xarxa de drenatge central, que és la conca del riu Llobregat. A l'àrea occidental de la comarca hi ha zones (Montmajor, Gòsol i Llinars) que desguassen a la conca de riu Cardener.

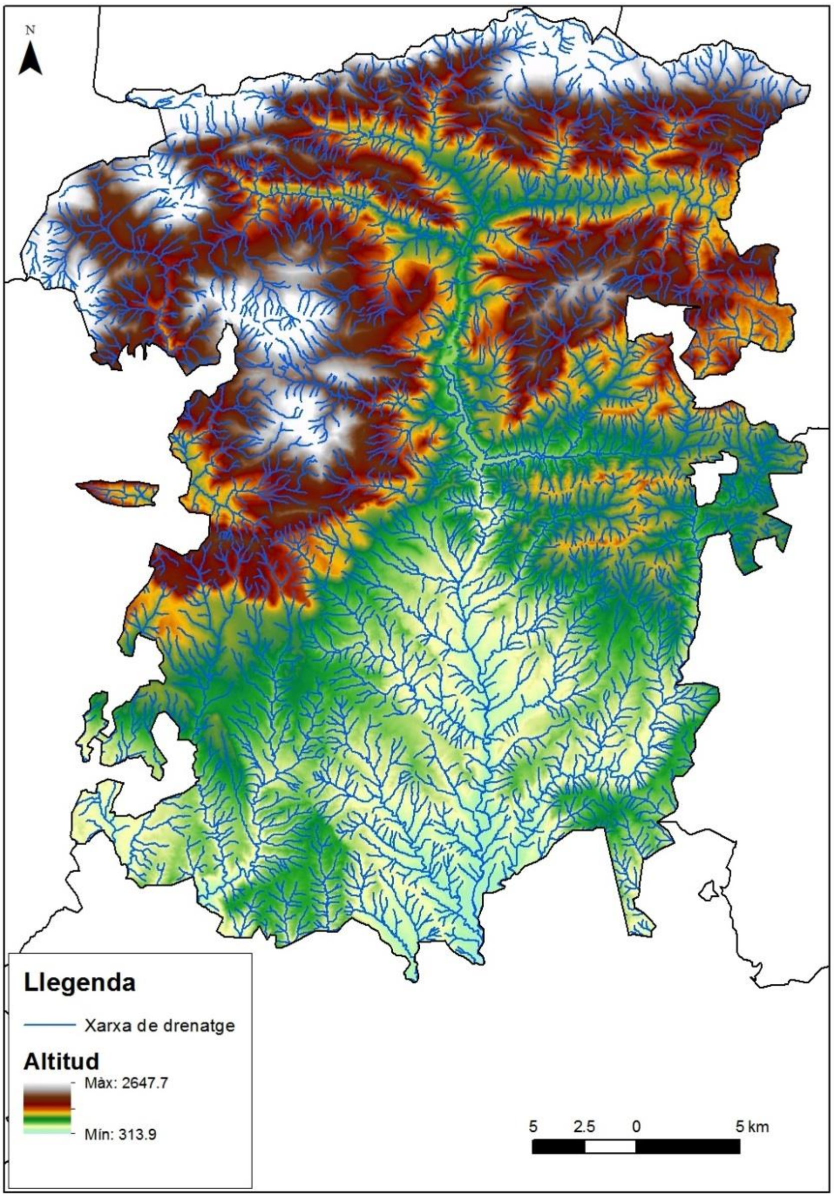


Figura 2.6. Xarxa hidrogràfica de la comarca del Berguedà

2.7 Pendents

Els pendents del Berguedà són ben diferenciats entre el Baix Berguedà i l'Alt Berguedà. El Baix Berguedà generalment té pendents baixes i moderades. És per això que és l'àrea amb més agricultura de la comarca. L'Alt Berguedà té pendents forts. A la figura 2.7 es pot observar el mapa de pendents elaborat a partir del model digital d’elevacions de 30 x 30 m.

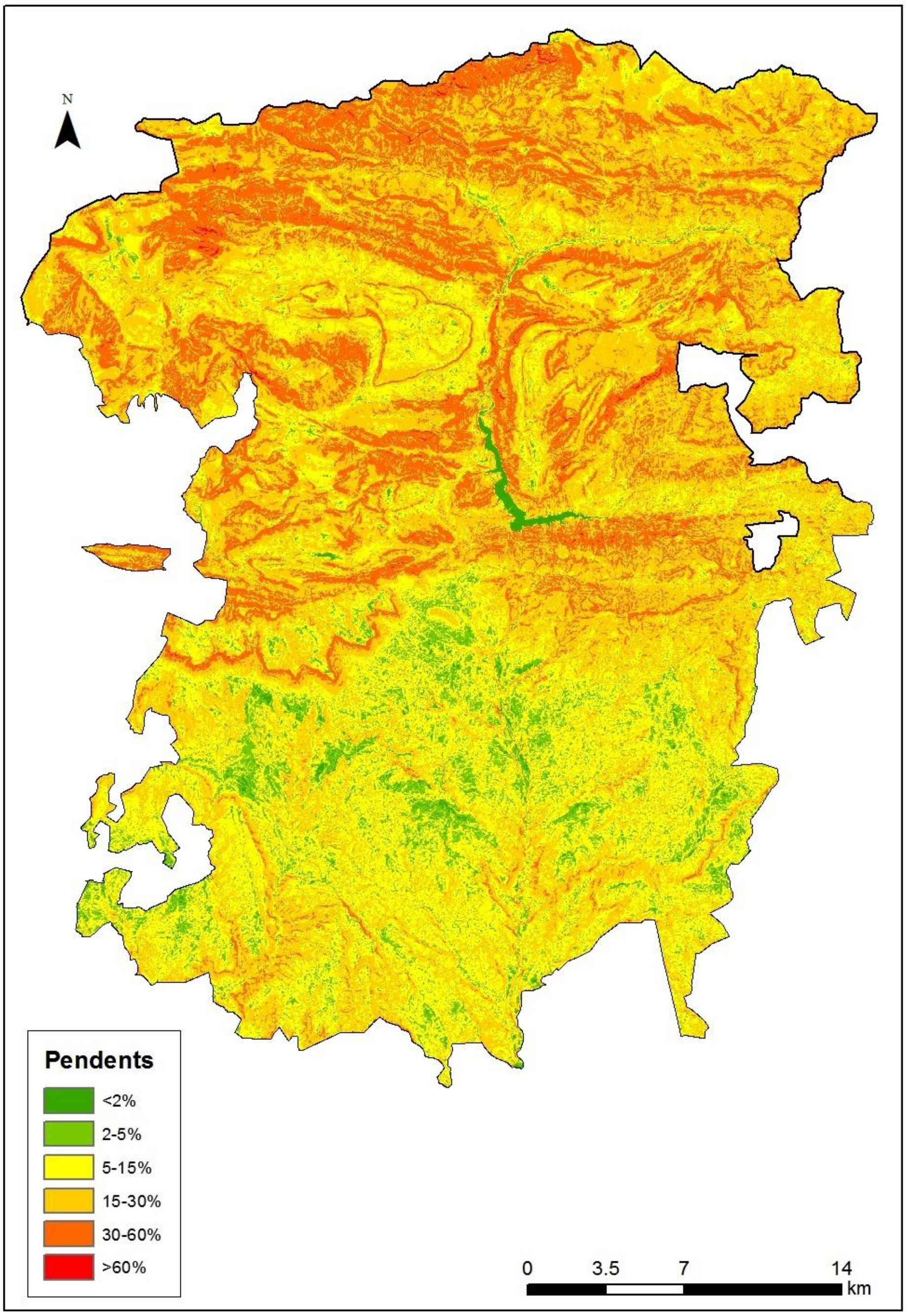


Figura 2.7. Mapa de pendents

2.8 Unitats fisiogràfiques

El mapa s'ha dividit en 4 unitats fisiogràfiques: Baix Berguedà, Conglomerats massius, Prepirineu i Pirineu Oriental, tal i com es pot veure a la figura 2.8.

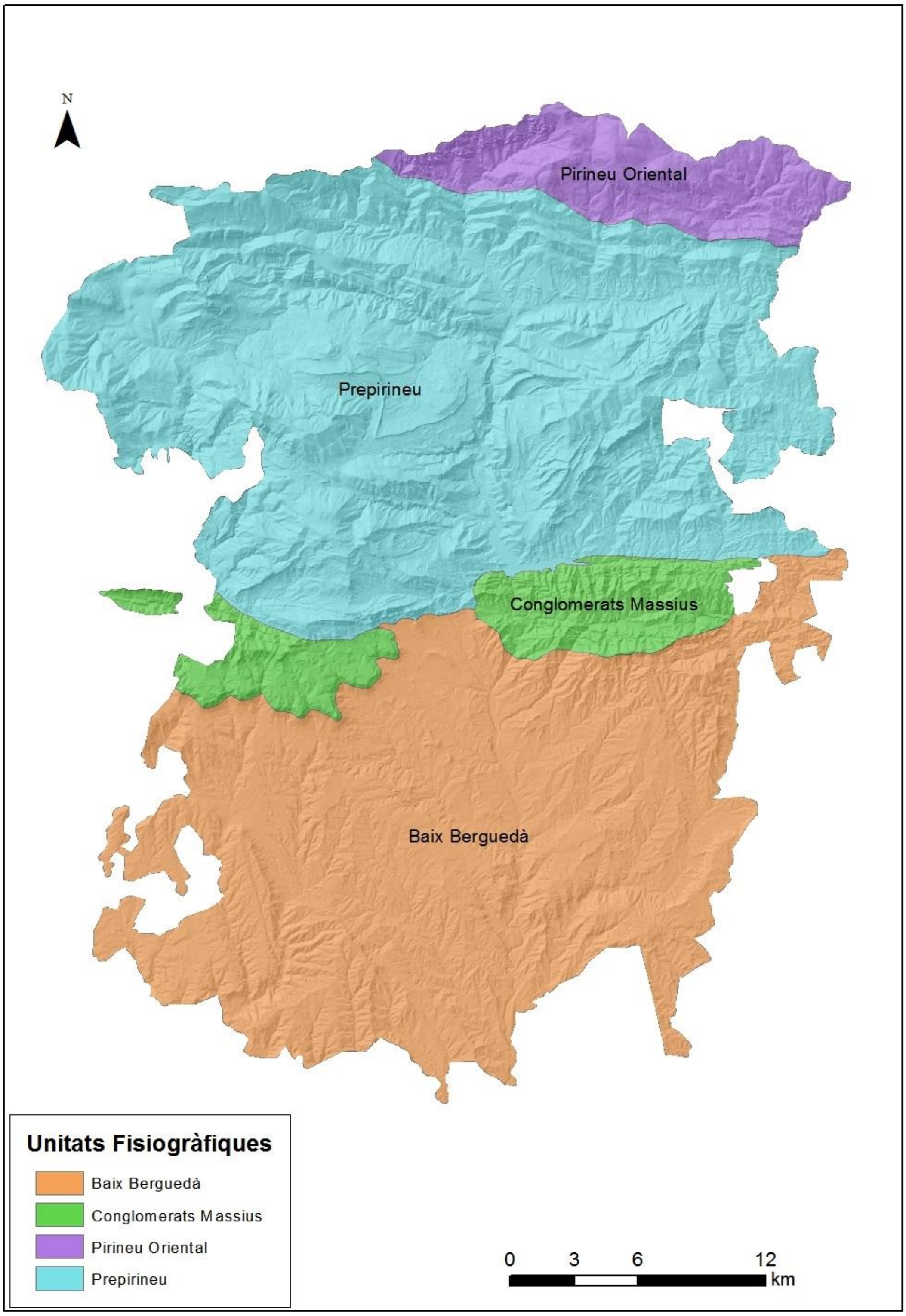


Figura 2.8. Unitats fisiogràfiques de la comarca del Berguedà

2.8.1 Baix Berguedà

El Baix Berguedà ocupa tota la part sud de la comarca fins a les àrees de conglomerats massius que la delimiten (Cingles de Capolat, Serra de les Tombes- St. Maurici de la Quar). Ocupa una superfície d'unes 47.000 ha.

Tota aquesta àrea, geològicament forma part de la Conca de l'Ebre. Està formada per materials del Paleògen (Eocè i Oligocè) lleugerament plegats a l'Anticlinal de Puig-Reig i la Sinclinal de Prats. Els materials que s'hi poden trobar bàsicament són estrats de lutites i gresos. A la zona més propera a l'àrea Prepirinenca, els gresos cada vegada són de gra més gruixut i fins i tot s'hi poden trobar estrats de conglomerat. També es pot observar que els estats de gresos són més potents i abundants en detriment dels estrats de lutites.

El paisatge del Baix Berguedà està configurat per aquesta alternança de gresos i lutites, que conforma un paisatge esglaonat format a partir de l'erosió diferencial d'aquests materials. A les àrees on els materials durs (gresos) són més potents s'hi han format plataformes extenses, amb pendents entre baixos i moderats, on s'hi ha pogut establir l'agricultura. Aquests gresos estructurals, en les zones més properes al Prepirineu, són de gra silícic amb poc ciment calcari, cosa que en facilita la meteorització. És per això que, en alguns casos (sobretot en plataformes inclinades), la xarxa de drenatge ha erosionat aquestes plataformes formant petits fons on s'hi acumulen materials detrítics. Les àrees convexes, una mica més elevades, han quedat erosionades deixant al descobert afloraments d'aquestes plataformes.

Els indrets on l'erosió de la xarxa de drenatge ha estat més efectiva i ha aconseguit tallar aquestes plataformes (amb més facilitat com més lluny de la zona Prepirinenca, on els estrats són menys potents), el paisatge que s'hi troba és molt més encaixat i amb pendents elevades.

Figura 2.8.1.1. Vista de l'àrea del Baix Berguedà des de la serra de Queralt

Figura 2.8.1.2. Plataforma de gres erosionada. Els materials detrítics terrígens s'acumulen en àrees còncaves deixant al descobert afloraments en les àrees convexes i de major pendent.

2.8.2 Conglomerats massius

L'àrea de conglomerats massius és al límit entre el Prepirineu i el Baix Berguedà. Bàsicament comprèn la Serra de Picancel (al marge esquerre del Llobregat) i Capolat (al marge dret). Ocupen una franja que continua a l'oest cap a la comarca del Solsonès, conformant la Serra de Busa, Bastets, Vilamala, etc. Ocupa una superfície d'unes 8.000 ha.

Les altituds d'aquesta unitat van des dels 650 m fins als 1500 m a la zona més elevada de Capolat.

Tot i tractar-se d'una unitat fisiogràfica clarament diferenciada per la seva posició i l'origen dels seus materials, s'hi poden trobar diferents tipus de relleus:

- Relleu montserratí, amb cingles, forts pendents i gran abundància d'afloraments (serra de Picancel i Cingles de Capolat).

- Plataforma, o relleu tabular, a l'altiplà de Capolat.

A l'altiplà de Capolat hi ha una zona agrícola i de pastures, allà on els pendents ho han permès. A les zones amb major pendent hi ha afloraments de conglomerat, i boscos de pi roig.

Figura 2.8.2.1. Serra del Picancel

Figura 2.8.2.2. Vista de la zona de pastures de Capolat, amb la Serra de Busa al fons.

Figura 3.3.2.3. Vista del pantà de la Baells i la Serra de Picancel a la seva dreta.

2.8.3 Prepirineu

L'àrea prepirinenca de la comarca del Berguedà s'estén des del nord de la ciutat de Berga fins a la serra del Cadí. És la unitat fisiogràfica de major extensió de la comarca del Berguedà, ocupa unes 55.000 ha.

Es tracta d'una zona de gran complexitat orogràfica amb molta diversitat de materials (apartat 2.5. Geologia i o litologia). És una zona muntanyosa, retallada per la part central (de nord a sud) per la xarxa de drenatge del Llobregat. Les altituds van dels 650 m al fons de les valls encaixades fins als 2.604 m del cim de Costa Cabriolera, al Cadí.

En ser una zona accidentada geogràficament, la vegetació és bàsicament forestal (exceptuant pastures altes i petites àrees agrícoles en les àrees amb menor pendent).

El Prepirineu del Berguedà té una gran diversitat i bellesa paisatgística i s'hi poden destacar:

- Àrees muntanyoses de calcàries i margues Mesozoiques: el Massís del Pedraforca, Serra d'Ensija, Cap del Verd, Queralt, Rasos de Peguera, Serra del Catllaràs.

- Serra del Cadí (Calcàries i margues eocenes)

- Zones de badlands, lutites i calcàries com la sinclinal de Vallcebre i Malanyeu

- Àrees de conglomerats (Llinars i el Catllaràs)

Figura 2.8.3.1. Vista de diverses àrees representatives del Prepirineu (Vallcebre, Ensija, Pedraforca i Serra del Cadí)

Figura 2.8.3.2. Serra del Cadí

Figura 2.8.3.3. Zona de badlands a Vallcebre

2.8.4 Pirineu Oriental

El Pirineu Oriental se situa a l'àrea nord-oriental de la comarca. En formen part les serres del Moixeró, la Tossa d'Alp i la zona de Castellar de l'Hug. Ocupa una superfície de 7.600 ha.

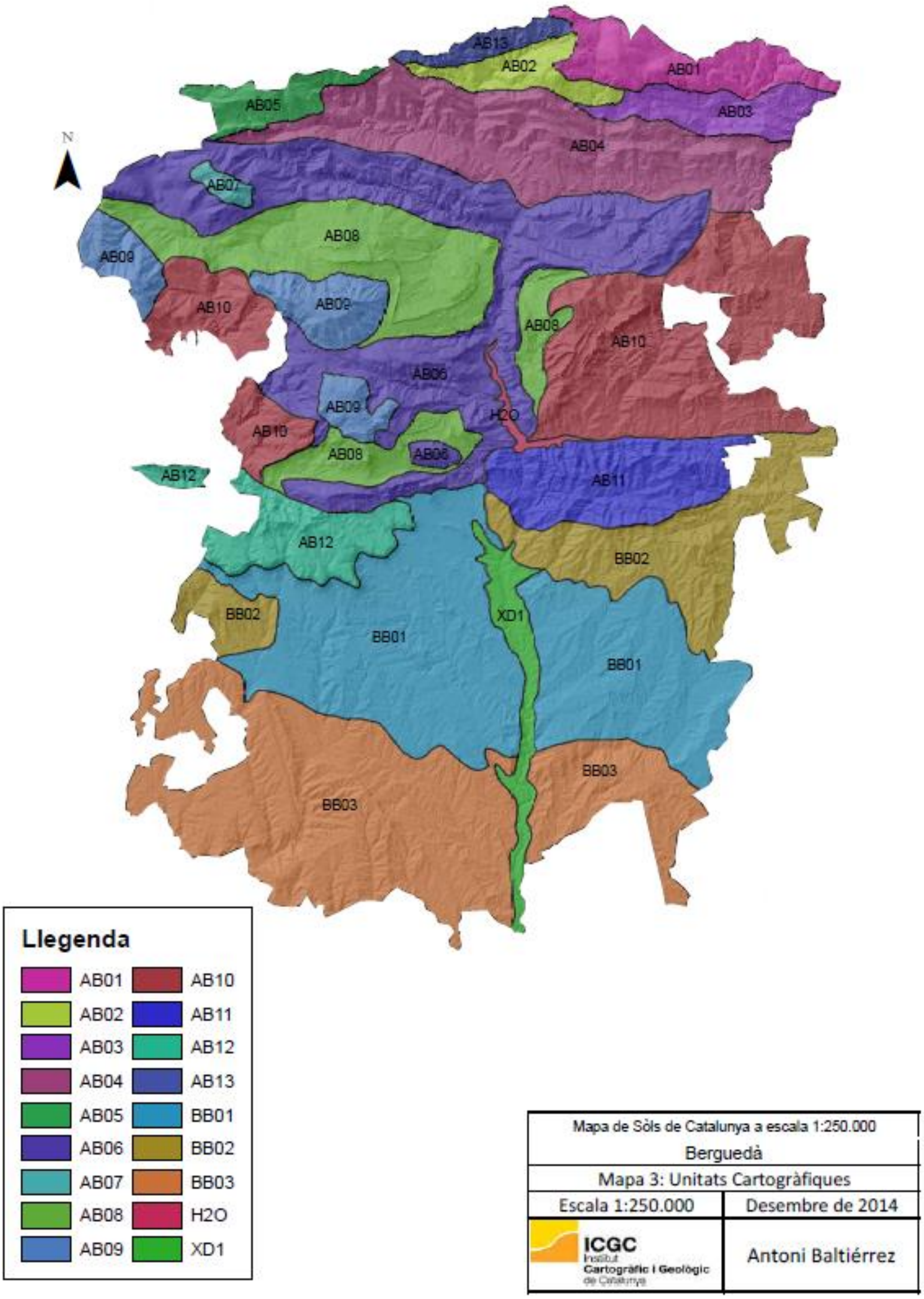
Els materials d'aquesta unitat fisiogràfica són els més antics que afloren a la comarca, del Paleozoic. Es tracta d'una unitat amb pendents abruptes als vessants i pendents més suaus a les zones altes. Als vessants hi ha vegetació forestal (pi roig i pi negre) i matollar, amb una presència important d'afloraments rocosos i tarteres. A les zones altes de la unitat hi ha prats alts. Les altituds d'aquesta unitat van des de 1000 m a 2.536 m de la Tossa d'Alp.

Figura 2.8.4. Pastures de les zones altes del Pirineu Oriental

2.9 Sòls. Mapa 1:250.000. Unitats cartogràfiques

Tot seguit, hi ha una taula-resum sobre les unitats cartogràfiques, extreta del mapa 1:250.000 del Berguedà.

U. fisio.	U. Cartogràfica	Composició	U. Taxonòmica	Classificació SSS (2006)	Classificació WRB (2006)	Profunditat	Material originari	Textura	Elements grossos	Pendent	Inclusions	Superfície (%)	Sup.(ha)	Geomorfologia	Ús del sòl
Baix Berguedà	BB01	30%	B-24	Haplustept típic	Haplic Cambisol (calcaric)	Molt profund	Gresos i lutites	Mitjana	Pocs	5-15%	Calciustept típic	19387	16%	Plataformes, fons	Cereal, farratges
		30%	B-25	Ustorthent típic	Haplic Cambisol (eutric)	Som		Mod. Fina	Pocs						
		30%	B-23	Ustorthent lític	Haplic Leptosol (eutric)	Som		Mod. Grossa	Pocs						
		10%	B-26	Haplustept fluvèntic	Fluventic Cambisol (calcaric)	Molt profund		Mod. Grossa	Pocs						
	BB02	35%	B-23	Ustorthent lític	Haplic Leptosol (eutric)	Som	Gresos i lutites	Mod. Grossa	Pocs	15-30%	Haplustalf lític	7524	6%	Vessants	Forestal
		35%	B-25	Ustorthent típic	Haplic Regosol (Calcaric)	Som		Mod. Fina	Pocs						
		10%	B-24	Haplustept típic	Haplic Cambisol (eutric)	Molt profund		Mitjana	Pocs						
	BB03	20%	B-27	Haploxerept típic	Haplic Cambisol (calcaric)	Molt profund	Gresos i lutites	Mod. Grossa	Freqüents	15-30 %	Calcixerept típic	18586	16%	Vessants, plataformes	Forestal, cereal
		40%	B-28	Xerorthent típic	Haplic Regosol (Calcaric)	Som		Mod. Fina	Freqüents						
		30%	B-29	Xerorthent lític	Leptic Regosol (Calcàric)	Som		Mitjana	Freqüents						
	XD1	40%	B-31	Haploxerept càlcic	Haplic Cambisol (calcaric, eutric,	Profund	Graves i detrítics terrígens	Mod. Grossa	Abundants	2-5%	Calcixerept típic	2017	2%	Terrasses	Cereal, urbà
		40%	B-26	Haplustept fluvèntic	Fluventic Cambisol (calcaric)	Molt profund		Mod. Grossa	Pocs						
		10%	B-30	Paleustalf pertocalcic	Petric Luvic Calcisol	Mod. Profund		Mod. Fina	Freqüents						
Pirineu oriental	AB01	35%	B-17	Haplocryept lític	Leptic Cambisol	Mod. Profund	Calcàries i esquistos	Mitjana	Freqüents	15-30 %	Cryrendoll lític	3100	3%	Cims	Prats
		15%	B-18	Haplocryoll lític	Leptic Phaeozem	Som		Mitjana	Molt freqüents						
		40%		Afloraments											
	AB13	50%	B-17	Haplocryept lític	Leptic Cambisol	Mod. Profund	Calcàries i esquistos	Mitjana	Freqüents	>60%	Haplocryoll lític	850	1%	Vessants	Matollar
		40%													
	AB02	30%	B-19	Udorthent típic	Haplic Cambisol (dystric)	Profund	Calcàries i esquistos	Mod. Grossa	Abundants	30-60%	Udorthent típic (BER-106)	1570	1%	Vessants	Pi roig
		30%	B-20	Udorthent lític	Haplic Leptosol	Som		Mod. Grossa	Abundants						
		30%		Afloraments		Som		Mitjana	Freqüents						
	AB03	50%	B-21	Eutrudept lític	Leptic Cambisol	Som	Lutites i gresos vermells	Mitjana	Freqüents	15-30%		2071	2%	vessants	Pastura, pi roig
		20%	B-22	Eutrudept típic	Hapic Cambisol (Eutric)	Mod. Profund		Mitjana	Freqüents						
		20%		Afloraments											
Prepirineu	AB04	30%	B-6	Udorthent típic	Haplic Regosol (Calcaric)	Profund	Margues grises i margocalcàries	Mod. Grossa	Freqüents	15-30 %	Hapludoll típic	9582	8%	Vessants	Pastures
		30%	B-7	Udorthent típic (col·luvial)	Haplic regosol (calcaric)	Molt profund		Mod. Fina	Freqüents						
		20%	RIP-T15	Udorthent lític	Leptic Regosol (eutric)	Som		Mitjana	Pocs						
		10%		Afloraments de margocalcàries											
	AB05	40%	B-8	Haplocryept lític	Cambic Leptosol (eutric)	Som	Margues grises i margocalcàries	Mod. Fina	Freqüents	30-60%	Cryrendoll lític	1479	1%	Vessants	Pastures
		50%		Afloraments i tarteres											
	AB06	50%	B-1	Udorthent lític	Haplic Leptosol (eutric)	Som	Margues i calcàries mesozoiques	Mod. Fina	Freqüents	30-60%		15937	13%	Vessants	Pi roig, fageda
		30%	B-2	Eutrudept típic	Haplic cambisol (eutric)	Profund		Mod. Fina	Molt freqüents						
		10%		Afloraments											
	AB07	90%		Afloraments i tarteres			Margues i calcàries mesozoiques			>60%	Cryrendoll lític	372	0%	Cingles	
	AB08	40%	B-10	Udorthent típic	Haplic Regosol (eutric)	Som	Lutites del Garumnià i calcàries	Mod. Fina	Pocs	15-30%	Udorthent típic (antròpic)	9810	8%	Vessants	Matollar, pastures
		30%	B-9	Eutrudept típic	Haplic Cambisol (Calcàric)	Molt profund		Mod. Fina	Molt freqüents						
		10%	B-1	Udorthent lític	Haplic Leptosol (eutric)	Som		Mod. Fina	Freqüents						
		10%		Afloraments de calcàries i lutites (badlands)											
	AB09	30%	B-5	Haplocryept lític	Leptic Cambisol (Eutric)	Som	Margues i calcàries mesozoiques	Mod. Fina	Molt freqüents	15-30 %		3895	3%	Cims	Pastures
		20%	B-4	Cryrendoll lític	Rendzic Leptic Phaeozem	Som		Mod. Fina	Freqüents						
		5%	B-3	Haplocryoll típic	Haplic Phaeozem	Mod. Profund		Mod. Fina	Pocs						
		25%		Afloraments de calcàries											
	AB010	40%	B-12	Udorthent típic	Hapic cambisol (calcaric)	Molt profund	Conglomerats, gresos i lutites	Mod. Grossa	Molt freqüents	30-60%	Eutrudept lític	14039	12%	Vessants	Pi roig, fageda
		30%	B-13	Udorthent lític	Epileptic Regosol (eutric)	Som		Mod. Grossa	Molt freqüents						
		20%	B-14	Haprendoll lític	Rendzic Mollic Leptosol (eutric)	Som		Mod. Fina	Molt freqüents						
		15%	B-15	Eutrudept típic	Haplic Cambisol	Profund		Mod. Grossa	Molt freqüents						
		5%		Afloraments de conglomerats											
Conglomerats massius	AB012	30%	B-16	Eutrudept típic	Haplic Cambisol (Calcaric)	Profund	Conglomerats, gresos i lutites	Mitjana	Pocs	15-30%		3383	3%	Vessants	Pi roig
		20%	B-12	Udorthent típic	Epileptic Regosol (eutric)	Som		Mod. Grossa	Molt freqüents						
		20%	B-14	Haprendoll lític	Rendzic Mollic Leptosol (eutric)	Som		Mod. Fina	Molt freqüents						
		15%	B-13	Udorthent lític	Hapic cambisol (calcaric)	Molt profund		Mod. Grossa	Molt freqüents						
		5%		Afloraments de conglomerats											
	AB011	25%	B-13	Udorthent lític	Hapic cambisol (calcaric)	Molt profund	Conglomerats, gresos i lutites	Mod. Grossa	Molt freqüents	>60%		4609	4%	Vessants	Pastura, pi roig
		25%	B-14	Haprendoll lític	Rendzic Mollic Leptosol (eutric)	Som		Mod. Fina	Molt freqüents						
		20%	B-12	Udorthent típic	Epileptic Regosol (eutric)	Som		Mod. Grossa	Molt freqüents						
		20%		Afloraments de conglomerats											



N
AB13
AB02
AB01
AB05
AB03
AB04
AB07
AB08
AB09
AB10
AB09
AB08
AB10
AB06
AB09
H2O
AB10
AB08
AB06
AB12
AB11
AB12
BB02
BB02
XD1
BB01
BB01
BB03
BB03
Llegenda
AB01
AB02
AB03
AB04
AB05
AB06
AB07
AB08
AB09
AB10
AB11
AB12
AB13
BB01
BB02
BB03
H2O
XD1
Mapa de Sòls de Catalunya a escala 1:250.000
Berguedà
Mapa 3: Unitats Cartogràfiques
Escala 1:250.000
Desembre de 2014
ICGC
Institut Cartogràfic i Geològic de Catalunya
Antoni Baltiérrez

3 Itinerari


P7: Saldes. Vessants col·luvials del Pedraforca
P3: Vallcebre. Sòls al·luvials
P4: Vallcebre. Monitorització d'una conca.
P5: Pradell. Restauració de mines a cel obert.
P6: Pradell. L'abans i el després de la mineria.
P2: Queralt. Vistes al Baix Berguedà
P1: Cal Rosal. Terrassa del Llobregat
Saldes
Vallcebre
Cap de la Gallina Pelada
Gisclareny
Bagà
Guardiola de Berguedà
Sant Julià de Cerdanyola
Fígols
RASOS DE PEGUERA
Cercs
Panta de la Baells
la Nou de Berguedà
Vilada
BERGA
Avià
Cal Rosal
Olvan
l'Espunyola
Gironella
0
2
4
8
km

P1 - Terrassa del Llobregat

Sòls moderadament profunds, ben drenats i textura moderadament fina amb elements grossos freqüents. El material originari d'aquests són graves i sediments detrítics terrígens.

La seqüència típica d'horitzons és A-Bt-Btk-Btkm

Aquest sòls es troben a les terrasses mitges i elevades del Llobregat a la zona propera a Berga. Són sòls situats en àrees estables que han sofert un procés de rentat de carbonats dels horitzons superiors cap als inferiors, on aquests s'hi han acumulat. Aquests sòls solen tenir un horitzó A/Ap descarbonatats, un horitzó Bt, també descarbonatat (on s'hi poden observar cutans argil·losos). Per sota, normalment coincidint amb una capa de graves, s'hi troba un horitzó petrocàlcic.

Perfil BER-002

Data descripció: 28/08/2014
Descrit per: A. Baltiérrez

Localització
Terme municipal: Olvan
Paratge: Cal Rosal
Coordenades: X- 406887 **Y-** 4657747
Altitud: 520 m

Temperatura i aigua en el sòl
Règim d'humitat: Ústic
Règim de temperatura: Mèsic
Classe de drenatge: Ben drenat
Nivell freàtic: Inaccessible

Geomorfologia
Escala d'observació: Decamètrica
Forma del relleu: Terrassa
Tipus de vessant: Simple
Modificació de la forma:
Trets erosius:
Morfologia local: Perfil situat en una àrea rectilínia
Situació del perfil: A la meitat de la forma
Pendent general: 2-5%
Pendent local: 2-5%
Orientació: SW

Vegetació i ús actual del territori
Tipus de vegetació: Bosc escleròtic
Ús: Forestal

Tecnologia: Secà sense drenatges

Material originari
Detritics terrígens

Material subjacent
graves

Pedregositat superficial
2-10% poligènics

Graverositat superficial
Sense

Afloraments rocosos
Sense

Classificació
SSS(2006): Petrocalcic Paleoustalf
WRB(2006): Petric Luvic Calcisol

Descripció

0-8 cm A
EST. HUMITAT: Lleugerament humit. COLOR DE LA MATRIU: 10YR3/4 (humit). TAQUES: Sense. EST. OXIDOREDUCCIÓ: Oxidació. TEXTURA: Arenosa. ELEMENTS GROSSOS: 1 - 5% (0,6-2,0 cm), arrodonit-esferoidal, poligènic. ESTRUCTURA: Moderada, granular composta, mitjana. CONSISTÈNCIA: Poc compacte. Friable. ACUMULACIONS: -. CIMENTACIONS: -. SISTEMA RADICULAR: Normal. ACTIVITAT BIOLÒGICA: -. ACTIVITAT HUMANA: -. ASSAIG DE CAMP: A la matriu, l'HCl (11%): Baixa. ESTUDI DE SUPERFÍCIES: -. AMPLITUD DEL LÍMIT: Net. FORMA DEL LÍMIT: pla.
HORITZÓ DIAGNÒSTIC: Òcric

8-37 cm Bt
EST. HUMITAT: Lleugerament humit. COLOR DE LA MATRIU: 2.5YR3/6 (humit). TAQUES: Sense. EST. OXIDOREDUCCIÓ: Oxidació. TEXTURA: Franco-argil·loarenosa. ELEMENTS GROSSOS: 1 - 5% (0,6-2,0 cm), arrodonit-esferoidal, poligènic. ESTRUCTURA: Moderada, en blocs angulars, fina. CONSISTÈNCIA: Poc compacte. Friable. ACUMULACIONS: -. CIMENTACIONS: -. SISTEMA RADICULAR: Normal. ACTIVITAT BIOLÒGICA: -. ACTIVITAT HUMANA: -. ASSAIG DE CAMP: A la matriu, l'HCl (11%): Nul·la. ESTUDI DE SUPERFÍCIES: <10 % cutans argilosos cares d'estructura. AMPLITUD DEL LÍMIT:. Net. FORMA DEL LÍMIT: pla.
HORITZÓ DIAGNÒSTIC: Argílic

37-55 cm Btk
EST. HUMITAT: Lleugerament humit. COLOR DE LA MATRIU: 2.5YR4/6 (humit). TAQUES: Sense. EST. OXIDOREDUCCIÓ: Oxidació. TEXTURA: Franco-argil·loarenosa. ELEMENTS GROSSOS: 5 - 15% (0,6-2,0 cm), arrodonit-esferoidal, poligènic. ESTRUCTURA: Sense estructura. CONSISTÈNCIA: Compacte. Friable. ACUMULACIONS: 20-40%.revestiment d'elements grossos, de carbonats CIMENTACIONS: -. SISTEMA RADICULAR: Normal. ACTIVITAT BIOLÒGICA: -. ACTIVITAT HUMANA: -. ASSAIG DE CAMP: A la matriu, l'HCl (11%): Molt alta. ESTUDI DE SUPERFÍCIES: -. AMPLITUD DEL LÍMIT: Net. FORMA DEL LÍMIT: pla.
HORITZÓ DIAGNÒSTIC: Càlcic

55-120/999 cm Bkm
EST. HUMITAT: Lleugerament humit. COLOR DE LA MATRIU: (humit). TAQUES: Sense. EST. OXIDOREDUCCIÓ: Oxidació. TEXTURA: -. ELEMENTS GROSSOS: >70% (6-25 cm), arrodonit-esferoidal, poligènic. ESTRUCTURA: -. CONSISTÈNCIA: -. ACUMULACIONS: 20-40%.generalitzades de carbonats CIMENTACIONS: Moderadament cimentat carbonats contínues. SISTEMA RADICULAR: Limitat per un horitzó cimentat. ACTIVITAT BIOLÒGICA: -. ACTIVITAT HUMANA: -. ASSAIG DE CAMP: A la matriu, l'HCl (11%): Molt alta. ESTUDI DE SUPERFÍCIES: -.
HORITZÓ DIAGNÒSTIC: Petrocàlcic

Resultats analítics:

Referència	Horitzó	HUMITAT 105 ºC %	pH (ext. 1:2.5 H2O)	COND.ELEC. 25ºC (ext. 1:5 H2O) dS/m	CARBONAT CÀLCIC EQUIV % s.m.s.	MAT.ORGANICA (W&B) % s.m.s.	CAP.INTERC.CAT. meq/100g s.m.s.
BER-002/1	A	1.38	8.11	0.15	0.00	4.24	14.60
BER-002/2	Bt	1.21	7.86	0.16	0.00	1.21	13.10
BER-002/3	Btk	1.19	8.41	0.14	34.00	1.31	11.40

ARENA GROSSA (0.2 < D < 2 mm) %	ARENA FINA (0.05 < D < 0.2 mm) %	LLIM GROS (0.02 < D < 0.05 mm) %	LLIM FI (0.002 < D < 0.02 mm) %	ARGILA (D < 0.002 mm) %	CLASSE TEXTURAL USDA
15.20	34.80	12.10	13.30	24.60	Franco-argil.loarenosa
25.70	24.90	10.20	12.80	26.40	Franco-argil.loarenosa
39.80	16.30	5.30	14.40	24.20	Franco-argil.loarenosa

P3 - Sòls col·luvials – al·luvials de Vallcebre

Les zones de l'Alt Berguedà amb substrat format per materials del Garumnià (lutites majoritàriament) es caracteritzen per tenir un elevat pendent i ser fàcilment erosionables. Els sòls en aquest tipus de vessants, fortament condicionats per aquests dos factors, solen ser poc profunds i amb unes clares limitacions per a l'agricultura. Per contra, els vessants al·luvials i col·luvials amb molts elements grossos, tenen una major estabilitat i han permès la formació de sòls profunds, normalment amb elevats continguts de matèria orgànica que han permès l'establiment de conreus i pastures. Habitualment els pobles de la zona es troben en àrees amb ventalls al·luvials o cons de dejecció on s'han format aquest tipus de sòls.

TRANS-16-1

Data descripció: 27/7/2016
Descrit per: A. Baltiérrez

Localització
Terme municipal: Vallcebre
Paratge: Vallcebre
Coordenades: X- 402472 **Y-** 4672893
Altitud: 1.172 m

Temperatura i aigua en el sòl
Règim d'humitat: Údic
Règim de temperatura: Mèsic
Classe de drenatge: Ben drenat
Nivell freàtic: Inaccessible

Geomorfologia
Escala d'observació: Decamètrica
Forma del relleu: Vessant
Tipus de vessant: Simple
Modificació de la forma:
Trets erosius:
Morfologia local: Perfil situat en una àrea convexa
Situació del perfil: Al terç superior de la forma
Pendent general: 10-20%
Pendent local: 5-10%
Orientació: SE

Vegetació i ús actual del territori
Tipus de vegetació: Bosc caducifoli

Ús: Forestal

Material originari
Detritics terrígens

Material subjacent
Detritics terrígens

Pedregositat superficial
3-15%, calcària

Graverositat superficial
3-15%, calcària

Afloraments rocosos
Sense

Classificació
SSS(2006): Haploudoll fluvèntic

Descripció

0-25 cm A
EST. HUMITAT: Lleugerament humit. COLOR DE LA MATRIU: 7,5YR3/3 (humit). TAQUES: Sense. EST. OXIDOREDUCCIÓ: Oxidació. TEXTURA: Franco-argil·losa. ELEMENTS GROSSOS: 1 - 5% (0,2-0,6 cm), subangular tabular, calcària. ESTRUCTURA: Forta, granular composta, fina. CONSISTÈNCIA: Poc compacte. Friable. ACUMULACIONS: -. CIMENTACIONS: -. SISTEMA RADICULAR: Normal. ACTIVITAT BIOLÒGICA: Formiguers. ACTIVITAT HUMANA: -. ASSAIG DE CAMP: A la matriu, l'HCl (11%): Alta. AMPLITUD DEL LÍMIT: Gradual. FORMA DEL LÍMIT: pla.
HORITZÓ DIAGNÒSTIC: Mòllic

25-60 cm Bw1
EST. HUMITAT: Lleugerament humit. COLOR DE LA MATRIU: 7,5YR3/4 (humit). TAQUES: Sense. EST. OXIDOREDUCCIÓ: Oxidació. TEXTURA: Franco-argil·losa. ELEMENTS GROSSOS: 5 – 15 % (6 -15 cm), subangular tabular, calcària. ESTRUCTURA: Forta, granular composta, mitjana. CONSISTÈNCIA: Poc compacte. Ferm. ACUMULACIONS: -. CIMENTACIONS: -. SISTEMA RADICULAR: Normal. ACTIVITAT BIOLÒGICA: -. ACTIVITAT HUMANA: -. ASSAIG DE CAMP: A la matriu, l'HCl (11%): Alta. AMPLITUD DEL LÍMIT: Difús. FORMA DEL LÍMIT: pla.
HORITZÓ DIAGNÒSTIC: -.

60-90/999 cm Bw2
EST. HUMITAT: Lleugerament humit. COLOR DE LA MATRIU: 7,5YR3/4 (humit). TAQUES: Sense. EST. OXIDOREDUCCIÓ: Oxidació. TEXTURA: Franco-argil·losa. ELEMENTS GROSSOS: 15 - 30% (6- 15 cm), subarrodonit tabular, calcària. ESTRUCTURA: Forta, en blocs subangulars, fina. CONSISTÈNCIA: Poc compacte. Molt ferm. ACUMULACIONS: -. CIMENTACIONS: -. SISTEMA RADICULAR: Normal. ACTIVITAT BIOLÒGICA: -. ACTIVITAT HUMANA: -. ASSAIG DE CAMP: A la matriu, l'HCl (11%): Alta. AMPLITUD DEL LÍMIT: Net. FORMA DEL LÍMIT: pla.
HORITZÓ DIAGNÒSTIC: -.

Resultats analítics:

Referència	Horitzó	HUMITAT 105 ºC %	pH (ext. 1:2.5 H2O)	COND.ELEC. 25ºC (ext. 1:5 H2O) dS/m	CARBONAT CÀLCIC EQUIV % s.m.s.	MAT.ORGANICA (W&B) % s.m.s.	CAP.INTERC.CAT. meq/100g s.m.s.
TRANS-16-1/1	A	2.94	8.2	0.189	9	6.08	39.6
TRANS-16-1/2	Bw1	2.73	8.36	0.134	12	1.74	
TRANS-16-1/3	Bw2	2.43	8.39	0.225	13	1.84	

Referència	Nitogen (Kjeldahl) %	Fòsfor (Olsen) mg/kg	Potassi (ext. ac. amònic) mg/kg	Calci (ext. ac. amònic) mg/kg	Magnesi (ext. ac. amònic) mg/kg	Sodi (ext. ac. amònic) mg/kg
TRANS-16-1/1	0.298	6.2	666	8735	198	18
TRANS-16-1/2						
TRANS-16-1/3						

Referència	ARENA GROSSA (0.2 < D < 2 mm) %	ARENA FINA (0.05 < D < 0.2 mm) %	LLIM GROS (0.02 < D < 0.05 mm) %	LLIM FI (0.002 < D < 0.02 mm) %	ARGILA (D < 0.002 mm) %	CLASSE TEXTURAL USDA
TRANS-16-1/1	16.9	8.8	10	21.5	42.8	Argilosa
TRANS-16-1/2	18.2	8.5	10.4	22.5	40.4	Argilosa
TRANS-16-1/3	23.3	8.8	8.5	19.3	40.1	Argilosa

P4 - Estudis hidrològics a les conques de Vallcebre. Carles Balasch

Hidrología de un ambiente Mediterráneo de montaña. Las cuencas de Vallcebre (Pirineo Oriental) I. 20 años de investigaciones hidrológicas

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ABSTRACT

Investigations started 20 years ago in the Vallcebre research basins with the objective of better understanding the hydrological functioning of Mediterranean mountains basins. The Vallcebre basins (0.15-4.17 km^2) are located in a Mediterranean mountain area of the Pyrenean ranges (1300 m a.s.l., North Eastern Spain), Average annual precipitation is 862 ± 206 mm and potential evapotranspiration is 823 ± 26 mm. Climate is highly seasonal leading to periods with water deficit in summer, and eventually in winter. Hydrological investigations in the basins are related to rainfall interception, evapotranspiration, soil moisture spatio-temporal dynamics, runoff response and runoff processes, suspended sediment dynamics and model application both at the plot and basin scales. Findings obtained during the last two decades have shown that due to their intermediate position between drier and wetter climatic areas, Mediterranean mountain areas present a particular hydrological dynamics.

Keywords: Mediterranean mountain; hydrological dynamics; research basins; Vallcebre.

INTRODUCCIÓN

Las investigaciones en las cuencas de Vallcebre se iniciaron hace 20 años con el objetivo de mejorar la comprensión del funcionamiento hidrológico de las áreas de montaña Mediterránea. Los resultados obtenidos durante las últimas dos décadas muestran que, debido a su situación intermedia entre ambientes secos y húmedos, las montañas Mediterráneas presentan una dinámica hidrológica particular. Además, al compartir alternativamente procesos hidrológicos característicos de condiciones húmedas y secas, las áreas de montaña Mediterránea pueden considerarse como ambientes interesantes para evaluar las consecuencias hidrológicas del cambio global.

LA CUENCAS DE VALLCEBRE

Las cuencas de Vallcebre (0.15-4.17 km^2, Figura 1), están situadas en un área de montaña Mediterránea del Pirineo (1300 m snm) con substrato sedimentario y suelos limo-arcillosos. La cubierta vegetal está formada por pastos y bosques de Pinus sylvestris de reforestación espontánea sobre antiguas terrazas de cultivo. Las cuencas presentan también pequeñas extensiones de cárcavas. La precipitación media anual es de 862 ± 206 mm y la evaporación de referencia de 823 ± 26 mm. Se observa una marcada estacionalidad que conlleva periodos con déficit hídrico en verano y eventualmente en invierno. El otoño es la estación más lluviosa, con eventos de precipitación de mayor magnitud. En las cuencas, además de la monitorización de las variables meteorológicas, la precipitación y los caudales, diversas variables de estado (humedad del suelo, tensiometría y niveles piezométricos) y procesos (interceptación de la lluvia y transpiración) son medidos en continuo o en periodos intermitentes.

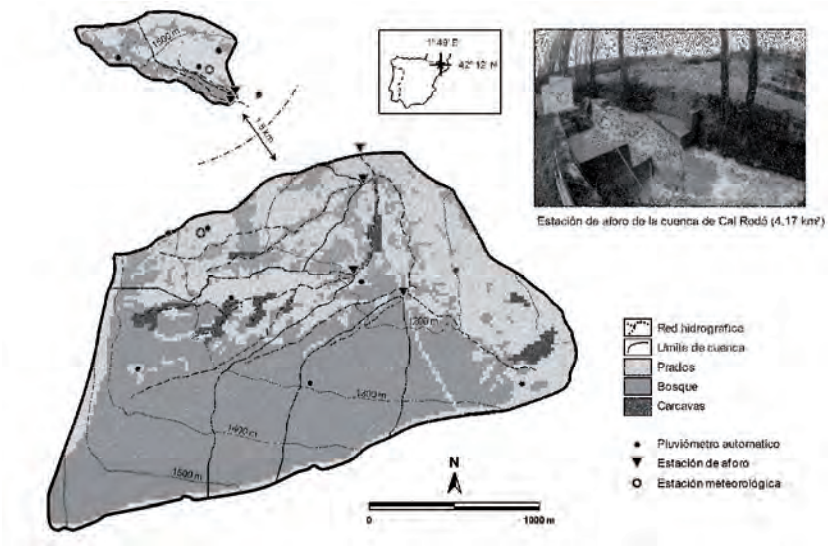

Figura 1. Mapa general de las cuencas de investigación de Vallcebre mostrando la localización de los principales instrumentos.

RESULTADOS DE LAS INVESTIGACIONES HIDROLÓGICAS

Las investigaciones en las cuencas se centran en la interceptación de la lluvia, la transpiración, la dinámica espacio temporal de la humedad del suelo, la respuesta hidrológica y el estudio de los procesos de escorrentía, la dinámica de sedimentos y la aplicación de modelos a escala de parcela y a escala de cuenca (Llorens & Gallart, 1992; Gallart *et al.* 1997, 2002, 2005a, 2005b). Los principales resultados muestran que:

- La interceptación forestal representa entre 15 y 24% de la precipitación anual dependiendo del tipo de bosque y es especialmente eficiente tanto durante largos periodos lluviosos en condiciones atmosféricas húmedas como en eventos cortos de moderada intensidad en condiciones atmosféricas secas (Llorens *et al.* 2007, 2009).

- La humedad del suelo muestra una importante variabilidad espacio-temporal con cambios frecuentes y significativos, y por la ocurrencia de un periodo de marcado déficit hídrico en verano y eventualmente en invierno (Figura. 2).

- La respuesta al déficit hídrico de los pinares y los robledales fue similar, pero los pinares fueron más sensibles a la sequía, reduciendo marcadamente su transpiración durante los períodos estivales (Llorens *et al.* 2009).

-.Las relaciones precipitación-escorrentía a escala de cuenca mostraron una fuerte variabilidad a lo largo del año. Por encima de un determinado umbral, la posición del nivel piezométrico influenció la respuesta hidrológica de las cuencas. Finalmente, se pudo evidenciar tres tipos de funcionamiento hidrológico característicos (Latron *et al.* 2008, 2009).

- Las concentraciones de sedimentos fueron bajas en la escorrentía originada en áreas con vegetación pero elevadas en las cuencas con cárcavas (Gallart *et al.* 1998; Soler *et al.* 2008). El patrón estacional de los procesos erosivos en las cárcavas se caracterizó por meteorización física durante el invierno, destrucción del regolito durante la primavera, erosión intensa en verano y transporte eficiente en otoño (Regüés & Gallart, 2004).

- Los ensayos realizados con diferentes modelos hidrológicos mostraron su capacidad de simular adecuadamente la respuesta de las cuencas durante condiciones húmedas, pero también evidenciaron la necesidad de incrementar la complejidad de los modelos para poder simular eventos de verano y de transición, y para mejorar el balance de agua de las cuencas (Gallart *et al.* 2009).

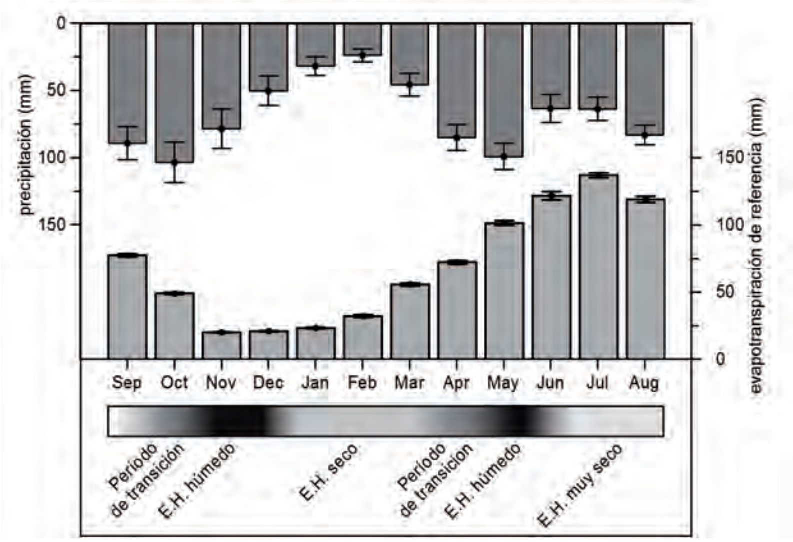

Figura 2. Valores medios mensuales de la precipitación y de la evapotranspiración de referencia en las cuencas de Vallcebre. El carácter estacional del clima mediterráneo favorece una sucesión característica de estados hidrológicos (E.H.) secos y húmedos a lo largo del año, separados por períodos breves de transición, durante los cuales la cuenca se recarga.

CONCLUSIONES

En las cuencas de Vallcebre, los procesos hidrológicos presentan una elevada variabilidad espacio-temporal, debido a la fuerte variabilidad de los regímenes de lluvia y de demanda evaporativa. La elevada estacionalidad climática se combina con una elevada heterogeneidad espacial de la topografía, los usos y tipos de suelo que aumenta la no-linealidad del funcionamiento hidrológico de las cuencas. Esta no-linealidad espacio-temporal dificulta la modelización de estas cuencas debido a la gran diversidad de procesos hidrológicos. La aplicación de modelos hidrológicos a estas cuencas han mostrado resultados satisfactorios (Anderton *et al*. 2002), aunque indican la necesidad de reducir la incertidumbre asociada a los parámetros (Gallart *et al*. 2007).

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REFERENCIAS

- Anderton, S. P., Latron, J., White, S. M., Llorens, P., Gallart, F., Salvany, C. & O'Connell, P. E. 2002. Internal evaluation of a physically-based distributed model using data from a Mediterranean mountain catchment. *Hydrology and Earth System Sciences* 6, 67-83.
- Gallart, F., Balasch, J.C., Regüés, D., Soler, M. & Castelltort, X. 2005a. Catchment dynamics in a Mediterranean mountain environment The Vallcebre research basins (southeastern Pyrenees) II: temporal and spatial dynamics of erosion and stream sediment transport. In C., Garcia & R.J., Batalla (Eds): *Catchment Dynamics and River Processes: Mediterranean and Other Climate Regions*. Elsevier, 17-29.
- Gallart, F., Latron, J. & Llorens, P. 2005b. Catchment dynamics in a Mediterranean mountain environment The Vallcebre research basins (southeastern Pyrenees) I: hydrology. In C., Garcia & R.J., Batalla (Eds): *Catchment Dynamics and River Processes: Mediterranean and Other Climate Regions*. Elsevier, 1-16.
- Gallart, F., Latron, J. & Regüés, D. 1998. Hydrological and erosion processes in the research catchments of Vallcebre (Pyrenees). In J., Boardman & D., Favis–Mortlock (Eds.) *Modelling erosion by water*. ANSI/NATO series 1-55, Springer–Verlag, Berlin, 487-498.
- Gallart, F., Latron, J., Llorens, P. & Beven, K. 2007. Using internal catchment information to reduce the uncertainty of discharge and baseflow predictions. *Advances in Water Resources* 30, 808-823.
- Gallart, F., Latron, J., Llorens, P. & Martínez-Carreras, N. 2009. Hydrology in a Mediterranean mountain environment-The Vallcebre research basins (North Eastern Spain). IV. Implementing and testing hydrological models. Este volumen.
- Gallart, F., Latron, J., Llorens, P. & Rabadà, D. 1997. Hydrological functioning of Mediterranean mountain basins in Vallcebre, Catalonia: Some challenges for hydrological modelling. *Hydrological Processes* 11, 1263-1272.
- Gallart, F., Llorens, P., Latron, J. & Regüés, D. 2002. Hydrological processes and their seasonal controls in a small Mediterranean mountain catchment in the Pyrenees. *Hydrology and Earth System Sciences* 6(3), 527-537.
- Latron, J., Soler, M., Llorens, P. & Gallart, F. 2008. Spatial and temporal variability of the hydrological response in a small Mediterranean research catchment (Vallcebre, Eastern Pyrenees). *Hydrological Processes* 22, 775-787.
- Latron, J., Soler, M., Nord, G., Llorens, P. & Gallart, F. 2009. Hidrología de un ambiente Mediterráneo de montaña. Las cuencas de Vallcebre (Pirineo Oriental) II. Relaciones precipitación-escorrentia y procesos hidrológicos. Este volumen.
- Llorens, P. & Gallart, F. 1992. Small basin response in a Mediterranean mountainous abandoned farming area: Research design and preliminary results. *Catena* 19, 309-320.
- Llorens, P., Poch, R., Latron, J. & Gallart, F. 1997. Rainfall interception by a Pinus sylvestris forest patch overgrown in a Mediterranean mountainous abandoned area .1. Monitoring design and results down to the event scale. *Journal of Hydrology* 199, 331-345.
- Llorens, P., Poyatos, R., Muzylo, A., Rubio, C., Latron, J., Delgado, J. & Gallart, F. 2009. Hidrología de un ambiente Mediterráneo de montaña.Las cuencas de Vallcebre (Pirineo Oriental) III. Vegetación y flujos de agua. Este volumen.
- Regüés, D. & Gallart, F. 2004. Seasonal patterns of runoff and erosion responses to simulated rainfall in a badland area in Mediterranean mountain conditions (Vallcebre, southeastern Pyrenees). *Earth Surface Processes and Landforms* 29, 755-767.
- Soler, M., Latron, J. & Gallart, F. 2008. Relationships between suspended sediment concentrations and discharge in two small research basins in a mountainous Mediterranean area (Vallcebre, Eastern Pyrenees). *Geomorphology* 98, 143-152.

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Short- and long-term studies of sediment dynamics in a small humid mountain Mediterranean basin with badlands

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ABSTRACT

Badland landscapes are the main sediment sources in the Vallcebre area (Eastern Pyrenees, Catalonia, Spain). Short-term studies (up to 3-years long) carried out between 1980 and 1994 were used to estimate the rates of both denudation on bare surfaces and sediment production at the plot scale, to analyse the seasonal dynamics of bedrock weathering and regolith behaviour, and to study the relationships between geomorphic activity and herbaceous plant colonisation. Since 1990, stream flow and suspended sediment loads have been monitored using three gauging stations equipped with infrared backscattering turbidimeters, ultrasonic beam attenuation solids sensors and automatic water samplers. The combination of the two different approaches has been useful for a better perception of the dynamics of the badland systems and to assess the long-term contribution of these areas to the basin sediment loads. Badland erosion at the event scale for a period of 15 years was simulated with the KINEROS2 model and allowed the long-term comparison between badland erosion and sediment yield at the small basin scale. Badlands are the main source of sediment in the basin for most of the events, but infrequent runoff events cause the removal of sediment stores and the activation of other sediment sources. The analysis of the uncertainty of sediment yield measurements for a range of record durations demonstrated that long records are needed for obtaining acceptable results due to the high interannual variability. Relatively low-cost short-term geomorphic observations may provide information useful for assessing the long-term sediment production in these basins with badland areas only if the observations are used to implement a model able to simulate long-term observations.

1. Introduction

Badlands have received increasing attention in the scientific literature (Gallart et al., in press), particularly as source areas of sediments (e.g. Clotet et al., 1988; Benito et al., 1992; Cantón et al., 2001; Mathys et al., 2003; Garcia-Ruiz et al., 2008; Nadal-Romero and Regüés, 2010). Although these landforms are considered characteristic of dry environments, they also occur in wetter areas where high-topographic gradients, bedrock weakness and high-intensity rainstorms, which are rather frequent in Mediterranean environments, coexist (Gallart et al., in press). Humid badlands (in the sense of Gallart et al., 2002a) develop in areas, usually mountainous, with annual precipitation exceeding 700 mm and with frequent summer rainstorms. Erosion rates in these humid badlands are typically higher than in dry ones (Gallart et al., 2002a). Furthermore, erosion rates in humid badland areas are several orders of magnitude higher than in the vegetated surrounding areas (Descroix and Mathys, 2003; Gallart et al., 2005a; Garcia-Ruiz et al., 2008). Nevertheless, erosion rate measurements depend both on the method used (Sirvent et al., 1997) and the spatial scale of observation (Nadal-Romero et al., 2011) as discoupling features within hillslopes and between hillslopes and channels may occur (Harvey, 2002). Moreover, measurements may vary significantly from one year to another (Descroix and Mathys, 2003; Gallart et al., 2005a). We thus believe that higher attention should be paid to the comparison of erosion rates obtained by diverse methods and to analyse the uncertainty associated with measurements taking into account their temporal variability.

The badlands of Vallcebre (Eastern Pyrenees, Catalonia, Spain) have been the subject of several studies since 1982 (Clotet et al., 1983). Since 1989, runoff and sediment yield have been permanently measured in a set of small basins that include some badlands (Balasch et al., 1992). The purpose of this paper is to revisit some of the main findings obtained during the last 30 years and to compare them with updated results. Badland erosion rates were simulated for a 15-year period and compared with monitored sediment loads at the small basin scale. Special attention has been paid to compare erosion rates estimated with other methods (erosion pins, small erosion plots and natural sediment traps) taking into account the uncertainties

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associated with the temporal variability of erosion and sediment transport events.

2. Characteristics of the study area

The Vallcebre research basins are located at the headwaters of the Llobregat River, on the southern-eastern of the Pyrenees (Catalonia, NE Spain) at latitude 42° 12′ N and longitude 1° 49′ E. Altitude ranges from 1100 to 1700 m a.s.l. The research area consists of two basin clusters, whose centres are 2.5 km apart. The main cluster (Fig. 1, Cal Rodó basin, 4.17 km^2) was sub-divided into three sub-basins, whereas the smaller cluster (Cal Parisa basin, 0.32 km^2) consists of two sub-basins of similar size.

The basins lie in sedimentary rocks. Bedrock corresponds to a Cretaceous–Palaeocene continental formation dominated by red smectite-rich mudstones susceptible to mass movements and erosion (Feist and Colombo, 1983). As a consequence, some small, intensely eroded badlands with little or no soil cover are present in the basins, usually well connected to the drainage network (Figs. 2 and 3). Elsewhere, silty-loamy soils (Rubio et al., 2008) are covered by pasture and *Pinus sylvestris* forests, most of them spontaneously growing on old terraced agricultural fields after land abandonment (Poyatos et al., 2003; Delgado et al., 2010). Forest now covers 60% of the Cal Rodó basin. The rest of the catchment is largely covered by pasture, with smaller areas of Mediterranean bushes on slopes with thinner soils (Latron et al., 2009).

Climate is humid Mediterranean, with a marked water deficit in summer. Mean annual temperature at 1260 m a.s.l. is 9.1 °C and long-term (1983–2006) mean annual precipitation is 862 ± 206 mm, with 90 rainy days per year on average. Snowfall accounted for less than 5% of the precipitation in volume over the record period. The Mediterranean influence is evident in the area, leading to high inter- and intra-annual rainfall variability. Rainfall characteristics (frequency, volume and intensity) were strongly dependent on the season, with large rainfall events of low or moderate intensity occurring in autumn and spring, and short intense downpours in summer. Winter is the season with least precipitation. The long-term (1989–2006) mean annual reference evapotranspiration, calculated by the Hargreaves–Samani method (Hargreaves and Samani, 1982) is 823 ± 26 mm.

Investigations in the Vallcebre research basins started in 1989, with the objective of better understanding the hydrological functioning of Mediterranean mountain basins. A complete overview of general hydrological findings in the Vallcebre research area can be found in several papers (Llorens and Gallart, 1992; Llorens et al., 1992; Gallart et al., 1994, 1997, 2002b, 2005b; Latron and Gallart, 2007, 2008; Latron et al., 2008, 2009, 2010). In addition to results on sediment dynamics and transport discussed in the present paper, findings on rainfall–runoff modelling (Anderton et al., 2002a,b; Gallart et al., 2007, 2008) and forest water balance analyses at the plot scale (Llorens, 1997; Llorens et al., 1997a, 2003; Poyatos et al., 2005, 2008; Llorens et al., 2010) were also obtained.

3. Methods

At Vallcebre two different methods and spatial and temporal scales were used to investigate the hydrological and erosional responses of badlands: experimental short-term (up to 3 years) investigations of processes and erosion rates on small elements of badland areas, and long-term monitoring of water discharge and sediment loads in gauging stations at the outlets of small basins (Table 1). Furthermore, the erosion model KINEROS2 (Woolhiser et al., 1990) was used to estimate the long-term (15 years) sediment production from the badlands at the Ca l'Isard sub-basin.

In order to make clearer the spatial scales involved, erosion rates are indicated in kg m^{-2} for small scale values obtained in badland areas, and in Mg ha^{-1} for basin-scale measurements or for badlands upscaled to the basin area, taking into account the relative badland area in the basin.

3.1. Short-term experiments on badlands

As part of a geomorphological study, areal denudation in badland hillslopes was measured during 1982–1984 at the La Barrumba area (Figs. 1 and 2) using a rectangular array of 6 erosion pins. In the same area, sediment production from a small badland hillslope and an elementary basin (37.5 m^2) were monitored during 1982 using large plastic bags provided with small orifices that allowed the drainage of water (Clotet et al., 1983; Clotet and Gallart, 1986).

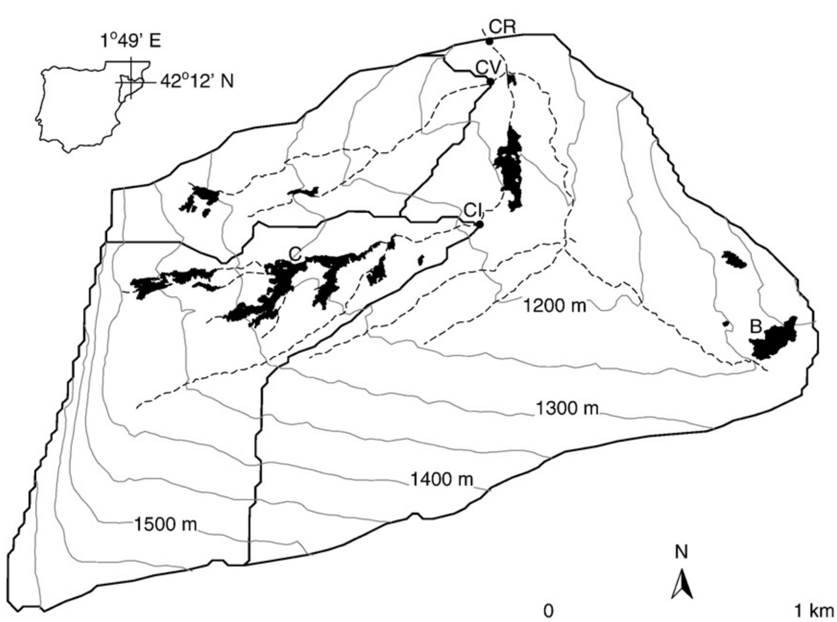

Fig. 1. Simplified map of the Vallcebre research basins. Grey lines: contours (50 m spacing); solid lines: sub-basin divides; dashed lines: drainage net; CR: Cal Rodó gauging station; CV: Can Vila gauging station; CI: Ca l'Isard gauging station. B: La Barrumba badlands. C: El Carot macro-plot. Badlands are shown in black.

Fig. 2. La Barrumba badlands.
Photo by J. Latron.

A few years later, a small badland area named 'El Carot' macro plot (1240 m^2, Figs. 1, 3 and 4) was monitored during 3-years (1990–1993) using a set of containers connected through 9-slot Geib divisors (Castelltort, 1995). The volume of sediments collected in the containers was measured at irregular temporal intervals, but leakage of water impeded the estimation of runoff rates.

Near the El Carot site, a small badland area was instrumented with two profiles of ground temperature sensors and the regolith was seasonally sampled for determination of bulk density and water content over a two and a half year period (Regüés et al., 1993, 1995). These observations were complemented with rainfall simulation experiments made with a portable nozzle-based rainfall simulator using an experimental area of 0.23 m^2 (Calvo et al., 1988) in order to analyse the response of the regolith and its seasonal variation (Regüés and Gallart, 2004).

In addition to the former experimental studies, the survey of the sediment accumulated upstream of a landslide dam that occurred in 1945 at Ca l'Andorrà, near to the study area and within the same geological setting, allowed the estimation of the long-term sediment yield from a small basin (3.1 ha) where 12% of the surface are badlands and 26% medium-degraded areas (Clotet et al., 1988).

3.2. Long-term modelling of sediment yield from badlands

In the absence of detailed long-term records of badland erosion rates (mainly due to logistical and practical constraints), Martinez-Carreras et al. (2007) used the three-year record obtained at the El Carot macro plot to calibrate the event-scale physically-based soil erosion model KINEROS2. The model was then used to estimate badland erosion during several rainfall events that occurred between 2000 and 2004. The Generalized Likelihood Uncertainty Estimation (GLUE, Beven and Binley, 1992) approach was used for assessing the uncertainty associated with model predictions, upon the assumption that many parameter sets can give acceptable simulations.

Fig. 3. El Carot badlands.
Photo by J. Latron.

The parameter set with the highest calibration efficiency has here been used to simulate badland erosion for an extended period (1994–2009, 91 rainfall events) to better analyse sediment production dynamics in comparison with the records at the basin scale. The model was implemented in four badland areas of the Ca l'Isard sub-basin, covering a total surface of 1.1 ha. Furthermore, in order to compare the simulation results with the sediment loads at the basin scale, the modelling results were multiplied by a factor to compensate the fact that 5.94 ha of the catchment corresponds to badlands.

3.3. Long-term monitoring of small basins: gauging stations

As stated in Section 2, the research area at Vallcebre has two main basin clusters: the Cal Rodó and Cal Parisa basins. There are no badlands in the Cal Parisa basin and consequently is considered hereafter only as a reference for sediment yield rates from areas without badlands.

The Cal Parisa basin consists of two sub-basins of similar sizes (17 and 18 ha) equipped with steel H-flumes, in which water stage, temperature and conductivity were recorded at 5-minute intervals. Water was sampled with both automatic (ISCO) and siphon stage samplers. These stations were set up in 1989 and closed down in 2004.

The Cal Rodó basin has three gauging stations equipped with diverse instruments for monitoring both water discharge and suspended sediment loads: Can Vila (0.56 km^2), Ca L'Isard (1.32 km^2) and Cal Rodó (4.17 km^2). The stations are hierarchically distributed within the drainage network which allows spatial and temporal comparisons of the generation of discharge and sediment flux (Fig. 1).

In this study only the data from the Ca l'Isard are used. This is the sub-basin with the most extensive and active badlands (4.5% of the area). Land cover is forest, grassland, abandoned terraces and badlands. It has been equipped with a gauging station since 1990 that was improved in 1994 (Fig. 5). Only the data recorded since the latter year have been used here for the sake of uniformity.

An automatic weather station and networks of rain recorders, soil moisture and depth to the water table measurement networks are also operational in the basins. Furthermore, short-term measurements of forest water balance fluxes (throughfall, stem flow and sap flow) have been made in several plots of *P. sylvestris* and *Quercus humilis*, although the corresponding results are not relevant for the main purpose of this paper. Some of the more relevant papers on these issues are cited at the end of Section 2.

The Ca l'Isard gauging station is controlled by a rectangular notch weir designed for ensuring a unique relationship between stage and discharge, to flush sediment, and to enable the capture of a wide range of discharges (Balasch et al., 1992). The monitoring station continuously records the water level and suspended sediment proxy data

Table 1
Synthesis of the main characteristics of the experiments carried out at Vallcebre and mentioned in the text.

Experiment	Location	Method	Area (ha)	Badlands	Years	Main reference
Areal denudation	La Barrumba	Erosion pins	–	100%	1982–1984	
Sediment yield	La Barrumba	Plastic bag	0.000 4	100%	1982	Clotet et al. (1983)
Sediment yield	La Barrumba	Plastic bag	0.003 75	100%	1982	Clotet and Gallart (1986)
Sediment yield	Ca l'Andorrà	Natural trap	3.1	12%	40	Clotet et al. (1988)
Sediment yield	El Carot	Geib slot divisors	0.124	100%	1990–1993	Castelltort (1995)
Weathering	El Carot	Temp., moisture, b. density	–	100%	1992–1994	Regüés et al. (1995)
Infiltration rates	El Carot	Rainfall experiments	0.000 023	100%	1992–1994	Regüés and Gallart (2004)
Sediment yield	Cal Parisa-1	Gauging station	17	0%	1989–2004	Llorens et al. (1997b)
Sediment yield	Ca l'Isard	Gauging station	132	4.5%	1990–	Soler et al. (2008)
Sediment yield	Can Vila	Gauging station	56	0.9%	1996–	Soler et al. (2008)
Sediment yield	Cal Rodó	Gauging station	417	2.8%	1990–	Gallart et al. (2005a)

in order to estimate water discharge and suspended sediment concentration (SSC) with high-frequency acquisition (20 min during base flows and 2 min during high-discharge events). Bedload transport is not regularly measured at the Vallcebre stations, although observations using large net traps during a moderate event in 1994 suggested that it may not be more than 1% of the total load, due to the lithological characteristics of the bedrock in the basin (Castelltort, 1995). A data logger (Data Taker DT 50) is used to store all the records and to control the diverse instruments. Water level is measured continuously using a hydrostatic pressure probe (UNIDATA Model 6542B) fixed on the ground in the middle of the gauging station. For the Ca l'Isard gauging station, a theoretical stage–discharge relationship (rating curve) is applied.

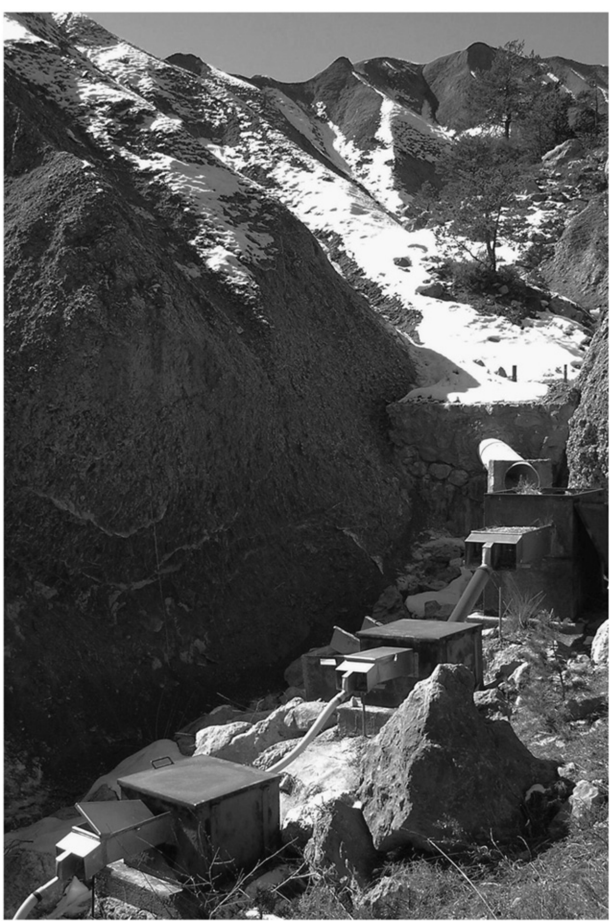

Fig. 4. Containers connected through Geib slot divisors at El Carot macro-plot. Photo by F. Gallart.

Water turbidity is continuously measured by an optical backscattering turbidity sensor (OBS-3 from D&A). This sensor sends out a beam of infrared light ($\lambda \sim 0.790\ \mu m$) emitted by an infrared emitting diode and the light backscattered at angles between 140° and 160° is measured by a phototransistor. The output of the instrument is nearly proportional to the sediment concentration when sediment characteristics (particularly grain size) are constant. Saturation value is reached at approximately 7 g l^{-1} (2000 NTU) for the suspended sediments during most events ($d_{50} \sim 10\ \mu m$). Nevertheless, during large events the grain size of the suspended sediment becomes coarser ($d_{50} \leq 96\ \mu m$), inducing a relevant change in the SSC/turbidity ratio, and an increase in concentration (up to 22 g l^{-1}) before the instrument becomes saturated (Soler et al., in press).

As the turbidimeter becomes insufficient to measure high sediment concentrations during most events, an ultrasonic beam attenuation suspended sediment sensor Bestobey-Mobrey MSM-40 was also installed. This instrument operates by transmitting short ultrasound bursts (3.5 MHz) emitted from a transducer to a receiver situated 10 cm away, where the transmitted fraction of the sound beam is measured. Instrument saturation is reached at approximately 140 g l^{-1} for the common type of suspended material in Vallcebre. When coarser sediments are transported during high discharges, the instrument is saturated at concentrations of about only 50 g l^{-1} due to higher attenuation of the ultrasound beam (Soler et al., in press).

These instruments are located in a pool downstream of the hydraulic control structure. At this location the instruments are protected from bedload and other potential damage caused by the floods. Turbulence is deemed enough to afford a good representativeness of measurements (Julien, 1998), although air bubbles produced by the hydraulic jump can disturb the ultrasonic measurements.

Fig. 5. Gauging station at Ca l'Isard. Photo by J. Latron.

An automatic water sampler (Teledyne ISCO 2700) containing 24 bottles of 1 L capacity operates approximately 2 m above the intake of the pumping pipe. The data logger (Datataker DT50) triggers water sampling when water depth exceeds the critical threshold. Both the water depth threshold and the sampling frequency were adjusted according to SSC dynamics and seasonal variability.

3.4. Long-term monitoring of small basins: laboratory analyses and time-integration of instantaneous measurements

Water samples taken by the automatic samplers were processed in the laboratory to measure SSCs. Additionally, some of the samples collected during floods were analysed using a laser diffraction particle size analyzer. Particle size distribution was characterized by the determination of the D10, D50, and D90 sizes.

General calibrations of the optical backscattering turbidity sensors and the ultrasonic beam attenuation sensors were obtained using SSC measurements of water samples collected during the period 1996–2009. The calculation of the continuous series of SSC was based therefore on three sources of information: SSC derived from the optical backscattering turbidity sensor, SSC derived from the ultrasonic beam attenuation sensor and SSC derived from water samples.

First, all the events were identified and treated separately. For each event, if there were enough water samples, the responses of the optical backscattering turbidity sensor and the ultrasonic beam attenuation sensor were calibrated using the SSC measurements of water samples. These calibrations could differ significantly from the general calibrations obtained with the samples collected during the whole 1996–2009 period. Such discrepancies are often attributed to variations in sediment and/or water properties and event types, especially in small mountainous river basins (Gippel, 1995). At the Cal Rodó station, grain size was identified as the main control (Soler et al., in press). During a few events, water samplers or sediment sensors malfunctioned due to diverse causes such as electric power failures, obstruction by vegetal debris and sediment burial. The following methodology was then employed:

(i) Optimal case: measurements made by both sediment sensors are good and there are enough water samples. In these cases, the calibrations of both sensors were updated with the samples. Then, the turbidity sensor was applied for low values of SSC and the calibration of the ultrasonic beam attenuation sensor was applied for high values of SSC.
(ii) Intermediate case: measurements made by both sediment sensors are good but there are no water samples or they are insufficient. In these cases, the general calibrations or those obtained for similar events were applied, paying attention to the relationships between the responses of both sensors.
(iii) Bad case: measurements made by one or both sediment sensors are incomplete or inconsistent, but there are enough water samples. In these cases, linear or non-linear regressions were performed using the SSC measurements of water samples and water discharges.
(iv) Worst case: measurements made by one or both sediment sensors are incomplete or inconsistent and there are not enough water samples. In these cases, the SSC was estimated through the use of sediment rating curves (SSC–discharge relationships) obtained during previous events of similar magnitude and season.

The uncertainty associated with the measurement of suspended loads during events increases from the optimal to the worst case. In the first case, the difference between the two 90% confidence bounds is about 6% of the mean value, whereas for the worst cases the two bounds may differ in one order of magnitude (Catari, 2010).

3.5. Analysis of the uncertainty associated to the temporal variability of measurements

The comparison between the diverse measurements of erosion rates and sediment loads was carried out taking into account the uncertainty of the long-term values related to the temporal variability of the annual estimates. Both, the 15-year record of sediment loads at the Ca l'Isard sub-basin and the sediment yield from the badlands in this basin simulated with KINEROS2 using the parameter calibration obtained at the El Carot macro-plot, were subject to an analysis of the uncertainty of the annual estimates for increasing record lengths.

The observed and simulated annual values were fit to respective known distribution functions (bi-modal log-normal distributions, Fig. 8) and sets of 500 random sediment yield values for every year were generated from these distributions. Subsequently, for the successive first to fifteenth years, 500 annual sediment yield multi-annual averages were obtained using random chains of the generated annual values. Finally, for every year, the 500 averaged multi-annual sediment yield samples were ordered by size and the 5% and 95% values were selected for defining the 90% probability bounds of the corresponding multi-annual value. This method was preferred to the use of a resampling procedure given the limited length of the records.

4. Results and discussion

This section combines the review of published results, the update of long-term records, and a brand new comparison of results obtained with diverse methods along with an analysis of the uncertainties associated with measurements given the temporal variability of the observations. Section 4.1 is an update of former results, Section 4.2 refers to published results, and Sections 4.3 to 4.5 include updates of former results with new data analyses.

4.1. Hydrological processes and response

During the water years 1995–2007, mean annual runoff in the Vallcebre basins was around 302 ± 222 mm (standard variation). This was equivalent to 37% of mean annual rainfall, but storm runoff coefficients varied between 1% in summer and 50% in winter. Mean daily specific discharge over the period was $9.6\ \mathrm{l\ s^{-1}\ km^{-2}}$. However, stream-flow was highly seasonal; the stream dried out in summer for a period ranging from 15 to 40 days every 2 years on average. Stream-flow is rather flashy in the basins, with response times of around 1 h.

The rainfall–runoff relationship at the basin scale is strongly nonlinear throughout the year, as there is a switching behaviour between semiarid-type processes in summer and wet-type ones during the remaining part of the year (Latron et al., 2008, 2009). Three types of characteristic hydrological behaviour with different dominant runoff generation processes occur during the year as shown by soil water potential data alongside runoff and water table data (Latron and Gallart, 2008). Under dry summer conditions, runoff is generated essentially as infiltration excess overland flow in scattered low permeability areas such as badlands, inducing flashy runoff events with high suspended sediment loads. Throughout the remaining part of the year, saturation excess overland flow dominates during wetting-up and wet conditions over most of the basin producing the main runoff events. During the wetting-up transition, contributing saturated areas result from the development of scattered perched water tables, whereas in wet conditions they are linked to the rise of the shallow water table (Latron and Gallart, 2007).

4.2. Geomorphic processes on badlands

Early field observations demonstrated the relevant role of frost heaving on the dynamics of badland surfaces in Vallcebre (Clotet and Gallart, 1986), as already described in other montane areas (Schumm, 1964). Regolith bulk density sharply decreases with the occurrence of repeated freezing cycles, leading to the formation of spongy "popcorn" features at the surface. This phenomenon is particularly active when a snow cover lasts for some weeks. The monitoring of regolith temperature, moisture and bulk density over a three year period (Regüés, 1995; Regüés et al., 1995) revealed opposite seasonal patterns of regolith bulk density and moisture. The lowest regolith bulk density was measured in January (0.83 g cm^{-3}) and the highest in September (1.46 g cm^{-3}). The latter value is related to both regolith compaction and erosion by intense rainstorms. Laboratory experiments demonstrated that repeated freeze–thaw cycles lead to the disruption of the soft bedrock and the formation of "popcorn" features, whilst the wetting–drying cycles are a much less efficient weathering process (Pardini et al., 1995, 1996). The analysis of the amounts of different kinds of energy available for weathering and erosion confirmed the dominant role of freezing and its strong difference between sunny and shady aspects, explaining the preferred occurrence of badlands on north-facing slopes (Regüés et al., 2000).

The analysis of vegetation clearly demonstrated that in these humid conditions, badlands on northern aspects bear more impoverished vegetation both in terms of cover and species composition than the less frequent badlands on south-facing aspects. The lower temperatures and the shorter growth period on northern aspects constitute stronger limiting factors on vegetation development than the lower water availability on southern aspects (Regüés et al., 2000).

This seems to be a distinct characteristic of Mediterranean humid badlands (Gallart et al., in press) as semiarid badlands usually occur on sunny hillslopes (Cantón et al., 2001; Alexander et al., 2008) even in mountain areas (Schumm, 1964; Faulkner, 1987), whereas hillslope gully systems in other wet mountain environments seem to develop with little aspect control (Harvey, 1992).

Rainfall simulation experiments were repeatedly performed over a period of two and a half years (Regüés, 1995; Regüés and Gallart, 2004). Results showed that infiltration rates on badland surfaces were relatively high (mean 18 mm h^{-1}) and varied significantly throughout the year, reaching values between 1 and 40 mm h^{-1} at the end of summer and winter, corresponding to 0.3 and 29 mm of rainfall before runoff initiation, respectively. Infiltration rates in winter showed the largest variability, whereas changes were much smaller throughout the rest of the year, with the exception of a cluster of high-runoff rates in October. This behaviour was attributed to the contradictory roles of regolith bulk density and moisture. Infiltration rates in vegetated soils in areas without badlands are usually much higher (K_s about 300 mm h^{-1}), but also show large seasonal and spatial variations due to the opening and closure of cracks (Gallart et al., 1997) and the effect of old farming activities (Llorens et al., 1997b), respectively.

Field evidence indicates that several geomorphic processes are active on badlands. Rill and splash erosion are the more active ones, but the rills usually disappear during winter because of regolith creeping and the disturbing action of freezing. Shallow regolith mudflows seldom occur, and then primarily during snow blanket melting. When a frozen regolith dries out, small fragments frequently collapse, forming colluvial deposits on most of the footslopes and elementary channels (Clotet et al., 1988). Similar seasonal alternations of rill formation in summer and disappearance in winter due to frost heaving have been described in other montane badlands elsewhere (Schumm, 1964; Harvey, 1992).

Sediment yield monitoring at the El Carot macro-plot over a three year period (Castelltort, 1995) demonstrated that the main driver of event erosion at this scale was rainfall intensity (Fig. 6a), followed by rainfall depth (Fig. 6b), overriding the role of regolith behaviour. The most important erosive events were consequently grouped during the warmest part of the year, with 70% of the total annual erosion occurring between May and early August (Fig. 7). This result diverges

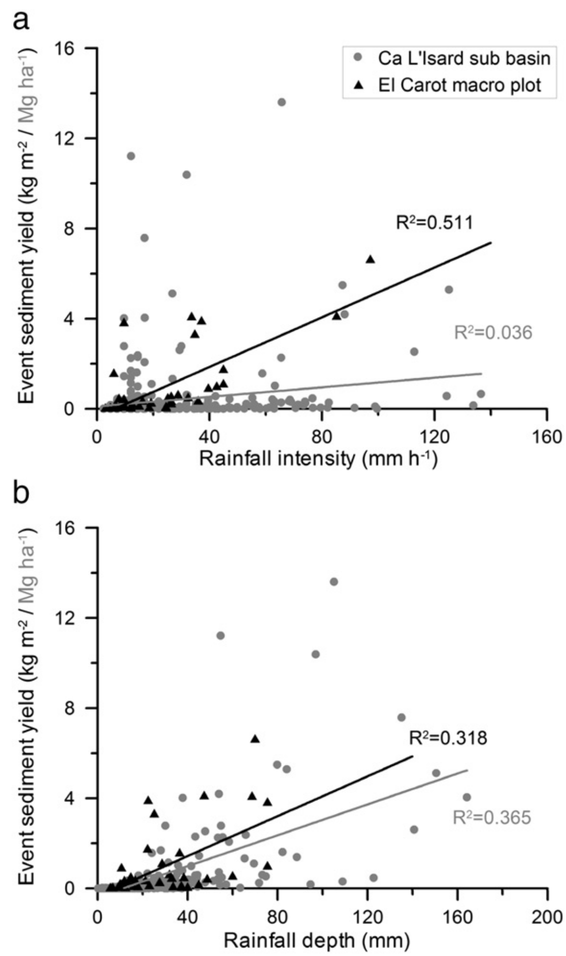

Fig. 6. Relationships between event sediment yields and a) rainfall intensity and b) rainfall depth at the El Carot macro-plot and the Ca l'Isard sub-basin. All coefficients of determination are significant at the 1% level.

from those obtained in other wetter mountain areas where gully onslope sediment production is higher in winter due to the main role of mass movements and snow melting runoff (Harvey, 1992).

4.3. Erosion rates in badlands

Several estimates of erosion rates were obtained with diverse methods and at diverse temporal and spatial scales in Vallcebre. At La Barrumba, sediment yield from elementary badland surfaces measured with collecting plastic bags during one year was estimated to be 11–14 kg m^{-2}. In the same area, the three-year estimate using erosion pins was 23 kg m^{-2} $year^{-1}$ whereas shorter measurement periods evidenced the seasonal expansion of the regolith due to ground freezing. At El Carot macro-plot, maximum measured event erosion rate was as high as 6.6 kg m^{-2}, with a mean annual erosion rate of 12 kg m^{-2} (mean of 3 years).

A sample of 91 rainfall events that occurred between 1994 and 2009, which produced 85% of the total sediment transport measured at the Ca l'Isard sub-basin outlet, was used for simulating badland erosion with the KINEROS2 model. A mean annual erosion rate of 8.4 kg m^{-2} $year^{-1}$ was obtained for all the simulated badland areas (1.1 ha), whereas an erosion rate of only 4.2 kg m^{-2} $year^{-1}$ was obtained for the El Carot macro-plot. The difference with the measured rate in the latter (12 kg m^{-2} $year^{-1}$) may be attributed to the high precipitation during the monitoring period and can be deemed satisfactory given the usual low accuracy of erosion models (Jetten et al., 1999). The seasonal arrangement of simulated erosive events (Fig. 7) was similar to the arrangement of observed ones,

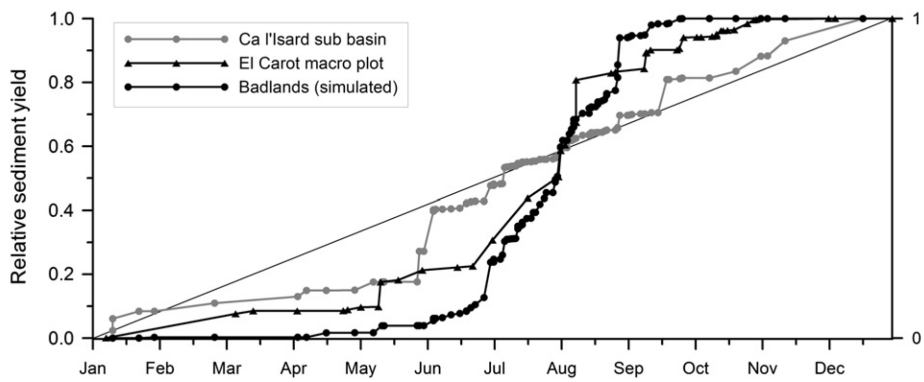

Fig. 7. Cumulated relative event sediment yield using an annual scale at the Ca l'Isard sub-basin (15 years), the El Carot macro-plot (3 years) and simulated for the badlands in the Ca l'Isard sub-basin (15 years). Individual events were ranked according to the day of the year before being cumulated.

although the model underestimated the role of relatively low intensity events in spring and autumn. Simulated annual erosion rates showed a wavy distribution, with a good fit to a bimodal log-normal distribution (Fig. 8), showing that there were some years with rare summer rainstorms. In this graph and the subsequent Figs. 9 and 11, the values obtained at the small scale were upscaled to represent the badland contribution to the sediment yield at the scale of the Ca l'Isard sub-basin. Fig. 9 shows the evolution of the uncertainty bounds of annual sediment yield averaged for increasing record durations. The range between the uncertainty bounds was very large for one and two year records, and after the third year there was a progressive decrease in the uncertainty range width with increasing record length. For a 15-year record, the ratio between the upper and lower uncertainty bounds was 2.2.

On the other hand, the analysis of the sediment trap at Ca l'Andorrà showed that the long-term (40 years) estimate of sediment yield from badland areas in this very small basin was between 5.9 and 17 kg m^{-2} $year^{-1}$, depending on whether all the areas with scattered vegetation in the basin are assumed to have had the same erosion rate or if all the sediment is assumed to come from well-developed vegetation-free badlands, respectively (Clotet et al., 1988).

4.4. Sediment loads at the basin scale

The monitoring of sediment loads at the Ca l'Isard sub-basin resulted in a mean annual sediment yield of 8.8 Mg ha^{-1} $year^{-1}$; the uncertainty of this value has not yet been assessed, but the width of the 90% confidence bounds should be larger than 12% of the mean value at this scale due to instrumental errors (Catari, 2010). This value contrasts with the 0.04 Mg ha^{-1} $year^{-1}$ estimated

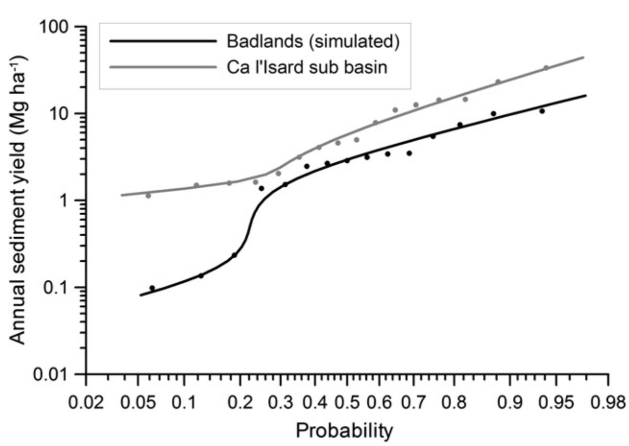

Fig. 8. Distribution functions of annual sediment yields measured at the Ca l'Isard sub-basin (grey) and sediment yields simulated for the badlands in this basin (black). Lines shown fit bimodal log-normal distributions.

for the badland-free Cal Parisa small basin (Llorens et al., 1997b) and is reasonably larger than the 4.3 Mg ha^{-1} $year^{-1}$ estimated for a period of 25 years in the upper Llobregat basin (532 km^2) from sediment surveys at La Baells reservoir (CEDEX, 2002). The event sediment loads were independent on rainfall intensity (Fig. 6a) and fairly dependent on rainfall depth (Fig. 6b), whereas they were well correlated with peak discharge, a surrogate of stream power (Fig. 10). The seasonal pattern of event loads measured in the basin was substantially different from that of observed and simulated events on badlands (Fig. 7); 12 large events in the equinoxes transported as much sediment (39% of the total) as 70 events during summer. Badland erosion was simulated as null for some big events with large stream sediment loads during wet conditions, whereas much higher badland erosion rates associated with low stream sediment loads were simulated for intense summer rainstorms, when the basin was dry. There was consequently a poor correlation between simulated badland erosion volumes and stream sediment loads at the event scale; the linear correlation coefficient was $r = 0.19$, non significant, but rising to 0.46, ($p < 0.01$), if simulations with null sediment output were omitted. When loads were cumulated at the annual scale (Fig. 11), the correlation coefficient improved ($r = 0.51$).

Hysteresis loops of the relationship between SSC and water discharge at Ca l'Isard are usually negative during flashy summer events and positive during large events and over the rest of the year (Soler et al., 2008). Stream beds become typically muddy during summer because the flashy events are unable to transport away all the sediment eroded from the badlands. This disagreement between badland and basin scales may be explained by the fact that, as stated before, the hydrology of the basin is driven mainly by saturation mechanisms over the vegetated areas, whereas the hydrological contribution of badlands is only noticeable during summer, when antecedent conditions are dry and heavy showers trigger runoff and erosion in the badlands. In mountain areas where snow precipitation is more important, a similar but more regular spatio-temporal coupling has been described, with summer storms inducing the more eroding events at the hillslope and low order channel scales, and snow melting runoff being the main sediment transporting process at larger basin sizes (Faulkner, 1987).

Fig. 11 shows the cumulative plots of sediment loads at the basin scale and those simulated for badlands, once scaled to the basin scale taking into account the area of badlands in the basin. This plot shows that the cumulated simulated badland erosion accounted for only about one half of the sediment exported from the basin. However, if a period without large events (between January 2000 and January 2008) is considered, the simulated badland erosion was as much as 82% of the basin loads. Badland erosion can therefore justify basin sediment loads during most of the time, except when infrequent runoff events (about 5-year return period) mobilise sediment stores in the drainage network and other sources of sediments, causing channel entrenchment (Gallart et al., 2002b, 2005a). These results

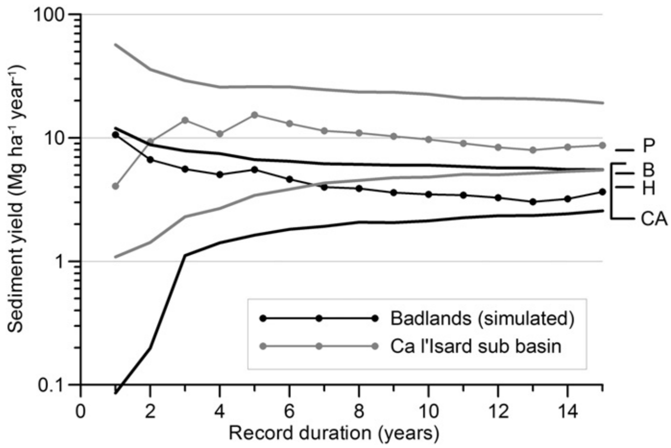

Fig. 9. Sediment yields estimated with different methods for increasing record duration. Grey plots: 15 years of measured sediment yields with 90% confidence bounds. Black plots: 15 years of simulated badlands contribution to sediment yield using KINEROS2, with 90% confidence bounds. Letters on the right side represent badland contribution to sediment yield estimated from other measurements using erosion pins (P), plastic bags in an elementary basin (B) and a small hillslope (H), and the range derived from the survey of the Ca l'Andorrà natural sediment trap (CA).

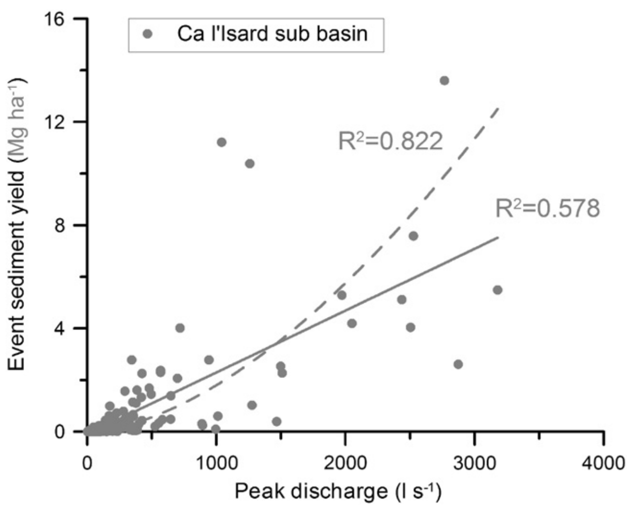

Fig. 10. Relationships between event sediment yields and peak discharge at the Ca l'Isard sub-basin, fitted to a linear regression (solid line) and potential (log-log) regression (dashed line). Both determination coefficients are significant at the 1% level.

may give some light to the analysis of long-term evolution of these badlands in terms of sediment transport and form connectivity (e.g. Harvey, 2002; Faulkner, 2008); frequent summer events alone would induce the deposition of sediments in the low orders drainage net and the discoupling of badlands from the main net (this does occur in some minor forms), but major and extreme events, in terms of rainfall totals, induce the generalized scouring of stream channels as well as scattered mass movements in hillslopes that can be the origin of new badlands (Gallart and Clotet, 1988).

Annual estimates of specific sediment yield at Ca l'Isard showed a good adjustment to a bimodal log-normal distribution (Fig. 8). The evolution of uncertainty bounds of annual sediment yield for increasing record duration (Fig. 9) shows a high uncertainty for short records and a progressive decrease with increasing length. For a 15-year record, the ratio between the upper and lower uncertainty bounds was 3.3.

4.5. Comparison between methods

The badland contribution to the total sediment yield at the Ca l'Isard sub-basin in the different estimates of erosion rates was calculated taking into account the area of these landforms in the basin. Mapping badlands is a relatively easy task in Vallcebre given the dense forest cover of most of the area, although there are also some areas with scattered vegetation on relatively hard bedrock that do not have the erosional features of badlands, as stated before for the Ca l'Andorrà area (Clotet et al., 1988).

The sediment yield results obtained with the different methods are shown in Fig. 9. Except for the one- and two-year-long records, the width of the uncertainty bounds for the basin measurements is larger than those for the simulated badland erosion, presumably due to the role of occasional large events. Furthermore, the lower uncertainty bound for the basin is below the upper uncertainty bound for the simulated badland erosion over the entire plot except at the end of the record. This suggests that, in the long run, sediments coming from badlands do not explain all the sediment loads in the basin. Other relevant sources of sediment in addition to badlands seem to be therefore needed to account for the basin sediment yield. Stream channel erosion and mass movements occur in the basin (Gallart et al., 2005a), although their sediment contribution has not yet been assessed.

At a first glance, the three-year estimate using erosion pins (P) and the upper bound of the 40-year estimate obtained at the Ca l'Andorrà trap (CA) fall well within the 15-year bounds of sediment yield measured at the basin outlet. The other estimates fall below these bounds. Nevertheless, the width of the uncertainty bounds for records shorter than 5 years is larger than one order of magnitude. Consequently, any type of measurement of erosion rates with a record shorter than five years cannot provide estimates better than the order of magnitude under climatic and geomorphic conditions such as those at Vallcebre. Nevertheless, the above results indicate that short-term observations

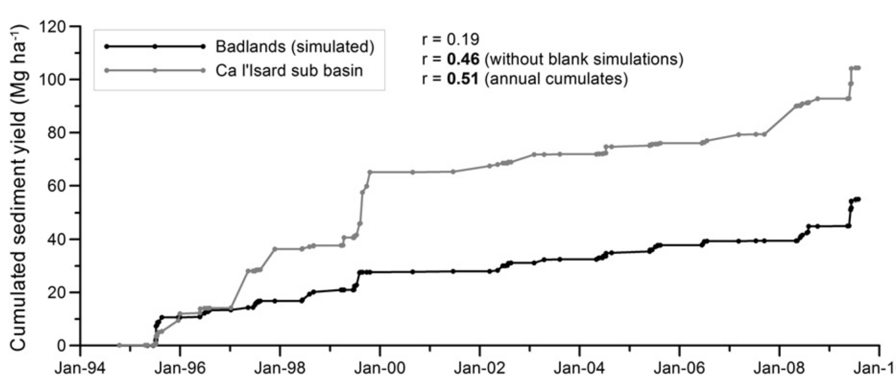

Fig. 11. Cumulated event sediment loads observed at Ca l'Isard and erosion weights simulated with KINEROS2 for the badlands in this sub-basin. The correlation coefficients significant at the 1% level are indicated in **bold**.

may be successfully used for long-term estimates if an adequate model can be implemented with the data.

5. Conclusions

Sediment dynamics in the Vallcebre catchments is dominated by the occurrence of badlands. Ground freezing in winter is the main weathering mechanism, and the regolith shows noticeable seasonal changes in moisture, bulk density and infiltration capacity. Erosion in badlands is especially active in summer, due to the occurrence of intense rain events. The preferred occurrence of these badlands on northern (shady) aspects illustrates the differences between these humid badlands and those occurring in drier areas.

Erosion rates from badland areas have been investigated at Vallcebre using several methods and record periods. Plastic bags were used during 1 year to measure sediment production from small areas (11–14 kg m^{-2} $year^{-1}$). Erosion pins were used during 3 years to measure ground lowering (23 kg m^{-2} $year^{-1}$) and the survey of a natural 40-year old sediment trap (landslide damming a small stream) allowed the estimation of sediment yield from badlands in a 3.1 ha basin (5.9–17 kg m^{-2} $year^{-1}$). The monitoring of sediment production from a 1240 m^2 macro-plot during 3 years allowed the assessment of sediment production (12 kg m^{-2} $year^{-1}$), the study of the relationships between rainfall characteristics and sediment yields, and the implementation of the KINEROS2 event erosion model.

The application of the KINEROS2 model to a set of badland areas for a period of 15 years allowed the analysis of the temporal patterns of erosive events, a longer-term estimate of sediment production (8.4 kg m^{-2} $year^{-1}$), as well as the assessment of the uncertainty of the estimates associated with variable temporal scales of observation.

Three small nested basins are instrumented with gauging stations since 1990–1994 for monitoring of runoff and sediment loads. The 15-year record at the Ca l'Isard sub-basin (1.32 km^2) showed a sediment yield of 8.8 Mg ha^{-1} $year^{-1}$ and allowed the analysis of the uncertainty of the measurements associated to the length of the recording period. The comparison with the erosion events simulated with the KINEROS2 model showed that sediment loads from this basin may be attributed mainly to the role of badlands if infrequent large events are excluded, in which sediment stores and other sources of sediments are mobilised.

The comparison between the diverse estimates of erosion rates in badlands, in the light of the temporal variability of erosion events simulated with the KINEROS2 model and the sediment load events monitored at the Ca l'Isard sub-basin, demonstrated that records longer than 5 are needed to assess the order of magnitude of the erosion or transport rates in the climatic conditions at Vallcebre. The results obtained with the KINEROS2 erosion model demonstrated that relatively short record periods with simple experimental instruments may be used to assess long-term erosion rates if an adequate model is implemented.

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References

Alexander, R.W., Calvo-Cases, A., Arnau-Rosalén, E., Mather, A.E., Lázaro-Suau, R., 2008. Erosion and stabilisation sequences in relation to base level changes in the El Cautivo badlands, SE Spain. Geomorphology 100, 83–90.

Anderton, S.P., Latron, J., Gallart, F., 2002a. Sensitivity analysis and multi-response, multi-criteria evaluation of a physically based distributed model. Hydrological Processes 16, 333–353.

Anderton, S.P., Latron, J., White, S.M., Llorens, P., Gallart, F., O'Connell, P.E., 2002b. Internal evaluation of a physically-based distributed model using data from a Mediterranean mountain catchment. Hydrology and Earth System Sciences 6, 67–83.

Balasch, J.C., Castelltort, F.X., Llorens, P., Gallart, F., 1992. Hydrological and sediment dynamics network design in a Mediterranean mountainous area subject to gully erosion. In: Bogen, J., Walling, D.E., Day, T. (Eds.), Erosion and Sediment Transport Monitoring Programmes in River Basins. IAHS Publication, pp. 433–442.

Benito, G., Gutiérrez, M., Sancho, C., 1992. Erosion rates in badland areas of the central Ebro Basin (NE-Spain). Catena 19, 269–286.

Beven, K., Binley, A., 1992. The future of distributed models — model calibration and uncertainty prediction. Hydrological Processes 6, 279–298.

Calvo, A., Sirvent, J.M., Palau, E., Romero, M., 1988. Un simulador de lluvia portátil de fácil construcción. Métodos y técnicas para la medición en el campo de procesos geomorfológicos. In: Sala, M., Gallart, F. (Eds.), Monograph No. 1. Sociedad Española de Geomorfología, Zaragoza, pp. 6–19.

Cantón, Y., Domingo, F., Solé-Benet, A., Puigdefábregas, J., 2001. Hydrological and erosion response of a badlands system in semiarid SE Spain. Journal of Hydrology 252, 65–84.

Castelltort, X., 1995. Erosió, transport i sedimentació fluvial com a integració de processos geomorfològics d'una conca (Conca de Cal Rodó, Alt Llobregat). Ph. Dr. Thesis, Universitat de Barcelona, Barcelona, 234 pp.

Catari, G., 2010. Assessment of uncertainties of soil erosion and sediment yield estimates at two spatial scales in the Upper Llobregat basin (SE Pyrenees, Spain). Ph. Dr. Thesis, Universitat Autònoma de Barcelona, Bellaterra (Barcelona), 236 pp.

CEDEX, 2002. Estudios batimétricos de embalses: embalse de La Baells, Barcelona, Centro de estudios y experimentación de obras públicas. Ministerio de Fomento, Madrid.

Clotet, N., Gallart, F., 1986. Sediment yield in a mountainous basin under high Mediterranean climate. Zeitschrift für Geomorphologie Supplementband 60, 205–216.

Clotet, N., Gallart, F., Calvet, J., 1983. Estudio de la dinámica de un sector de Badlands en Vallcebre (prepirineo Catalán): Puesta a punto de la metodología y primeras aproximaciones cuantitativas. Reunión del Grupo Español de Geología Ambiental y Ordenación del Territorio, Lleida, pp. 4.20–4.38.

Clotet, N., Gallart, F., Balasch, J.C., 1988. Medium term erosion rates in a small scarcely vegetated catchment in the Pyrenees. Geomorphic processes: Vol. II. Geomorphic systems. Catena Supplement 13, 37–41.

Delgado, J., Llorens, P., Nord, G., Calder, I.R., Gallart, F., 2010. Modelling the hydrological response of a Mediterranean medium-sized headwater basin subject to land cover change: the Cardener River basin (NE Spain). Journal of Hydrology 383, 125–134.

Descroix, L., Mathys, N., 2003. Processes, spatio-temporal factors and measurements of current erosion in the French Southern Alps: a review. Earth Surface Processes and Landforms 28, 993–1011.

Faulkner, H., 1987. Gully evolution in response to both snowmelt and flash flood erosion, Wn. Colorado. In: Gardiner, V. (Ed.), International Geomorphology 1986, Part I. Wiley, Chichester, pp. 947–969.

Faulkner, H., 2008. Connectivity as a crucial determinant of badland morphology and evolution. Geomorphology 100, 91–103.

Feist, M., Colombo, F., 1983. La limite Crétacé-Tertiaire dans le NE de l'Espagne du point de vue des charophytes, Colloque sur le Sénonien. Géologie Méditerranéenne 303–326.

Gallart, F., Clotet, N., 1988. Some aspects of the geomorphic processes triggered by an extreme rainfall event: the November 1982 flood in the Eastern Pyrenees. Catena Supplement 13, 79–85.

Gallart, F., Llorens, P., Latron, J., 1994. Studying the role of old agricultural terraces on runoff generation in a small Mediterranean mountainous basin. Journal of Hydrology 159, 291–303.

Gallart, F., Latron, J., Llorens, P., Rabadà, D., 1997. Hydrological functioning of Mediterranean mountain basins in Vallcebre, Catalonia: some challenges for hydrological modelling. Hydrological Processes 11, 1263–1272.

Gallart, F., Solé, A., Puigdefábregas, J., Lázaro, R., 2002a. Badland systems in the Mediterranean. In: Bull, J.L., Kirkby, M.J. (Eds.), Dryland Rivers: Hydrology and Geomorphology of Semi-arid Channels. Wiley, Chichester, pp. 299–326.

Gallart, F., Llorens, P., Latron, J., Regüés, D., 2002b. Hydrological processes and their seasonal controls in a small Mediterranean mountain catchment in the Pyrenees. Hydrology and Earth System Sciences 6, 527–537.

Gallart, F., Balasch, J.C., Regüés, D., Soler, M., Castelltort, X., 2005a. Catchment dynamics in a Mediterranean mountain environment: the Vallcebre research basins (southeastern

Pyrenees) II: temporal and spatial dynamics of erosion and stream sediment transport. In: García, C., Batalla, R. (Eds.), Catchment Dynamics and River Processes: Mediterranean and Other Climate Regions. Elsevier, Amsterdam, pp. 17–29.
Gallart, F., Latron, J., Llorens, P., 2005b. Catchment dynamics in a Mediterranean mountain environment: the Vallcebre research basins (southeastern Pyrenees) I: hydrology. In: García, C., Batalla, R. (Eds.), Catchment Dynamics and River Processes: Mediterranean and Other Climate Regions. Elsevier, Amsterdam, pp. 1–16.
Gallart, F., Latron, J., Llorens, P., Beven, K., 2007. Using internal catchment information to reduce the uncertainty of discharge and baseflow predictions. Advances in Water Resources 30, 808–823.
Gallart, F., Latron, J., Llorens, P., Beven, K.J., 2008. Upscaling discrete internal observations for obtaining catchment-averaged TOPMODEL parameters in a small Mediterranean mountain basin. Physics and Chemistry of the Earth 33, 1090–1094.
Gallart, F., Marignani, M., Pérez-Gallego, N., Santi, E., Maccherini, S., in press. Thirty years of studies on badlands, from physical to vegetational approaches. A succinct review. Catena. http://dx.doi.org/10.1016/j.catena.2012.02.008.
Garcia-Ruiz, J.M., Regüés, D., Alvera, B., Lana-Renault, N., Serrano-Muela, P., Nadal-Romero, E., Navas, A., Latron, J., Marti-Bono, C., Arnaez, J., 2008. Flood generation and sediment transport in experimental catchments affected by land use changes in the central Pyrenees. Journal of Hydrology 356, 245–260.
Gippel, C.J., 1995. Potential of turbidity monitoring for measuring the transport solids in streams. Hydrological Processes 9, 83–97.
Hargreaves, G.H., Samani, Z.A., 1982. Estimating potential evapo-transpiration. Journal of the Irrigation and Drainage Division-Asce 108, 225–230.
Harvey, A.M., 1992. Process interactions, temporal scales and the development of hillslope gully systems: Howgill Fells, northwest England. Geomorphology 5, 323–344.
Harvey, A.M., 2002. Effective timescales of coupling within fluvial systems. Geomorphology 44, 175–201.
Jetten, V., De Roo, A., Favis-Mortlock, D., 1999. Evaluation of field-scale and catchment-scale soil erosion models. Catena 37, 521–541.
Julien, P.Y., 1998. Erosion and Sedimentation. Cambridge University Press, Cambridge. 279 pp.
Latron, J., Gallart, F., 2007. Seasonal dynamics of runoff-contributing areas in a small Mediterranean research catchment (Vallcebre, Eastern Pyrenees). Journal of Hydrology 335, 194–206.
Latron, J., Gallart, F., 2008. Runoff generation processes in a small Mediterranean research catchment (Vallcebre, Eastern Pyrenees). Journal of Hydrology 358, 206–220.
Latron, J., Soler, M., Llorens, P., Gallart, F., 2008. Spatial and temporal variability of the hydrological response in a small Mediterranean research catchment (Vallcebre, Eastern Pyrenees). Hydrological Processes 22, 775–787.
Latron, J., Llorens, P., Gallart, F., 2009. The hydrology of Mediterranean mountain areas. Geography Compass 3, 2045–2064.
Latron, J., Llorens, P., Soler, M., Poyatos, R., Rubio, C., Muzylo, A., Martínez-Carreras, N., Delgado, J., Regüés, D., Catari, G., Nord, G., Gallart, F., 2010. Hydrology in a Mediterranean Mountain Environment — The Vallcebre Research Basins (Northeastern Spain). I. 20 years of Investigation of Hydrological Dynamics, Status and Perspectives of Hydrology in Small Basins. IAHS Publ., Goslar-Hahnenklee, Germany.
Llorens, P., 1997. Rainfall interception by a *Pinus sylvestris* forest patch overgrown in a Mediterranean mountainous abandoned area.II. Assessment of the applicability of Gash's analytical model. Journal of Hydrology 199, 346–359.
Llorens, P., Gallart, F., 1992. Small basin response in a Mediterranean mountainous abandoned farming area — research design and preliminary results. Catena 19, 309–320.
Llorens, P., Latron, J., Gallart, F., 1992. Analysis of the role of agricultural abandoned terraces on the hydrology and sediment dynamics in a small mountainous basin. Pirineos 139, 27–49.
Llorens, P., Poch, R., Latron, J., Gallart, F., 1997a. Rainfall interception by a *Pinus sylvestris* forest patch overgrown in a Mediterranean mountainous abandoned area.1. Monitoring design and results down to the event scale. Journal of Hydrology 199, 331–345.
Llorens, P., Queralt, I., Plana, F., Gallart, F., 1997b. Studying solute and particulate sediment transfer in a small Mediterranean mountainous catchment subject to land abandonment. Earth Surface Processes and Landforms 22, 1027–1035.
Llorens, P., Oliveras, I., Poyatos, R., 2003. Temporal variability of water fluxes in a *Pinus sylvestris* forest patch in Mediterranean mountain conditions (Vallcebre research catchments, Catalan Pyrenees). Hydrology of Mediterranean and Semiarid Regions: In: Servat, E., Najem, W., Leduc, C., Shakeel, A. (Eds.), IAHS Publication No. 278, Wallingford, pp. 101–105.
Llorens, P., Poyatos, R., Latron, J., Delgado, J., Oliveras, I., Gallart, F., 2010. A multi-year study of rainfall and soil water controls on Scots pine transpiration under Mediterranean mountain conditions. Hydrological Processes 24, 3053–3064.
Martinez-Carreras, N., Soler, M., Hernandez, E., Gallart, F., 2007. Simulating badland erosion with KINEROS2 in a small Mediterranean mountain basin (Vallcebre, Eastern Pyrenees). Catena 71, 145–154.
Mathys, N., Brochot, S., Meunier, M., Richard, D., 2003. Erosion quantification in the small marly experimental catchments of Draix (Alpes de Haute Provence, France). Calibration of the ETC rainfall–runoff-erosion model. Catena 50, 527–548.
Nadal-Romero, E., Regüés, D., 2010. Geomorphological dynamics of subhumid mountain badland areas — weathering, hydrological and suspended sediment transport processes: a case study in the Araguas catchment (Central Pyrenees) and implications for altered hydroclimatic regimes. Progress in Physical Geography 34, 123–150.
Nadal-Romero, E., Martinez-Murillo, J.F., Vanmaercke, M., Poesen, J., 2011. Scale-dependency of sediment yield from badland areas in Mediterranean environments. Progress in Physical Geography 35, 297–332.
Pardini, G., Pini, R., Barbini, R., Regüés, D., Plana, F., Gallart, F., 1995. Laser elevation measurements of a smectite-rich mudrock following freeze–thawing and wet–drying cycles. Soil Technology 8, 161–175.
Pardini, G., Guidi, G.V., Pini, R., Regüés, D., Gallart, F., 1996. Structure and porosity of smectitic mudrocks as affected by experimental wetting–drying cycles and freezing–thawing cycles. Catena 27, 149–165.
Poyatos, R., Latron, J., Llorens, P., 2003. Land use and land cover change after agricultural abandonment — the case of a Mediterranean mountain area (Catalan Pre-Pyrenees). Mountain Research and Development 23, 362–368.
Poyatos, R., Llorens, P., Gallart, F., 2005. Transpiration of montane *Pinus sylvestris* L. and Quercus pubescens Willd. forest stands measured with sap flow sensors in NE Spain. Hydrology and Earth System Sciences 9, 493–505.
Poyatos, R., Llorens, P., Piñol, J., Rubio, C., 2008. Response of Scots pine (*Pinus sylvestris* L.) and pubescent oak (Quercus pubescens Willd.) to soil and atmospheric water deficits under Mediterranean mountain climate. Annals of Forest Science 65 (306/1-306/13).
Regüés, D., 1995. Meteorización física en relación con los procesos de producción y transporte de sedimentos en un área acarcavada. Universidad de Barcelona. 302 pp.
Regüés, D., Gallart, F., 2004. Seasonal patterns of runoff and erosion responses to simulated rainfall in a badland area in Mediterranean mountain conditions (Vallcebre, southeastern Pyrenees). Earth Surface Processes and Landforms 29, 755–767.
Regüés, D., Llorens, P., Pardini, G., Pini, R., Gallart, F., 1993. Physical weathering and regolith behaviour in a high erosion rate badland area at the Pyrenees: research design and first results. Pirineos 141 (142), 63–84.
Regüés, D., Pardini, G., Gallart, F., 1995. Regolith behaviour and physical weathering of clayey mudrock as dependent on seasonal weather conditions in a badland area at Vallcebre, Eastern Pyrenees. Catena 25, 199–212.
Regüés, D., Guardia, R., Gallart, F., 2000. Geomorphic agents versus vegetation spreading as causes of badland occurrence in a Mediterranean subhumid mountainous area. Catena 40, 173–187.
Rubio, C.M., Llorens, P., Gallart, F., 2008. Uncertainty and efficiency of pedotransfer functions for estimating water retention characteristics of soils. European Journal of Soil Science 59, 339–347.
Schumm, S.A., 1964. Seasonal variations in erosion rates and processes on hillslopes in Western Colorado. Zeitscrift für Geomorphologie Supplementband 5, 215–238.
Sirvent, J., Desir, G., Gutierrez, M., Sancho, C., Benito, G., 1997. Erosion rates in badland areas recorded by collectors, erosion pins and profilometer techniques (Ebro Basin, NE-Spain). Geomorphology 18, 61–75.
Soler, M., Latron, J., Gallart, F., 2008. Relationships between suspended sediment concentrations and discharge in two small research basins in a mountainous Mediterranean area (Vallcebre, Eastern Pyrenees). Geomorphology 98, 143–152.
Soler, M., Nord, M., Catari, G., Gallart, F., in press. Assessing suspended sediment concentration measurement error in relation to particle size using continuous sensors at the Vallcebre catchment (Eastern Pyrenees). Zeitschrift für Geomorphologie.
Woolhiser, D.A., Smith, R.E., Goodrich, D.C., 1990. KINEROS, A Kinematic Runoff and Erosion Model: Documentation and User Manual. U.S. Department of Agriculture, Agricultural Research Service. 130 pp.

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LAND EVALUATION AND EROSION CONTROL PRACTICES ON MINED SOILS IN NE SPAIN

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Summary

A basic aim of land evaluation is to assess land suitability for sustained land use; erosion poses a major risk in permanent use in reclaimed mined land.

Several aspects need to be considered in relation to erosion processes and land use:

- The effects of erosion in the reclaimed land itself.
- The environmental effects of the erosion products.

To evaluate the effectiveness of soil conservation practices in a subhumid environment, a study has been carried out on land affected by opencast coal mining in the pre-pyrenean area (NE Spain). The study area is 20 ha in extent and is situated 3 km upstream from "La Baells" reservoir. Before mining, the land was occupied by pine and oak forest. A well developed drainage network existed, and the mean slope was 20%. Both factors, together with climate and surface spoil material characteristics are the main causes of the erosion processes.

The mean annual temperature is 11,5°C and the average rainfall is 950 mm/y. The rain falls mainly in spring, but August has the monthly maximum in a few showers.

The soil surface horizons were not preserved during mining and when it ended in 1979, the materials left on the surface were mainly unweathered calcareous siltstone and claystone with a massive structure, low infiltration and low permeability.

To prevent the expected erosion, several conservation measures were taken: bench terraces to infiltrate water on the lowest part, and sowings of grasses and legumes all over the spoil banks.

Erosion occurred from the beginning. Conservation measures were useless and even increased the erosion processes.

Because a vegetation cover never existed, splash and sheet erosion are important: the theoretical amount of detached material due to splash erosion according to MIRSTSKHULAVA (1970) is 2500 Mg/ha/y. In spite of that, the most important erosion processes are produced by concentrated runoff: the measured weight of removed material is 200 Mg/ha/y due to rills, and 234 Mg/Ha/y due to gullies, while the theoretical erosion estimated by the USLE is 160 Mg/ha/y.

Key factors in the development of the

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gully network are the lack of interception ditches for the outcoming runoff, failure to take the previous drainage network into consideration, and the inadequacy of the conservation measures for the soil and climate conditions.

Suitability of an area for mining should be assessed in advance. The establishment of a permanent land use plan and the maintenance of the environmental impact below permissible levels is only possible under certain conditions. For the study area, to reach these aims can be too costly, because the allowable erosion rates would have to be very low.

1 Introduction

Research reported in this paper focuses on the effectiveness of erosion control measures implemented in surface mining sites in Catalonia (NE of Spain), in areas where erosion processes are very active and erosion control measures will be taken.

The results of the research in these areas could be applied very soon. Once the surface mining ceases, Catalonia laws (Llei de Catalunya 12/1981 and Decret 343/1983) oblige the mine companies to replenish the pits and to reclaim the area in such a way that the mined land becomes integrated into the surrounding landscape, in view of the environmental quality conservation.

The first concern is the stabilization of slopes, to prevent catastrophic mass movements. Surface hydrology has been neglected and soil conservation techniques are not properly applied. As a result some areas reclaimed after surface mining in Catalonia show severe degradation after only 5–10 years due to soil erosion.

Land evaluation seems to offer a suitable framework to plan mining and reclamation processes. The erosion control measures will have to be handled within an erosion control system that depends on land evaluation for long-term land use. This could help to show reclamationists the importance of integrated planning of reclamation with mining.

2 Material and methods

2.1 General characteristics of the study area

The study area is located in the NE of Spain (fig.1) in the SE corner of the Figols-Vallcebre sincline basin, 5°30′E, 42°10′N and an altitude of about 1.000 m (fig.1). The coal is extracted by surface mining technology (fig.2). The mean annual air temperature is 11.5°C, July being the month with the maximum mean of 20.5°C. The soil temperature regime is mesic (S.S.S. 1975). The mean annual rainfall is about 950 mm, with an irregular distribution throughout the year and two maxima in March and August.

The rainfall factor, R. of the USLE (WISCHMEIER et al. 1965) computed from pluviograph records and mean rainfall intensity data is EI30 = 1800 MJ·mm/ha· year. The maximum rainfall intensity in 30 minutes, $I30 = 459 + 0.8074 \cdot Im$ ($r = 0.85$), and the mean intensity, Im, are related by this equation. Tab.1 shows the maximum rainfall daily and hourly for different return periods according to the Gumbel method.

The PET is 678 mm/year according to Thornthwaite and 816 mm/year, according to Papadakis and the soil moisture regime is udic (SSS 1975). The climate can be described as moist mediterranean (Emberger); moist, with no or

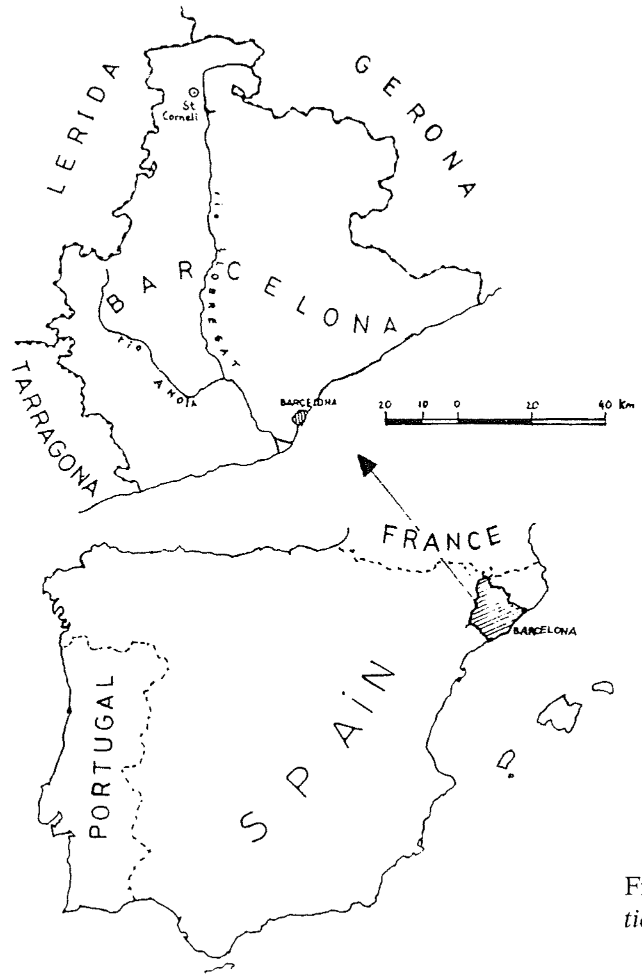

Fig. 1: *General localization of the studied area.*

Return period (years)	Maximum rainfall (mm) 24 h	1 h
2	84.6	21.0
5	127.2	31.8
10	155.5	38.9
15	171.4	42.8
20	182.5	45.6
25	192.0	—
30	198.1	—
40	209.0	52.0
50	217.5	54.4
100	243.8	60.9

Tab. 1: *Maximum rainfall in 24 h and 1 h, according to Gumbel method (Cercs, Spain).*

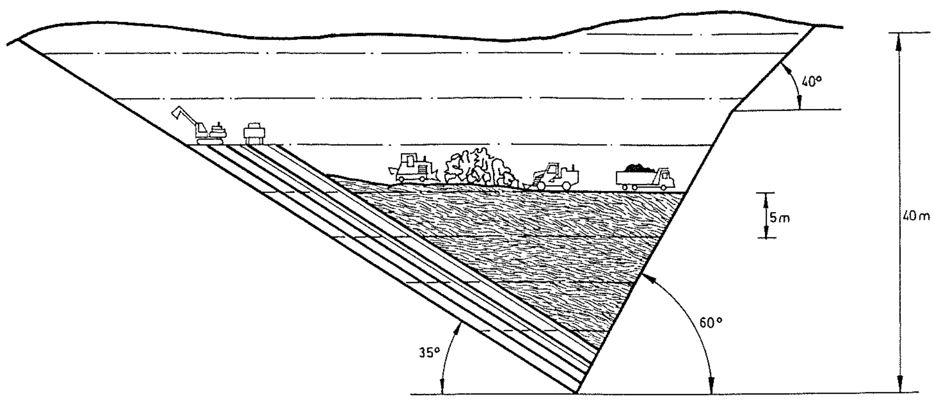

Fig. 2: *Type of opencast coal mine of the area. Final slopes are indicated.*

small water shortage in July, mesothermic and with a summer concentration of the thermic efficiency of 50.2% (Thornthwaite); moist temperate without dry season (Köppen).

The outcropping geological materials are calcilutites (marls) and lutitic limestones; the mined coal belongs to the St. Corneli formation. The soils in the unmined area around the dump are Typic and Lithic Udorthents, Lithic and Entic Hapludolls and Lithic Rendolls; in areas well above 1000 m the soil temperature regime becomes cryic and the soils are Cryorthents and Rendolls. Natural erosion processes are very active in the area. Between 800 and 1300 m in height the vegetation is mainly *Pinus sylvestris* and pastures; between 1600 and 2200 m the subalpine stage is found, with *Pinus uncinata*. The study area, before mining, was used for forestry, pastures and locally for arable farming.

2.2 Characteristics of the spoil bank

The spoil bank consists of calcilutitic mine overburden, with large limestone boulders and some coal; all of them can be found in the minesoil surface. Soil removed before the mining operation was mixed with overburden.

Minesoil spatial variability is very large because lithological and compactation changes exist: the surface materials are mainly composed of two kinds of calcilutites, with different behavior in respect to erosion phenomena. The compaction changes are due to the effect of machine traffic during dump construction.

The miscellaneous soils of the spoil bank are very stony and even bouldery in some places; they have low organic matter content, low physical (high bulk density, low water holding capacity) and chemical fertility (tab.2). The high calcium carbonate content reacts with the sulfate formed by oxidation of the pyrites and it results in the formation of gypsum (PORTA et al. 1983).

Revegetation was done with *Pinus sylvestris* and seeding grasses (*Dactylis glomerata* and *Agropyrum repens*) and legumes (*Medicago sativa* and *Trifolium*), but establishment was unsuccessful. Bare mineral soil is dominant, because calcilutitic overburden was not a good medium

Refer-ence	Depth cm	pH 1:2,5 H_2O	O.C. %	o.m. %	$CaCO_3$ equiv %	Size class USDA (%) Coarse sand	Fine sand	Silt	Clay	Texture USDA	Water content -33 KPa %	-1500 KPa %	P ppm	K ppm	dS/m a 25°C EC 1/5	EC_s
53	0–15	7.8	—	—	33.8	5.0	15.0	45.0	35.0	CL	—	—	5	—	1.59	—
54	0–15	7.9	—	—	25.3	2.0	9.0	73.0	16.0	SL	—	—	2	—	0.96	—
55	0–15	8.2	—	—	31.7	6.0	17.0	37.0	40.0	CL	—	—	2	—	0.51	—
57	0–15	7.8	—	—	30.4	3.0	13.0	67.0	17.0	SL	—	—	2	—	2.06	—
58	0–15	8.6	—	—	21.1	2.0	10.0	53.0	35.0	SCL	—	—	4	—	0.21	—
59	0–15	7.8	—	—	25.0	11.0	16.0	40.0	33.0	CL	—	—	3	—	1.82	2.83
60	0–15	8.7	—	—	23.7	2.0	30.0	36.0	32.0	CL	—	—	2	—	0.19	0.87
62	0–15	7.9	—	—	19.0	3.0	10.0	47.0	40.0	SCL	—	—	2	—	1.67	—
63	0–15	7.8	—	—	34.0	4.0	15.0	67.0	14.0	SL	—	—	21	—	1.82	—
64	0–15	7.76	—	—	24.4	4.0	17.0	65.0	14.0	SL	—	—	2	—	2.20	2.79
65	0–15	8.7	—	—	37.2	1.0	5.0	56.0	38.0	SCL	—	—	2	—	0.20	—
66	0–15	7.3	—	—	31.7	—	—	—	—			—	3	—	0.26	—
67	0–15	8.1	—	—	29.0	2.0	16.0	62.0	20.0	SL	—	—	20	—	0.53	—
2077	Superf	8.2	0.5	0.9	39.5	—	—	—	—	—	19.8	9.0	8	140	0.24	—
2078	Superf	8.1	3.9	6.7	33.9	—	—	—	—	—	24.0	12.9	6	190	0.75	—
2079	Superf	8.8	0.7	1.2	35.9	—	—	—	—	—	21.2	9.7	15	253	0.31	—
2080	Superf	8.9	—	—	25.6	—	—	—	—	—		—	5	184	0.25	—
2081	Superf	8.8	—	—	95.6	—	—	—	—	—	27.7	14.6	3	82	0.13	—

SL = silt loam; SCL = silty clay loam; CL = clay loam

Tab. 2: *Chemical data from top mine soil.*

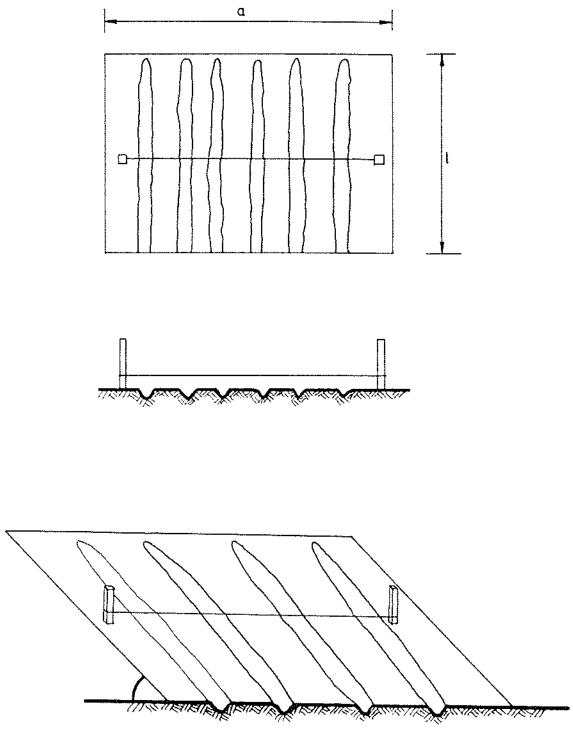

Fig. 3: *Rill erosion: Procedure to control and measure the soil losses along transects marked with iron sticks.*
If x is the intercepted vertical area by rills, the volume of eroded material per surface A is $V = (x \cdot l)/(a \cdot l)$

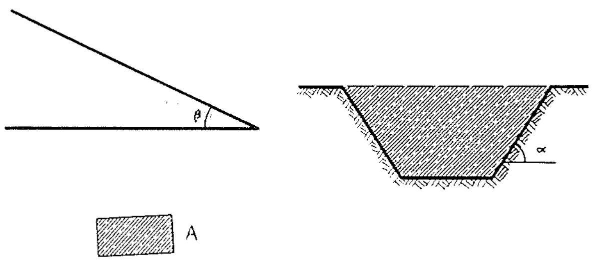

Fig. 4: *Gully erosion: Morphometric parameters of a gully.*
α = side slope
A = mean intercepted area
β = mean base slope (talweg slope)

for growth and topsoil material removed before mining operation had been mixed with mine overburden and could not be replaced.

2.3 Methodology used to study the erosion processes

The erosion processes were studied in the field on a spoil bank built in 1980, where berms had been constructed as the only conservation measures. Surveys done before and after mining operations were

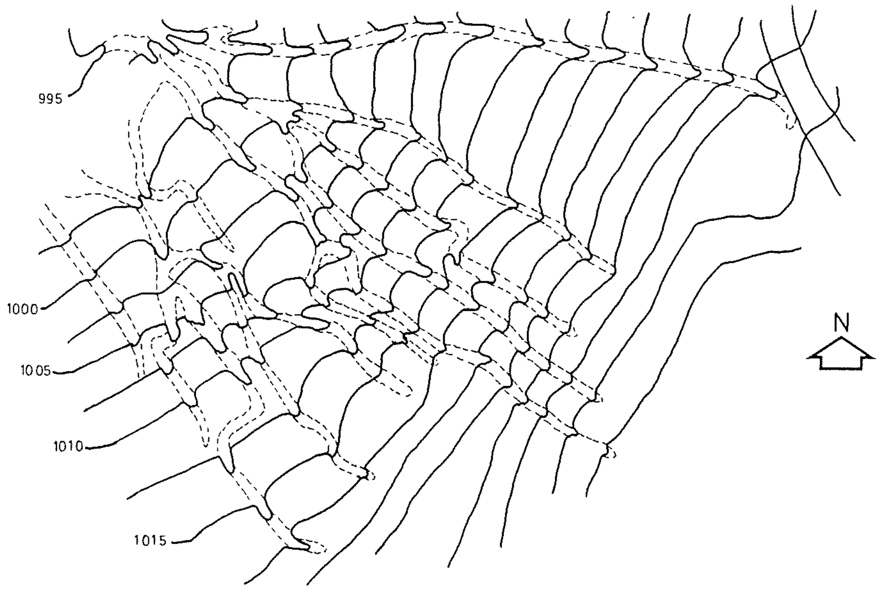

Fig. 5: *Map of the "A" gully network installed on the minesoil (original scale 1:500). Scale ≃ 1:2000.*

available (Carbones de Berga SA, 1977; BRAVO 1987), and provide knowledge of the initial characteristics of the mine reclaimed surface. In that surface the erosion processes have acted freely and these areas can be studied to test the efficiency of the conservation measures in temperate, moist climates.

The purpose of the methodology used was to identify and describe the erosion processes. The gully network has been mapped at the scale 1:500 (BRAVO 1987), and is schematically presented in fig.5 and 6. The shape and volume of material removed by the gullies and rills has been described and measured along its course, and iron rods have been used to measure the changes that ocurred in the course of time (fig.3, 4). The order of the different gullies and rills of the drainage system has been studied following HEEDE (1978) and HORTON (1945). The geometry of the berms was also measured. Studies are now in progress with measurements of soil loss from 1 m^2 parcels, with Gerlach boxes and with a Parshall Flume in a subcatchment.

From a theoretical point of view the erosion processes are quantified according to MIRSTSKHULAVA (1970, cited by ZACHAR 1982) in the case of splash erosion and according to USLE in the cases of sheet and rill erosion (WISCHMEIER & SMITH 1962, SINGER 1982, ROSS et al. 1980, WISCHMEIER 1978). The quantitative and qualitative results belong to a first year's work; two areas of the dump with different morphology and with different conservation measures are compared.

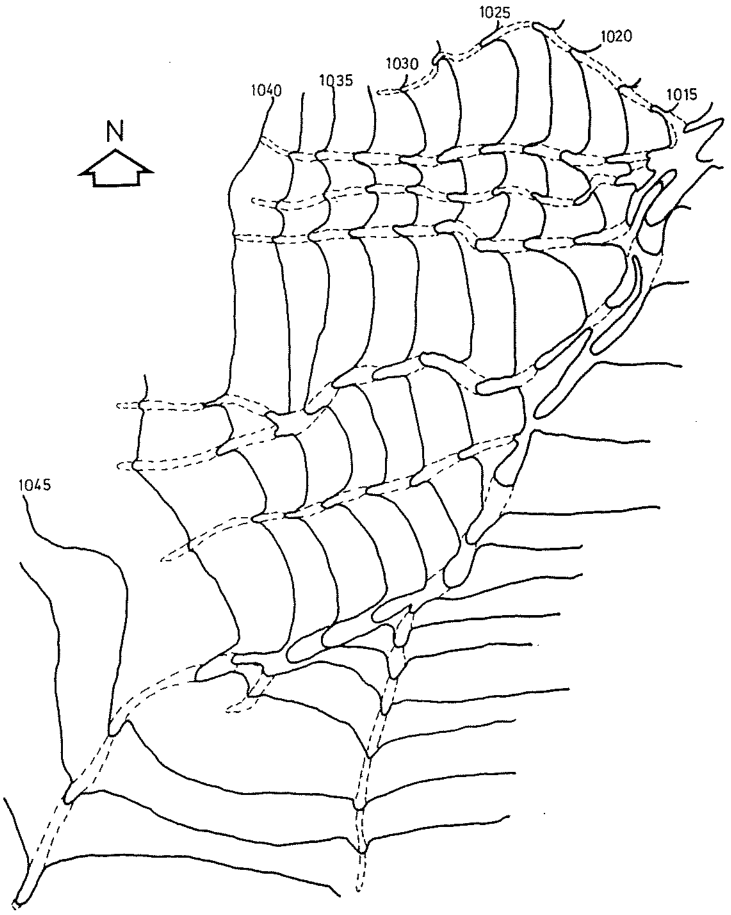

Fig. 6: *Map of the "B" gully network installed on the minesoil (original scale 1:500). Scale ≃ 1:2000*

2.4 Land evaluation methodology

A physical land evaluation was made following the FAO framework (FAO 1976), with the two stage approach, but only the first was developed. The land use considered relevant for the dump reclamation are pasture and forest.

The basic land qualities for the proposed land uses are: risk of erosion and possibility of establishment of the vegetation controlled in turn by conditions for germination, availability of water, availability of nutrients and/or lack of toxicity.

The main diagnostic criterium which has been used is the total amount of eroded material from the spoil bank to the La Baells dam.

Points	Hydraulic conductivity m/day	SINEDARES evaluation	Infiltration rate mm/h	SINEDARES evaluation
1	0.270	Medium	1.3	Very low
2	0.002	Very low	2.4	Very low
3	0.012	Low	—	—
4	0.017	Low	11.5	Medium to high
5	0.062	Low	0.001	Very low

Tab. 3: *Hydraulic conductivity and infiltration rate of miscelaneous soils on surface mined area.*

3 Results

3.1 Erosion processes: Description and quantification

3.1.1 Splash erosion

Splash erosion effects are more evident near local watersheds. But it occurs in all parts of the area. Pedestals due to the presence of gravels and plants are frequent on the top parts of the reclaimed area. After MIRSTSKHULAVA (1970) model, the quantity of material affected by splash erosion may be estimated at 2.500 Mg/ha/year in this minesoil.

The action of raindrops on soil particle is very intense and a surface crust may be observed after rain. Infiltration capacity which is already low due to the massive structure of the materials is decreasing because of this effect (tab.3) and surface runoff is thus considerably increased.

3.1.2 Sheet erosion

Hortonian flux has been observed on these surface mining sites. Water flow is concentrated in rills at a short distance from local watersheds. The material is not saturated by water and infiltration rate of calcilutites is very low.

The areas affected by sheet erosion are those that have a low slope, where water cannot be concentrated; i.e. the dump top and interrills areas.

3.1.3 Rill erosion

According to measures on surface mining, rill erosion is active at 1 to 1.5 m from local watersheds.

In the period from March to July 1987, with rains of maximal intensity, measurements along transects marked with iron rods have been done (fig.3). Soil losses by rill erosion was accounted at 200 Mg/ha/year (tab.4).

Criteria of BOON & SAVAT (1980) were tested to evaluate rill erosion susceptibility. Rains with intensities higher than 40 mm/h promote rill formation if the slope length is greater than 20 m.

Causative factors of rill erosion observed in this area are the irregularity and compactness of mine soil, the mechanical effects of machinery during overburden replacement, the changes of surface material properties, the presence of vegetation and surface stoniness.

3.1.4 Gully erosion

Gully systems are characterized by continuous gullies, without head scarps.

Processes of tunnel erosion have been observed on gully slopes in lowlying ar-

Site	Slope	Vegetation cover	Intercepted vertical area by rills (m^2/m)		Increment 22/3–21/7			Eroded material			Ratio of eroded material in the measured period annual mean
	%	%	22/3	21/7	m^2/m	%	m^3/ha	m^3/ha total	m^3/ha annual	Mg/ha annual	%
1	34	30	0.199	0.219	0.020	10.0	211	2313	289	507	73
2	25	40	0.059	0.063	0.004	7.5	41	649	81	138	51
3	23	25	0.053	0.067	0.014	27.1	144	687	86	146	140
4	43	20	0.214	0.216	0.002	1.1	22	2351	294	500	7
5	32	40	0.035	0.053	0.018	51.0	189	556	70	119	270
6	32	0	0.040	0.070	0.030	75.3	315	735	92	156	350

Tab. 4: *Characteristics and results of the rilled slopes: Measures along transects marked with iron sticks.*

Gully hierarchy		Number of gullies	Bifuraction indexes
Network A	1	9	
	2	3	3.0
	3	2	1.5
		Mean	2.25
Network B	1	15	
	2	3	5.0
	3	1	3.0
	4	1	1.0
		Mean	3.0
Total	1	24	
	2	6	4.0
	3	3	2.0
	4	1	3.0
		Mean	3.0

Tab. 5: *Characteristics of morphology of gullies: Bifurcation indexes of gully network.*

Gully Order		Criteria: Mean Base Slope %	Mean Intercepted Area m^2	Side Slope %	Roughness*	Vegetation **	Development Degree
C5	3	21.5	1.6	207	0	2	Very Low
P19	4	12.0	8.1	155	2	1	Very Low
Z	1	18.2	1.7	149	3	1	Low
AB1	2	13.7	5.6	117	2	2	Low to Medium
AC	1	19.2	3.3	122	1	2	Low

Criteria:
* 0 very high, 1 high, 2 medium, 3 low, 4 very low, 5 nihil
**0 nihil, 1 very low, 2 low, 3 medium, 4 high, 5 very high

Tab. 6: *Classification of gullies after criteria of HEEDE (1978): Development degree.*

Gully	Length (m)	20/8/86 m^3	3/1/87 m^3	Volume increment m^3	29/7/87 m^3	Volume increment m^3	Material losses (m^3/m) 20/8–3/1	3/1–29/7	total
C5	163.5	254.5	296.0	41.5	372.3	76.3	0.25	0.47	0.72
P19	525.4	2403.9	2496.0	92.1	2826.9	330.9	0.18	0.63	0.81
Z	97.2	104.1	126.3	22.2	170.7	44.4	0.23	0.46	0.69
AB1	173.6	677.7	827.4	149.7	960.2	132.8	0.86	0.77	1.63
AC	129.5	337.2	380.1	42.9	410.8	30.6	0.33	0.24	0.57
Total	1089.2	3777.4	4125.8	348.4	4740.9	615.1	0.32	0.56	0.89

Tab. 7: *Volume of removed material by gully erosion.*

eas.

A gully system was surveyed (fig.5) and two models of development were identifed, due to differences in erosion control measures. In both cases gullies cut berms perpendicularly.

According to HORTON's ordination system mean bifurcation indices (tab.5) are 2.2 (A Area) and 3.0 (B Area). These values reflect the previous drainage condition of the area, B area being more ramified because a drainage system existed before mining.

The degree of maturity of the gully network (fig.5) may be assessed after HEEDE (1978) and it is summarized in tab.6. In all cases the gully network shows a low or very low degree of maturity.

The mean loss of material by gully erosion during the 8 years of existence of the spoil bank is 234 Mg/ha/year. It has been calculated through the extrapolation of the gully measurements (tab.7) to the total length of the gully network (fig.7).

3.1.5 Predicting soil losses on the minesoil surface

The universal soil loss equation (USLE) developed by WISCHMEIER et al. (1959, 1965, 1978) and associates, ROSS (1980), SINGER (1982), is used for predicting soil loss due to water erosion on minesoil surface, and for determining the effectiveness of various erosion control measures.

The erodibility of the soil, K factor, was calculated according to WISCHMEIER et al. (1978) in SI units using the monograph of JOHNSON et al. (1971). It was applied to the average characteristics of the two kinds of calcilutites which could be found on the surface. Although their behaviour seems different, their distribution over the area is highly irregular and the use of average values is the most suitable to evaluate the mean soil losses of all the spoil bank.

The data used for the calculation of the average value of K is in tab.8.

The topographic factor, LS factor, is calculated for the whole spoil bank which was previously divided into areas with slope less than 18% and slope more than 18%. In the area with slope <18% the formula of WISCHMEIER (1978) was used; in the other one, the modification of SINGER (1982) was used.

To calculate the C factor the method of ROSS et al. (1980) is followed.

To estimate the P factor the value 1 is assumed for most of the area. For the area where berms are functional P = 0.73

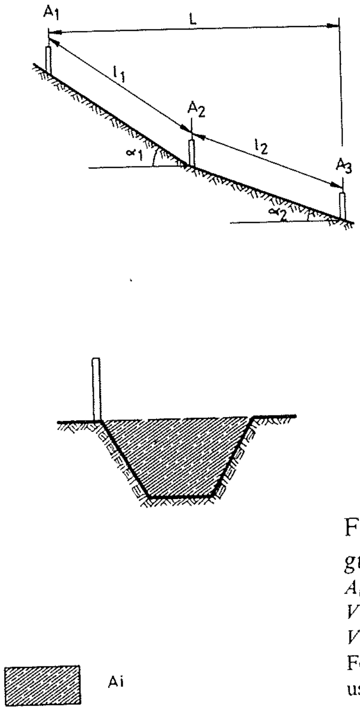

Fig. 7: *Measurements of material removed by gully erosion: Parameters used.*
A_i = intercepted area
V = total volume of removed material
$V = \frac{A1+A2}{2} \cdot \sin\alpha_1 \cdot l_1 + \frac{A2+A3}{2} \cdot \sin\alpha_2 \cdot l_2$
For extrapolation to all the gully network, the V/L value is used.

Organic matter and oxidable coal content	2%
Structure	massive
Permeability (Porchet method)	1.5 cm/h
Texture	Silty loam
Fine sand + silt	80%
Coarse sand (0.1 to 2 mm)	15%
K	0.074 SI units

Tab. 8: *Average data used to calculate soil erodibility for the spoil bank materials.*

Rainfall erosivity (R)	1793.6
Soil erodibility (K)	0.097
Slope and length of slope (LS)	8.28
Cropping factor (C)	0.1516
Conservation measures (P)	0.73
SOIL LOSS (T)	159 Mg/ha/year

Tab. 9: *Factors of USLE and total soil loss for the Sant Corneli dump.*

is taken.

The soil loss for the entire dump is computed at 159 Mg/ha/year (tab.9).

4 Discussion

4.1 Land evaluation and mining

The reclamation of mined land has to have an aim. The best way to clarify it is to define that aim in terms of land use types (LUT). Each land use type has its own land use requirements and knowledge of them helps in the planning of the reclamation (fig. 8).

Sustained land use, without degradation in the longterm, is one of the principles of land evaluation (FAO 1976). In spoil banks the degradation of the environment is mainly through erosion.

A spoil bank can be treated as a land evaluation unit (LEU). Adjustments in the planned land use can be used to fit the land suitability criteria.

The land use types which can be considered in this area for mined land after reclamation are: pasture and forestry. In the reclamation, which has taken place in the study area, the land use requirements have not been considered by the reclamationist. Two main land qualities should be considered (tab.10): possibilities to establish vegetation and risk of erosion.

The selection of plants well adapted to the climate and resistant to drought, and the prevention of grazing in the first years, are examples of adjustments between land quality and land use requirements.

But mined land has to have a certain level of quality to ensure success of the land reclamation. This level has to be reached in the reclamation process and in the study area this can be obtained by: having topsoil in all the spoil bank and controlling the surface hydrology through ditches and berms.

4.2 Amount of soil losses: Use of USLE in mined land to estimate erosion hazards

Soil losses measured by th USLE are mainly those of sheet and rill erosion, which are the kinds of erosion expected in arable lands. The importance of sheet erosion in the studied spoil bank, measured with Gerlach boxes, has a much less importance compared with erosion due to concentrated runoff (POCH et al. 1988). Therefore the only values that are to be compared are the measured rill erosion along slopes (mean value: 200 Mg/ha/y) and the predicted soil loss by the USLE (159 Mg/ha/y).

The comparison has to asume that the USLE gives an estimation of mean erosion of many years, and the rill erosion value was obtained after only one year of measurements, while the rainfall events which are more effective in this kind of erosion are high intensity storms, being them very variable.

The fact that both values come from different kinds of erosion has also to be taken into consideration. In spite of these observations, the estimated value of the USLE has the same order of magnitude of the measured soil losses, and may be useful to evaluate risk of erosion in mining area through the study of its different factors.

The K factor could be diminished when soil material is removed before the mining operation and replaced on the graded overburden and then topsoil exists. The K is about 0.02 for the natural soils present around the spoil bank, about 4 times smaller than the mean val-

Land qualities	Land characteristics
Possibilities to establish vegetation	Water availability: texture soil depth rainfall slope Lack of toxicities: sulphur content salts acidity Availability of nutrients: organic matter P-Olsen K
Risk of erosion	Rainfall characteristics Slope length and steepness Infiltration capacity Run-off, run-on Water holding capacity Existing conservation measures Stoniness

Tab. 10: *Main land qualities and land characteristics in of mined land in NE Spain.*

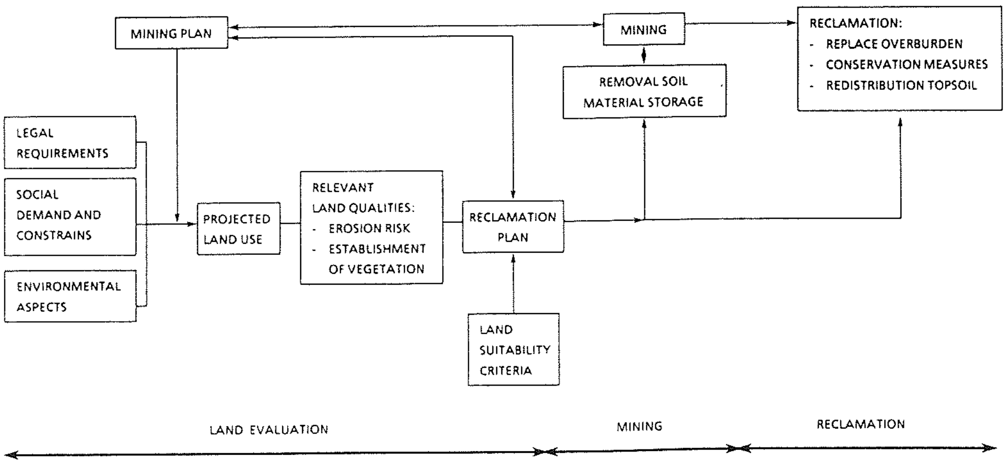

Fig. 8: *Land evaluation and soil conservation in Integrated surface mining and reclamation planning.*

ues for the top of the spoil bank.

The LS factor could be made smaller by modifications of the slope length by the construction of terraces to drain out the runoff. Berm construction modifies the LS factor but their effects are better taken into account by the P factor. The slope and the slope length, are both affected by the number and disposition of the berms, and LS and P factors are related to them. Prior to the final design of the spoil bank calculations of the attainable P and T values for a given LS value can be made. At that stage corrections to the design of the spoil bank can be made to reach acceptable T values.

In the study area the mean LS factor is 8.3. Reductions up to 50% on that value could be achieved with another shape of the spoil bank (A Area, fig.5 and 6), at similar costs of construction of overburden spoil.

The C factor is dependent on the soil cover. The establishment of a vegetation cover is very difficult when only minesoil exists because the physical and chemical fertility are low, and the mechanical properties of the first centimeters are unfavorable to the establishment of sedlings due to the lack of structure, and a high tendency to crust formation. In addition the studied minesoil has many stones and boulders, which prevent a good sowing of the seeds.

Surface stoniness has a complex effect on soil erosion. It prevents direct impact of raindrops on the soil surface and increases the surface storage capacity of the soil. But it also helps in the formation of rills when infiltration capacity and surface storage are exceeded, thus acting as concentrators of sheet flow.

At present vegetation gives good cover in a few spots only; the C factor is about 0.152 (tab.9). If topsoil is present herbaceous vegetation cover can be similar, after 2–3 years, to the surrounding natural areas and the C factor may be about 0.010.

Conservation practices can be used over all the spoil bank, and the P factor can be 0.18. At present it can be estimated to be 1, because of failure of the berms to control soil erosion.

The USLE can be used as an estimator of soil losses in mined land only when measures are taken to ensure gully erosion does not occur. The studied spoil bank is very prone to gully erosion, which produce a soil losses much larger than other types of erosion.

4.3 Rill and gully formation and growing

Rill formation has been observed under many different situations, being the slopes much higher than threshold values reported by DE PLOEY (1983) for rill formation. These have been observed with ground cover from 0% to 40% and various degrees of stoniness. This ubiquity of the rill phenomena in the spoil bank may be attributed to the high erodibility of the overburden, made mainly of calcareous silty material. The high erodibility of this kind of materials has been attributed to poor structural conditions (IMESON et al. 1985) leading to crusting and slaking which promote high runoff. These facts have been widely observed in the studied spoil bank, where the first few millimeter of soil becomes quickly saturated when rains and sealing occurs and also a crust forms very fast when it dries.

Material lost by gullies is larger than is eroded by other forms of erosion; then any conservation measure in the minespoil has to take into account gully formation. The factors controlling gully formation are different in areas A and B (fig.5 and 6). In area A gully growth is promoted by breakdown of berms, but also because piping occurs; rill broadening plays a minor role. Area B receives water from adjacent upstream areas and gully formation is mainly from rills.

The growth of gullies is very active in all the area due to very low degree of development in the sense defined by HEEDE (tab.5 and 6). Soil losses produced by gullies are very high (234 Mg/ha/y measured during 1986 and 1987), but more important than the total amount is the amount per unit of length (0.89 m^3/m/y, tab.7).

The growth of gullies is irrespective of the materials, being controlled by external factors: water inflow and base level. Gullies develop in slopes well below 20%.

4.4 Conservation measures and mining

Conservation measures were used in the studied spoil bank with a poor understanding of surface hydrological processes. Only calculations were made for stability and mass movement prevention. Berms were constructed with a very small slope. Waterways to remove possible excesses of water were not considered; therefore the initial objective of the berms is assumed to be removal of excess water through infiltration.

After a short time berms revealed unable to remove runoff. Also inflow of water from badly designed trenches and surrounding areas created erosion. The failure of the present conservation measures should be attributed to improper design under conditions of heavy rainfall (tab.1), in soils with low water acceptance (tab.3). Also revegetation was very slow, because topsoil was removed increasing thus runoff.

The conservation measures to be adopted in spoil banks should aim to reach a full control of erosion. Spoil banks are places where erosion develops quickly and gullies start very soon. To avoid this, drainage terraces with protected waterways seems to be suitable measures for areas like the one of the study. In the case of waterways with high slopes it will be necessary to build up small dams in order to diminish erosive power of the streams.

5 Conclusion

1. The interest in studying erosion processes in restored surface-mined areas it is not due to the extension of these areas, but to the fact that the reclamation of these areas allows the implementation and testing of erosion control practices. In these areas land morphology may be previously designed and initial conditions may be known.

   In the study area, erosion processes have been very active in a period of less than ten years. For that reason this reclaimed area may be of great interest for educational purposes in soil erosion.

2. Land evaluation in a reclaimed mined land shows whether the requirements of a previously selected land use type have been achieved or not. Land use must be permanent without degrading the soil.

   These aspects were not taken into account in the study area. For this reason, present land evaluation shows the inadequacy of land use requirements in relation to land qualities, and that land degradation by erosion is very active.

3. The study area, which had been reclaimed ten years ago, is degraded due to the lack of a proper control of erosion processes. In it splash, sheet, rill and gully erosion processes have been identified and studied.

   The conservation berms seem unsuitable for the erosion control in the study area. Their use has caused the development of a gully network, because the infiltration capacity of the material is low, and protected waterways were not constructed. Such effects could be avoided if soil conservation criteria were used when the berms were build.

4. Computation with the USLE have been made, and the values found are about 20% less than the experimentally measured rill and sheet erosion in the field.

5. The level of knowledge available in soil conservation is greater than that usually employed in the reclamation of mined land in Catalonia until a few years ago.

6. The key factors in the development of the gully network are: lack of interception ditches for the outcoming runoff, failure to take into consideration the previous drainage network in the reclamation design; and the inadequacy of the conservation berms in relation to soil and climate conditions.

   There is need to link reclamation and erosion control measures. A good rehabilitation scheme from the beginning would have been more effective and cheaper, because the present system needs to be corrected.

Acknowledgement

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References

BOON, W. & SAVAT, J. (1981): A Nomograph for the Prediction of Rill Erosion. In: Morgan, R.P.C. (Ed.), Soil Conservation: Problems and Prospects. John Wiley and Sons, 303–319.

BOX, J.E. Jr. & MEYER, L.D. (1984): Adjustment of the Universal Soil Loss Equation for Cropland Soils Containing Coarse Fragments. SSSA Special Publication n. **13**, 83–90.

BRAVO, A. (1987): Estudio topográfico de una area rehabilitada de mineria a cielo abierto en Sant Corneli (Barcelona). EUETA. Lleida.

DE PLOEY, J. (1983): Runoff and rill generation on sandy and loamy topsoil. Zeitschrift für Geomorphologie, Suppl. Bd. **46**, 15–23.

FAO (1976): A Framework for land evaluation. Rome.

FOSTER, G.R., McCOOL, D.K., RENARD, K.G. & MOLDENHAUER, W.C. (1981): Conversion of the universal soil loss equation to SI metric units. J. of Soil and Water Conservation, 355–359.

HEEDE, B.H. (1982): Gully Control: Determining Treatment Priorities for Gullies in a Network. Environmental Management **6,5**, 441–451.

HEEDE, B.H. (1978): Designing gully control systems for eroding watersheds. Environmental Management **2,6**, 509–522.

IMESON, A.C. & VERSTRATEN, J.M. (1985): The erodibility of highly calcareous soil material from Southern Spain. CATENA **12**, 291–306.

ISRAELSEN. C.E. & ISRAELSEN, E.K. (1982): Controlling Erosion on Surface Mining Sites. Symposium on Surface Mining Hydrology, Sedimentology and Rclamation, Univ. of Kentucky, 329–337.

MORGAN, R.P.C. (1986): Soil Erosion and Conservation. Longman Sci. & Technical. Essex, 298 pp.

POCH, R.Ma, PORTA, J. & BOIXADERA, J. (1988): Estudi dels processos superficials i de revegetació en zones afectades per mineria a cel obert al Berguedà (Barcelona). Memoria CIRIT.

PORTA, J., SERRA, E., ARAN, M. & MASALLES, R.M. (1983): Projecte de rehabilitació de sòls a l'explotació a cel obert de Coll de Pradell. Carbones de Berga SA.

ROSS, J.J., De TAR, W.R. & CUNNINGHAM, R.L. (1980): Estimating the C factor in the Universal Soil Loss Equation for Landscape Slopes: A Field Rating System. J. of Soil and Water Conservation **35(1)**, 42–44.

SAVAT, J. & DE PLOEY, J. (1982): Sheetwash and rill development by surface flow. In: Bryan et al.: Badland geomorphology and piping. Norwich.

SIDERIUS, W. (ed.) (1986): Land Evaluation for Land-Use Planing and Conservation in Sloping Areas. ILRI Publication n. **40**. Wageningen, The Netherlands, 334 pp.

SINGER, M.J. (1982): Slope angle-interrill soil loss relationships for slopes up to 50%. Soil Science Society of America Journal, **46(6)**, 1270–1273.

STOCKING, M.A. (1977): Rainfall Energy in Erosion; Some Problems and Applications. Research Discussion Paper n. **13**. Dep. of Geography, U. of Edinburgh. 29 pp.

WISCHMEIER, W.H. & SMITH, D.D. (1965): Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains. Agric. Handbook **282**, 47 pp.

WISCHMEIER, W.H. & SMITH, D.D. (1978): Predicting Rainfall-Erosion Losses — A Guide to Conservation Planning. USDA Agric. Handbook n. **537**. Washington DC, 58 pp.

ZACHAR, D. (1982): Soil Erosion. Elsevier, Amsterdam, 547 pp.

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P6 - Els sòls i les transformacions de la zona de coll de Pradell afectades per la mineria a cel obert. Miquel Aran

1.- ANTECEDENTS

A principis dels anys vuitanta del passat segle es va produir una forta expansió de la mineria a cel obert que també va afectar a la comarca del Berguedà. Les raons d'aquest impuls eren, en el cas de les explotacions de carbó, la seva revalorització com a conseqüència de les diverses crisis i alces en el preu del petroli que s'havien produït en els anys setanta i vuitanta. Aquesta circumstància del mercat internacional, juntament amb els menors costos d'explotació a cel obert respecte la subterrània, varen donar un impuls a aquest model d'explotació minera. Les zones amb tradició minera com el Berguedà i Astúries varen impulsar aquest model de productiu que va suposar un activació de les economies locals.

Aquesta opció, no obstant, presentava un fort impacte ambiental i va despertar oposicions potents en diversos sectors. Amb el Decret 343/1983, el D.P.T.O.P (Departament de Política Territorial i Obres Públiques) de la Generalitat de Catalunya, es va requerir a les empreses mineres la presentació d projectes de restauració de les àrees a explotar. En aquells anys els projectes d'estudi d'impacte ambiental eren escassos i també els projectes de restauració ambiental. La zona de Coll de Pradell va ser una de les primeres objecte d'estudi ja que estava inclosa en el pla d'explotació minera de l'empresa, l'any 1983.

En aquesta context es va firmar un conveni de col·laboració amb el Departament de Sòls de l'Escola d'Enginyeria agrària de Lleida (UPC) que va permetre desplegar una sèrie d'estudis a la zona.

2.- DESCRIPCIÓ SINTÈTICA DE LA ZONA

La zona es localitza a la comarca del Berguedà. En concret entre el nuclis de Vallcebre i Saldes (Figura 2.1).

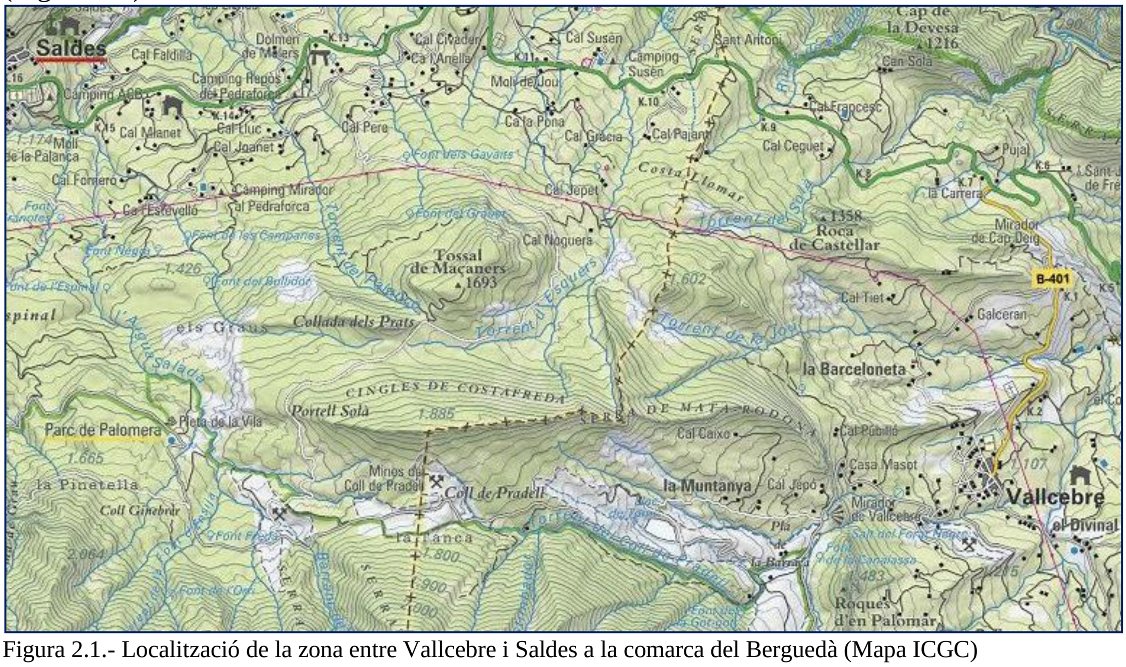

Figura 2.1.- Localització de la zona entre Vallcebre i Saldes a la comarca del Berguedà (Mapa ICGC)

A les figures 2.2, 2.3 i 2.4 s'observen les fotos aèries que reflecteixen l'evolució de la coberta vegetal del sòl a la zona del Coll de Pradell.

Figura 2.2.- Fotograma aeri de la zona l’any 1956 (Foto del vol americà, ICGC)

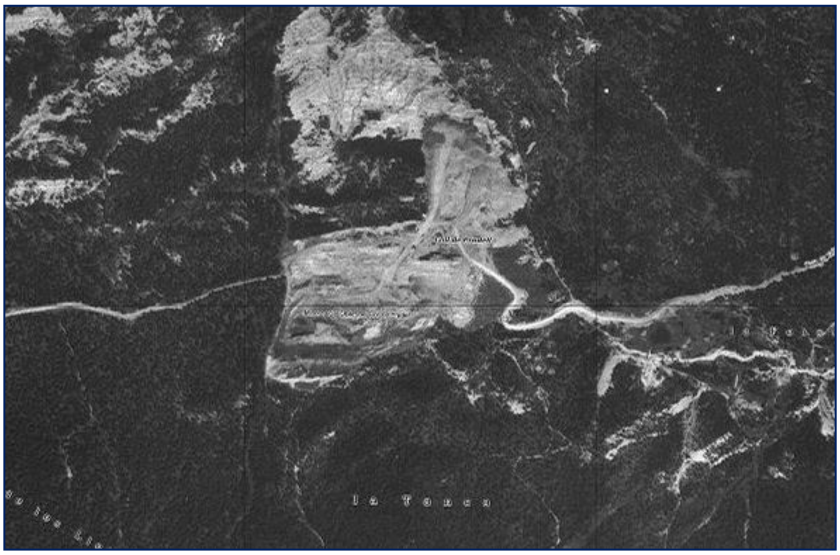

Figura 2.3.- Fotograma de la zona de Coll de Pradell en una foto aèria de 1983 (ICGC)

Figura 2.4.- Fotograma d ela zona de Coll de Pradell en una foto aèria recent (ICGC)

Evolució de la coberta vegetal de la zona

Els fotogrames aeris indiquen una evolució de la coberta vegetal important en la segona meitat del segle XX. S'observa un augment de la densitat del bosc i la presència de zones ja fortament erosionades abans de l'inici de l'explotació minera. Les petjades de l'explotació minera, ara paralitzada, són remarcables.

3.- NOTES AL MEDI FÍSIC DE LA ZONA

L'estudi del medi físic de la zona és un pas imprescindible en el diagnòstic de l'estat i valors de la situació actual i les perspectives d'accions de recuperació de l'entorn després de l'explotació. En el marc del projecte de restauració es van estudiar el clima, sòls, vegetació i geologia de la zona.
El factor erosió és rellevant. La zona presenta un alt potencial d'erosió, en base a la pròpia fisiografia i la intensitat de les pluges en aquesta zona de vessant mediterrània. Es va estimar una intensitat de 51 mm/hora en un període retorn de 10 anys. Per pluges en 24 hores i un període retorn de 10 anys es varen considerar 120 l/24h, amb les dades de l'estudi realitzat en 1983

Propietats dels sòls a la zona de Coll de Pradell (abans de l'explotació)

Es varen efectuar diversos perfils de caracterització del medi edàfic abans de l'explotació. (Veure descripció perfil).
Els sòls presentaven les següents característiques.
- Desenvolupats sobre calcàries i ocasionalment sobre aflorament de lutites carboníferes
- Perfil A – C o A – AC – C o amb possible presència d'horitzó O sota bosc
- En fort pendent, poc profunds en general
- Coberta forestal amb enriquiment superficial important en matèria orgànica.
- Alt risc d'erosió

A efectes de taxonomia els sòls es varen classificar coma *Typic cryorthents* (U.S.S., 1975). Sòls desenvolupats sobre calcàries, en vessants de fort pendent, en un règim de temperatures amb una mitjana entre 0ºC i 8ºC, més 1000 mm de pluviometria anual (observatori de Saldes) i vegetació forestal.
En relació a propietats químiques i físiques es destaca pH superior a 7, nivells alts de ,matèria orgànica, baixa conductivitat elèctrica i alts nivells de carbonat càlcic (amb variabilitat local); les classes texturals van de mitjanes a moderadament fines.
El material que forma els sòls autòctons presentava característiques diferenciades dels materials utilitzats normalment fins llavors en el procés de restauració.
Els resultats analítics (any 1983) dels sòls originals i dels materials de rebuig es presenten a les taules 3.1. i 3.2

Taula 3.1.- Resultats analítics de les mostres dels horitzons del perfils original

Horitz.	Prof,	pH	CE dS/m	MO %	Carb.%	Arena %	Llim %	Argila %	Classe textural
A	0-15/30	6,6 - 8,5	< 0,2	5-7	0-30	12-53	6-50	25-41	de franca a argilosa
C	15/30-	8,2 – 8,7	< 0,2	0,5-2,5	1 - 47	-	-	-	-

Horitz.	P ppm	K ppm
A	6-20	90-180
C	3-15	80-180

Taula 3.2.- Resultats analítics de les mostres dels materials de rebuig

pH	CE dS/m	MO %	Carb.%	P ppm	K ppm
8,1-8,9	0,13-0,75	0,5-0,7	25-95	3-14	80-250

4.- PROJECTE DE RESTAURACIÓ

L' estudi d'impacte ambiental i el projecte de restauració de paisatge incloïa, en síntesi:

- estudi de diverses alternatives de restauració
- es va proposar una alternativa de preservació i manteniment dels horitzons A (15 cm)
- rebliment de la fossa i disseny dels talussos per garantir la seva estabilitat
- disseny de les terrasses de desguàs
- selecció d'espècies herbàcies per la revegetació, dosis de sembra..
- incorporació d'un procés d'hidrosembra per assegurar la preservació del sòl en estadis inicials
- proposta de manteniment de les zones restaurades

Miquel Aran
Eng. Agrònom MSc

Annex 1: Fitxa de descripció del perfil segons SINEDARES 1983

PEDION: C-1-SAL, Espa@a, B.

LOCALIZACION: Saldes, Paraje : Coll de Pradell.

Cartografía topográfica: 1:50.000, hoja 254, Lat. 39º84'50" , Long. 46º73'00" , Z= 1740.

Teledetección: Aérea blanco y negro, S.C.D., 1:15.000, , Jun-82.

Descrito por: Aran MG, C.E.ETSIA Lleida, 06-Sep-83. Restauración del paisaje; promotor D.P.T.O.P.; BTR SINEDARES-Catalunya.

GEOMORFOLOGIA:

Geomorfología: Escala de observación, varios hectómetros; forma del relieve, ladera cóncava; dinámica de la forma erosión, moderada; longitud de la pendiente 300 m ; simple; perfil situado en un área rectilínea, en la mitad inferior de la forma; con una pendiente general del 30% , local del 20% y orientación N.

Pedregosidad superficial y afloramientos rocosos: Moderadamente pedregoso, fragmentos de caliza en un 1% .

Sin afloramientos rocosos.

Material original: Caliza, en un 3% , duro, poco alterados. VEGETACION: Bosque aciculifolio, con un recubrimiento del 4% , suelo desnudo; pinar de alta monta@a peninsular (con P. uncinata).

USOS DEL TERRITORIO: Abandonado, de 25 a 60 a@os, con una producción estimada según diversas fuentes, nivel de fiabilidad media, m3/Ha y a@o. Uso agrícola limitado por escaso espesor y por afloramientos rocosos.

TECNOLOGIA DE SUELOS: Monte alto no descrito.

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00 - /0 cm 4, O1(SINEDARES) , ligeramente húmedo. Manchas , no hay. Elementos gruesos muy pocos. No coherente, friable, débil. Materia orgánica muy abundante, restos y residuos, acículas, débilmente descompuesta. Actividad de la fauna, galerías. Sistema radicular normal; raíces de diámetro menor de 10 mm , muy abundantes, finas y muy finas , verticales, de distribución regular, vivas, raíces de diámetro mayor de 10 mm no hay. Porosidad global muy alta; poros finos, abundantes, discontínuos, verticales, interestructurales, intersticiales. Pruebas de campo, en el conjunto del horizonte, con HCl (11%) respuesta nula. Límite abrupto, plano.

0 / 4 - /15 cm 23A1, húmedo; color de la matriz, en húmedo 5YR 3/4 , pardo rojizo oscuro. En estado de oxidación. Elementos gruesos , pocos; caliza, heterométricos, gravilla y grava gruesa, subangular-tabulares, sin orientación definida, distribución irregular, poco alterados. Franco grueso. Poco compacto, ligeramente adherente, no plástico, friable, duro. Materia orgánica abundante, no directamente observable, bien descompuesta , bien incorporada. Actividad de la fauna, galerías. Raíces de diámetro menor de 10 mm frecuentes, de muy finas a gruesas, horizontales, de distribución irregular, vivas, raíces de diámetro mayor de 10 mm frecuentes, horizontales, vivas. Porosidad global moderada; poros finos, frecuentes, discontínuos, sin orientación. Pruebas de campo, en el conjunto del horizonte, con HCl (11%) respuesta baja. Límite neto, plano. Ochrico.

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15 / 23 - /+150 cm C, húmedo. En estado de oxidación. Elementos gruesos , muy abundantes ; caliza, heterométricos, de gravilla a bloques, subangular-tabulares, sin orientación definida, distribución irregular, poco alterados. Compacto. Materia orgánica inapreciable, no directamente observable. Raíces de diámetro menor de 10 mm muy pocas, raíces de diámetro mayor de 10 mm no hay. Porosidad global baja. Pruebas de campo, en el conjunto del horizonte, con HCl (11%) respuesta media.

Clasificación según S.S.S., 1975: Typic Cryorthent .

Banco territorial: SINEDARES - CATALUNYA

P7 - Vessants col·luvials de Saldes

En aquest punt observarem un vessant format per un col·luvi de calcàries anguloses provinents del massís del Pedraforca. Es tracta d'un vessant amb un fort pendent. Aquest col·luvi té la característica que s'hi pot observar cert ordre en la disposició dels elements grossos. El sòl que s'hi ha format conté un horitzó petrocàlcic, que a priori, per la seva situació (fort pendent) i alta pluviometria de la zona, fa difícil de pensar que s'hagi originat amb les condicions climàtiques actuals. En aquest punt analitzarem les condicions per la formació d'aquest tipus d'horitzons petrocàlcics, força habituals en vessants col·luvials del Prepirineu.

BER-061

Data descripció: 10/9/2014
Descrit per: A. Baltiérrez

Localització
Terme municipal: Saldes
Paratge: Saldes
Coordenades: X- 392574 **Y-** 4678996
Altitud: 1.775 m

Temperatura i aigua en el sòl
Règim d'humitat: Údic
Règim de temperatura: Mèsic
Classe de drenatge: Ben drenat
Nivell freàtic: Inaccessible

Geomorfologia
Escala d'observació: Decamètrica
Forma del relleu: Vessant
Tipus de vessant: Simple
Modificació de la forma:
Trets erosius:
Morfologia local: Perfil situat en una àrea rectilínia
Situació del perfil: Al terç inferior de la forma
Pendent general: 30-60%
Pendent local: 30-60%
Orientació: S

Vegetació i ús actual del territori
Tipus de vegetació: Matoll alt
Ús: Forestal

Material originari
Detritics terrígens

Material subjacent
Graves

Pedregositat superficial
10-30%, calcària

Graverositat superficial
30-70%, calcària

Aflorament rocosos
Sense

Classificació
SSS(2006): Typic eutrudept?
WRB(2006): Petric Calcisol

Descripció

0-15 cm A
EST. HUMITAT: Sec. COLOR DE LA MATRIU: 7,5YR3/3 (humit). TAQUES: Sense. EST. OXIDOREDUCCIÓ: Oxidació. TEXTURA: Franca. ELEMENTS GROSSOS: 5-15% (0,6-2 cm), angular esferoidal, calcària. ESTRUCTURA: Moderada, granular composta, fina. CONSISTÈNCIA: Poc compacte. Dèbil. ACUMULACIONS: -. CIMENTACIONS: -. SISTEMA RADICULAR: Normal. ACTIVITAT BIOLÒGICA: -ACTIVITAT HUMANA: -. ASSAIG DE CAMP: A la matriu, l'HCl (11%): Molt alta. AMPLITUD DEL LÍMIT: Gradual. FORMA DEL LÍMIT: pla.
HORITZÓ DIAGNÒSTIC: Mollic

>15 cm Bkm
EST. HUMITAT: Lleugerament humit. COLOR DE LA MATRIU: -. TAQUES: Sense. EST. OXIDOREDUCCIÓ: Oxidació. TEXTURA: -. ELEMENTS GROSSOS: >70 % (2-6 cm), angular esferoidal, calcària. ESTRUCTURA: -. CONSISTÈNCIA: -. ACUMULACIONS: Generalitzades. CIMENTACIONS: Moderadament cimentat, de carbonats, discontínu. SISTEMA RADICULAR: Limitat per horitzó cimentat. ACTIVITAT BIOLÒGICA: -. ACTIVITAT HUMANA: -. ASSAIG DE CAMP: A la matriu, l'HCl (11%): Molt alta.
HORITZÓ DIAGNÒSTIC: Petrocàlcic.

4 Bibliografia

Baltiérrez, A. 2014. “Cartografia d'unitats edafològiques de Catalunya a escala 1:250.000: Berguedà i Garrotxa, ED-004/14” Institut Cartogràfic i Geològic de Catalunya. Barcelona, 394 p.

FAO. (2006). Word reference base for soil resources. Word Soil Resources. FAO. Roma. 120 p.

Gallart, F.; Pérez-Gallego, N; Latron, J.; Catari, G.; Martínez-Carreras, N; Nord, G. (2013). Short- and long-term studies of sediment dynamics in a small humid mountain Mediterranean basin with badlands. Geomorphology 196 (2013). Pgs 242–25.

Martinez, A., Tudela, M. (2013) Els tresors geològics del parc Cadí-Moixeró. Itineraris Geològics.

Masachs, V. (1981). Itineraris geològics. Bages, Berguedà, Anoia i Solsonès. Universitat Politècnica de Barcelona. Escola Universitària de Manresa. Barcelona. 210p.

NRCS. (2006). Keys to Soil Taxonomy. Washington. 333p.

Poch, RM.; Porta, J.; Boixadera, J. (1989) XVI Reunión de la Sociedad Española de la Ciencia del Suelo. Erosión hídrica y rehabilitzación de areas mineres: Procesos, cuantificación e interés pedagogico. Lleida.

Porta, J.; Poch, RM.; Boixadera, J. (1989) Land Evaluation and erosion control practices on mined soils in NE Spain. Soil Teconolgy series 1. Pgs 189-206.

Porta, J.; M. López-Acevedo i C. Roquero. (1999). Edafologia para la agricultura y el medio ambiente. Ed. Mundi-Prensa. Madrid.

Solé Sabarís. (1962). Geografia de Catalunya. Editorial AEDOS. (4 volums)