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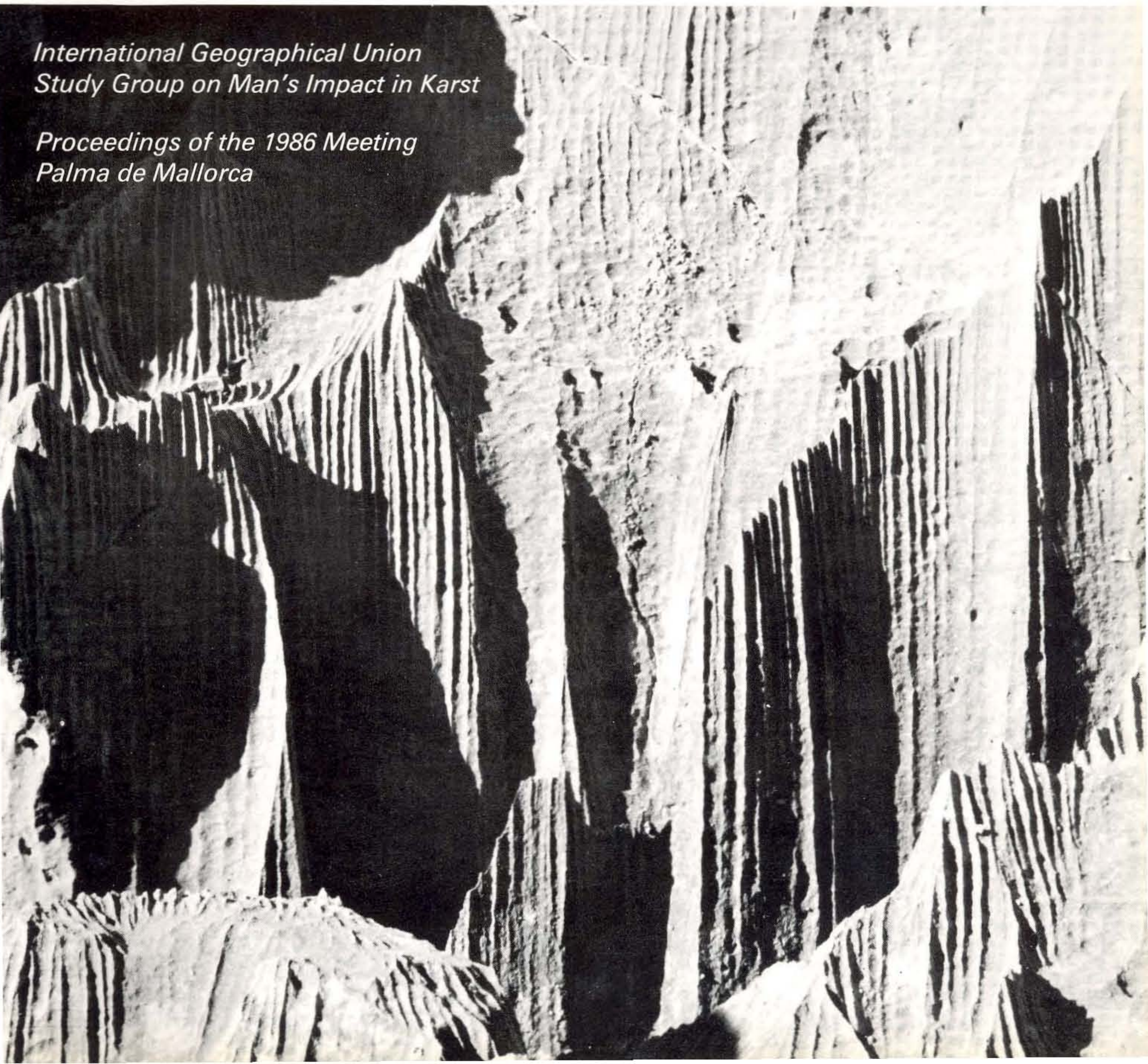

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Fotografia: Joaquín Ginés.

CARACTERÍSTICAS ESPELEOLÓGICAS DEL KARST DE MALLORCA

por Ángel GINÉS y Joaquín GINÉS
del Grup Espeleològic EST
Palma de Mallorca

Resum

Es realitza una síntesi dels coneixements disponibles sobre les formes endocàrstiques de Mallorca, aportant-se noves dades que permeten precisar les característiques principals del modelatge subterrani del carst mallorquí.

Amb aquest fi s'ha redactat una breu ressenya històrica, que resumeix el progrés de les exploracions espeleològiques des del 1839 quan J.M. Bover va publicar una descripció de la Cova Nova de Son Lluís. Es proposa tot seguit una classificació tipològica de les coves i avencs de Mallorca, basada en els respectius processos espeleogenètics que contribuïren a la seva formació. S'exposen així mateix certes generalitzacions en relació amb les diverses regions espeleològiques de l'Illa, intentant explicar la complexa distribució espacial de les distintes castes de formes endocàrstiques. La documentació gràfica, que acompanya al text, ajuda a posar de manifest algunes característiques topogràfiques dels diferents tipus de cavitats i permet establir els trets que diferencien les regions espeleològiques de Mallorca.

Abstract

Available knowledge on endokarstic forms in Mallorca is summarized. Likewise, new data allowing to more precisely point out the main characteristics of underground features of Majorcan karst are provided.

A brief historical account is given on how speleological explorations have progressed since 1839 when J.M. Bover published the description of the Cova Nova de Son Lluís. Afterwards, a typological classification of caves and pot-holes in Mallorca is proposed on the basis of their respective speleogenetic processes that seem to have contribute to their formation. Some generalisations concerning the different speleological regions in the island are also made in order to explain the complex spatial distribution of the several kinds of endokarstic forms.

Graphic documentation enclosed shows some topographic characteristics of the different cavity types and allow to set the distinctive features of the speleological regions in Mallorca.

Introducción: las exploraciones espeleológicas

Las formas endokársticas, que tanto interés han suscitado en el hombre desde tiempos remotos, son un aspecto fundamental para la comprensión del karst. El peculiar comportamiento hidrogeológico de los sistemas y aparatos kársticos debe muchas de sus características a la existencia de cavidades en el interior de la roca caliza. Por otra parte las propias cuevas y simas son la manifestación más elocuente de cómo los procesos de disolución de la roca, que son la base de la karstificación, no limitan sus efectos a la superficie del paisaje sino que prosiguen su acción erosiva en zonas bastante profundas de los terrenos calcáreos. Tampoco se puede olvidar que, tanto las morfologias de las cavernas como los sedimentos acumulados dentro de ellas, son un registro muy significativo del devenir del karst a lo largo del tiempo.

Sin duda hay un factor que influye en el diverso grado de conocimiento que se posee sobre el medio endokárstico de muchas regiones calizas: se trata de los especiales problemas y obstáculos físicos planteados por la observación sobre el terreno de esas importantes estructuras subterráneas del karst que son las cuevas y simas. En el mejor de los casos, ello obliga a utilizar técnicas de exploración muy particulares, las cuales dan buena parte de su personalidad a la Espeleología; rama de la ciencia cuyos límites son difíciles de trazar. Por consiguiente, la mayor parte de lo que se conoce sobre las formas endokársticas de un territorio está condicionado por el grado de accesibilidad al interior del karst; es decir, por la existencia de unas dimensiones mínimas de las cavidades que permitan el paso del hombre, por una suficiente comunicación (y por lo tanto, penetrabilidad) entre las cavidades y la superficie, y por la mayor o menor abundancia de exploraciones subterráneas realizadas por los espeleólogos en una determinada área kárstica.

Las más antiguas exploraciones espeleológicas se remontan en Mallorca al siglo XIX, si bien existen descripciones más o menos fantasiosas publicadas en tiempos anteriores. Quizás la primera auténtica exploración de una cueva mallorquina que exige una cierta técnica espeleológica, sea la consignada por Joaquín María Bover en un opúsculo de cuatro páginas (BOVER, 1839) en el que se relata la visita efectuada a la extensa Cova de Son Lluís (Porreres) y se realiza una descripción minuciosa, pero algo confusa, de las principales salas de la cueva. El recorrido de dicha caverna es complicado y bastante laberíntico, y a esa dificultad hay que añadir la elevada concentración de dióxido de carbono que, alcanzando valores superiores al 3,5 % en volumen, hace muy penosa cualquier actividad de exploración. Ese hecho fue advertido ya por Bover, quien dejó constancia en su escrito de que el aire de la cueva estaba enrarecido.

Por lo que se refiere a las primeras exploraciones de cavidades verticales mallorquinas, éstas tuvieron lugar en el Avenc de Son Pou (Santa Maria del Camí) con anterioridad al año 1865. Los datos de que se disponen (CONRADO, 1865) dan cuenta de varios descensos efectuados en esta sima por albañiles que trabajaban en el vecino predio de Son Torrella y que, dirigidos por Antonio Matas, improvisaron un sistema a base de cuerdas, poleas y andamios que les permitió franquear los casi 50 metros de profundidad del Avenc de Son Pou. Una pequeña crónica de las exploraciones realizadas en la sima fue publicada por Mariano Conrado, que participó en aquellos descensos, los cuales ciertamente planteaban dificultades técnicas muy considerables si se tiene en cuenta la fecha en que se hicieron.

Las exploraciones de E.A. Martel, a finales del siglo pasado, abren otra nueva etapa en la espeleología mallorquina (MARTEL, 1903) además de proporcionar a nuestras cuevas una justa celebridad internacional. Este momento coincide con el inicio del estudio de la fauna cavernícola de Mallorca, ya que en 1904 Emile G. Racovitza visita las Co-

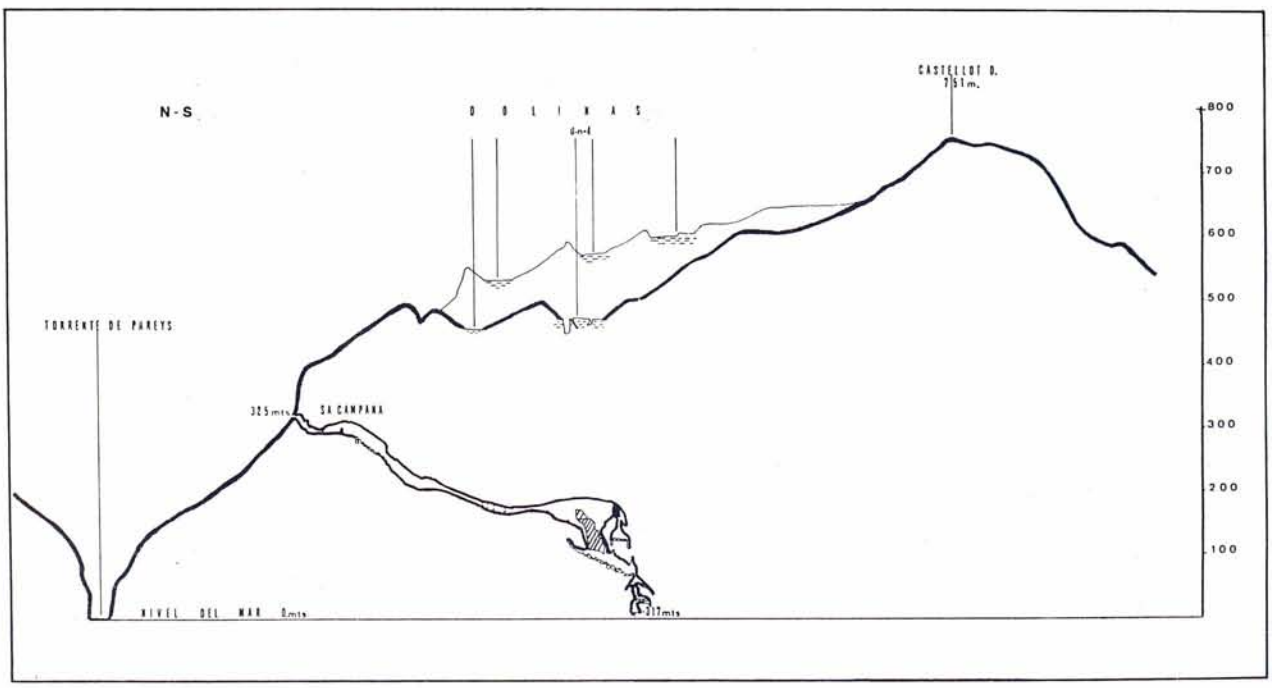

Figura 1. Sección esquemática de la Cova de sa Campana (Escorca) mostrando la localización de la cueva bajo las dolinas y campos de lapiaz de Es Castellots (según BARRERES et al., 1975-76).

ves del Drac (Manacor) y recolecta algunos ejemplares de animales troglobios, de entre los cuales el crustáceo *Typhlocirolana moraguesi* seria descrito al año siguiente (RACOVITZA, 1905); muchos autores ven en esta exploración una fecha histórica que marca el nacimiento de la Bioespeleología moderna. Posteriores campañas espeleológicas, bastante espaciadas en el tiempo, van ampliando progresivamente el conocimiento geográfico de nuestras cavernas, tal como lo ponen de manifiesto los trabajos de MAHEU (1912), JOLY (1929), LLOPIS-LLADÓ y THOMAS-CASAJUANA (1948), THOMAS-CASAJUANA y MONTORIOL-POUS (1953), PALAU (1955), MONTORIOL-POUS (1962, 1963) y ESCOLÀ (1970).

Sin embargo el número de cavidades exploradas hasta 1965, en que comienzan a organizarse los primeros grupos espeleológicos mallorquines, es muy exiguo pues apenas se sobrepasa la treintena. A partir de entonces se desarrolla una muy intensa actividad de exploración subterránea que modifica de una manera radical la situación precedente. Esta tendencia se puede apreciar repasando los sucesivos inventarios en los que se recogen los resultados de las nuevas exploraciones llevadas a cabo (GINÉS y TRIAS, 1972; ENCINAS et al., 1974). Durante el año 1978 se rebasa la cifra de 800 cavidades catalogadas, habiendo sido además topografiadas gran parte de ellas (TRIAS, et al., 1979). Este notable avance ha ido ampliando considerablemente los limitados conocimientos que se poseían hasta hace poco sobre las cuevas y simas de Mallorca. No parece aventurado decir que es ahora cuando se comienza a estar en condiciones de establecer ciertas generalizaciones sobre las características que presentan las numerosas formas endokársticas de la Isla. Sin duda la primera etapa en el estudio de las cavidades subterráneas, consistente en el reconocimiento, exploración y descripción topográfica de las mismas, se encuentra a un nivel bastante satisfactorio por lo que respecta a los principales conjuntos kársticos mallorquines, al disponerse en la actualidad de una base estadística de más de 900 cavidades inventariadas.

Las formas endokársticas mallorquinas

Las formas endokársticas existentes en Mallorca destacan sobre todo por su elevado número y por los variados e interesantes depósitos estalagmíticos (espeleotemas) que albergan en su interior. Pero, sin embargo, las dimensiones de las cuevas y simas mallorquinas sólo se pueden calificar de modestas. De hecho, no más de seis cuevas superan el kilómetro de longitud y ninguna sima, conocida hasta la fecha, supera los 200 metros de profundidad si exceptuamos los 304 metros de desnivel de la Cova de sa Campana (Escorca) (Figura 1).

Varios motivos han podido contribuir a que la intensa karstificación que se manifiesta en diferentes regiones de la Isla, incluso mediante formas de superficie muy espectaculares, no haya originado la excavación de grandes redes de cavidades. Por una parte, la considerable complejidad tectónica de las comarcas montañosas unida a la intercalación de materiales impermeables del Triásico y Cretácico han dado lugar a un verdadero mosaico de pequeños sistemas kársticos bastante independientes entre sí. Ello impide, en el caso de la Serra de Tramuntana y también en el de las Serres de Llevant, que se puedan reunir y canalizar localmente caudales importantes capaces de integrarse como tributarios de una misma surgencia, debido al aislamiento y compartimentación de las unidades geológicas karstificables.

Por otra parte, todo el karst de Migjorn muestra un comportamiento hidrodinámico muy peculiar, ya que, junto al especifico drenaje kárstico a través de cuevas, las calcarenitas del Tortoniense son además extremadamente porosas. Por ello coexiste una auténtica capa freática con grupos de cuevas más o menos dispersos; circunstancia que tampoco favorece el desarrollo preferencial de sistemas jerarquizados de cavidades. Por último, en ambos casos, la escasez de formas endokársticas de conducción (y/o surgencias) puede obedecer a la poca estabilidad del nivel del Mediterráneo desde finales del Terciario, lo que habiendo ocasionado importantes y continuadas fluctuaciones del nivel de base habrá inhibido probablemente la tendencia a la autoorganización de los niveles de surgencia, que es uno de los rasgos principales en la evolución de los sistemas kársticos (MANGIN, 1974).

Sea por la razón que sea, se constata que los karst mallorquines están caracterizados por una gran abundancia de pequeñas cavidades y por un muy reducido número de formas endokársticas de conducción. Paralelamente se aprecia una espectacular riqueza en formaciones estalagmíticas, así como un desarrollo considerable de dos estructuras endokársticas bien diferenciadas: las cavidades verticales de aspecto fusiforme y las grandes salas de origen clástico.

Así, mientras que son raras las cavernas constituidas por galerías estrechas, rectilíneas o laberínticas, son muchas las que poseen grandes salas. Incluso algunas cuevas, como la Cova de Can Sion (Pollença) y la Cova des Diners (Manacor), son gigantescas salas de suelo inclinado en las que grupos de columnas, coladas y estalagmitas crean subdivisiones y aislan grandes porciones de las mismas, de tal forma que la caverna entera parece estar constituida por una complicada sucesión de pequeñas salas independientes. Estas grandes sa-

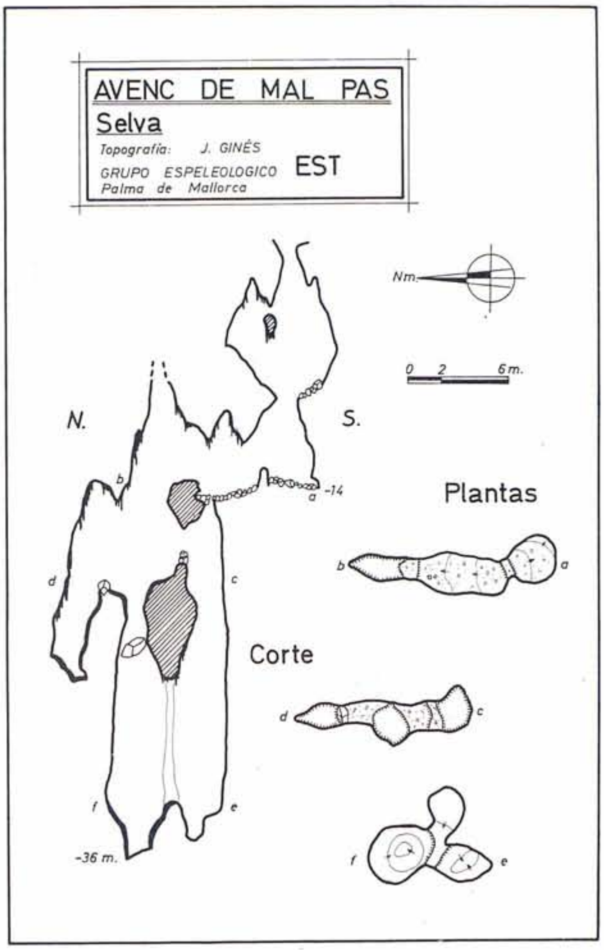

Figura 4. Topografía del Avenc de Mal Pas (Selva), en la que se distinguen varias cavidades fusiformes.

las son muy frecuentes en el karst mallorquín, tanto en las montañas como en la plataforma miocénica, y se pueden interpretar como el resultado de la actuación de importantes procesos clásticos que, por lo general, van asociados a las etapas seniles de la evolución morfológica de las cuevas. Parece evidente que los procesos clásticos son los responsables del hundimiento de extensos sectores de las bóvedas de las cavernas y que conjuntamente con el papel que desempeñan los mecanismos de estalagmitización, ambos procesos se encargan de configurar la mayor parte de nuestros paisajes subterráneos más representativos (Figuras 2 y 3). Además de las dos cavidades antes citadas, las Coves del Drac (Manacor), Coves dels Hams (Manacor), Cova de sa Campana (Escorca), Avenc den Corbera (Esporles), Avenc de Son Pou (Santa Maria del Camí), Cova Nova de Son Lluís (Porreres), Coves del Pirata (Manacor), Cova des Pont (Manacor) y otras muchas más pertenecen a esta clase de cavidades, las cuales están extraordinariamente bien representadas aquí.

El otro tipo de cavidad que adquiere notable importancia en los karst de montaña mallorquines son las cavidades verticales de aspecto fusiforme (Figura 4). Se las encuentra en elevado número en muchas de nuestras áreas kársticas más destacables, siendo dignas de subrayar las dimensiones excepcionales que poseen algunas de ellas, lo que se manifiesta en grandes verticales absolutas como los 117 metros del Avenc d'Escorca (Escorca), los 145 metros del Avenc des Travessets (Artà), los 120 metros del Avenc de Femenia (Escorca), los 115 metros del Avenc de S'Aigo (Escorca) y los más de 120 metros de l'Avenc Fonda (Pollença).

Para concluir el presente apartado se enumeran a continuación los tipos de cavidades representados en nuestro karst, siguiendo la clasificación propuesta por GINÉS y GINÉS (1974 b), con una breve mención de sus rasgos espeleomorfológicos principales. La Figura 6 recoge las proporciones porcentuales que corresponden a cada uno de los tipos de formas endokársticas, dentro de un muestreo de 300 cavidades mallorquinas.

TIPO 1. *Simas fusiformes.* Cavidades verticales consistentes en una o varias unidades independientes de aspecto aproximadamente ahusado (Figura 4), cuyas dimensiones pueden medir desde unos pocos metros hasta más de un centenar. Estas unidades o husos (MAUCCI, 1952) se establecen a lo largo de líneas de diaclasas, mostrándose como ensanchamientos bien individualizados que en muchos casos ni siquiera se abren a la superficie. Con frecuencia los husos se fusionan entre sí lateral o terminalmente, formando cavidades complejas constituidas por varios pozos que se suceden en profundidad o discurren más o menos paralelos, como ocurre en el Avenc de Sa Marineta (Deià), Avenc de Fangar (Campanet), Avenc des Porcs (Bunyola) y Avenc Fonda (Pollença). Las simas de estas características poseen bocas de reducidas dimensiones, pueden presentar abundantes coladas parietales y además sus secciones horizontales son a veces sorprendentemente elípticas o circulares. Desde un punto de vista espeleogenético están relacionadas con el drenaje vertical de las aguas de infiltración en la zona vadosa del karst y pueden corresponder a los denominados *gouffres absorbants* (GÈZE, 1953). Ciertas simas abiertas en el fondo de dolinas quizás son el resultado de la evolución ascendente de cavidades de esta clase, como lo parece indicar el Avenc de sa Mitjania (Escorca) o el Avenc del Pla de les Basses (Pollença).

TIPO 2. *Dolinas de hundimiento y otras cavidades verticales.* Simas que, si bien presentan un desarrollo en profundidad bastante superior a su recorrido en planta, no pueden ser encuadradas en ninguno de los otros grupos de cavidades verticales. Entran en esta clase, muy heterogénea, las pequeñas simas de lapiaz, las dolinas o simas de

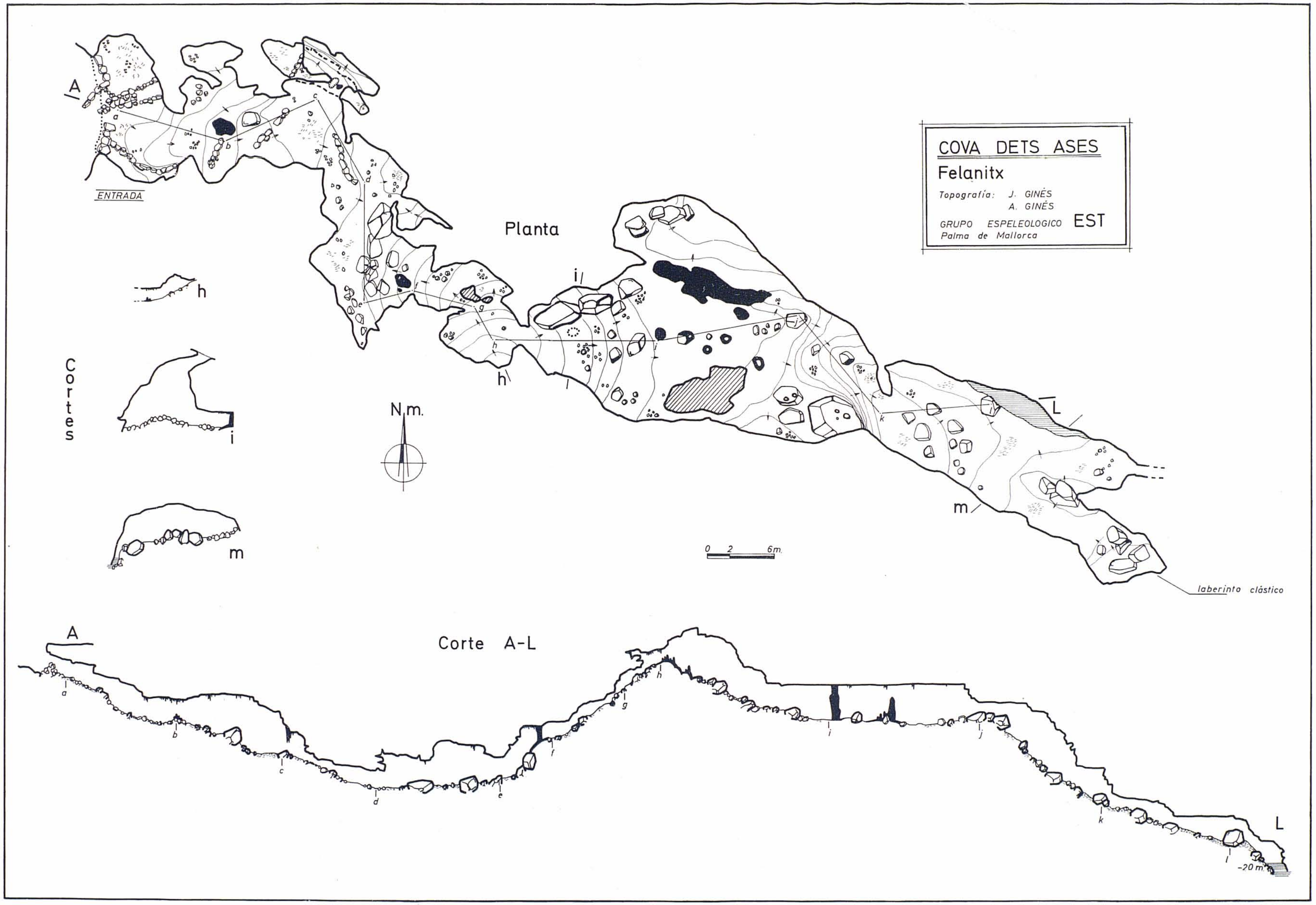

Figura 2. Topografía de la Cova dets Ases (Felanitx). En el corte A-L se aprecia la sección longitudinal de una sala en cuyo desarrollo han intervenido procesos clásticos.

hundimiento como el el Clot des Sero (Calvià) y la Cova de sa Gleda (Manacor), ciertas simas de trayecto irregular e incluso unas cuantas cavidades subverticales en las cuales desaparecen cursos de agua torrenciales, actuando como sumideros. Este último caso está bien ejemplificado por el Avenc des Gel (Escorca).

TIPO 3. *Simas «nivales».* Cavidades verticales subcilíndricas, de profundidad en general poco destacable, a las cuales les atribuimos una génesis nivo-kárstica. Constan básicamente de un solo pozo principal, abriéndose al exterior mediante bocas amplias, casi circulares e iguales o mayores que el fondo, tal como se puede apreciar en el Avenc de Massanella (Escorca) y en el Avenc des Tossals (Escorca). Son bastante frecuentes por encima de los 800 metros de altitud, donde se hallan asociadas con una particular modalidad de lapiaz exterior semejante al *kluftkarren.* Presentan unas morfologías análogas a las de los *tesserefts* descritos por QUINIF (1978) y como ellos parecen estar relacionados con una alimentación de precipitaciones nivo-pluviales (GINÉS, et al., 1980).

TIPO 4. *Simas megaclásicas.* Cavidades verticales generadas a expensas de importantes fracturas o megaclasas (Figura 5). Poseen una planta marcadamente rectilínea, que sigue el trayecto de las diaclasas sobre las cuales se ha producido la excavación de la sima. Las cavidades pertenecientes a esta clase están condicionadas en parte por

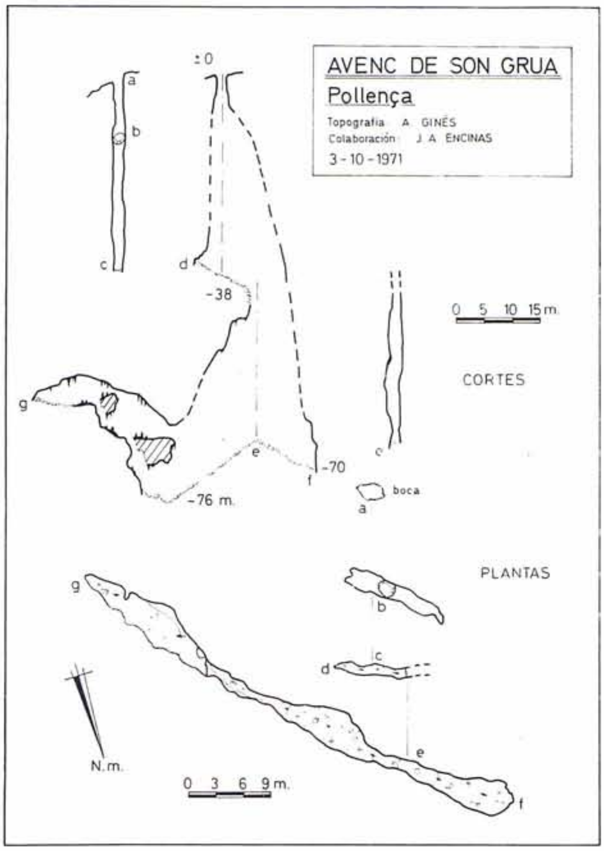

Figura 5. Topografia del Avenc de Son Grua (Pollença). Se puede apreciar que la excavación de la cavidad se ha realizado siguiendo una importante diaclasa.

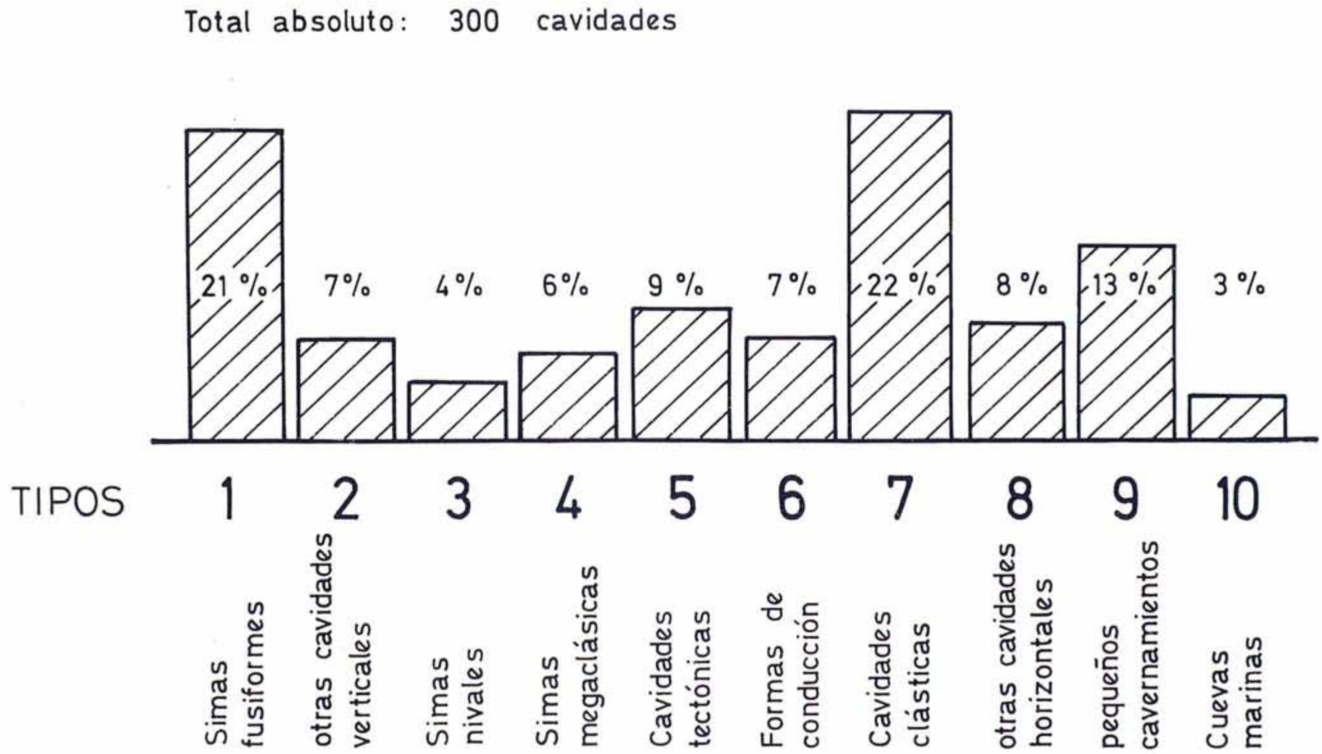

Figura 6. Histograma que representa, sobre un muestreo de 300 cavidades del conjunto de Mallorca, las proporciones correspondientes a los diferentes tipos de cuevas y simas establecidos en el texto (según GINÉS y GINÉS, 1974b).

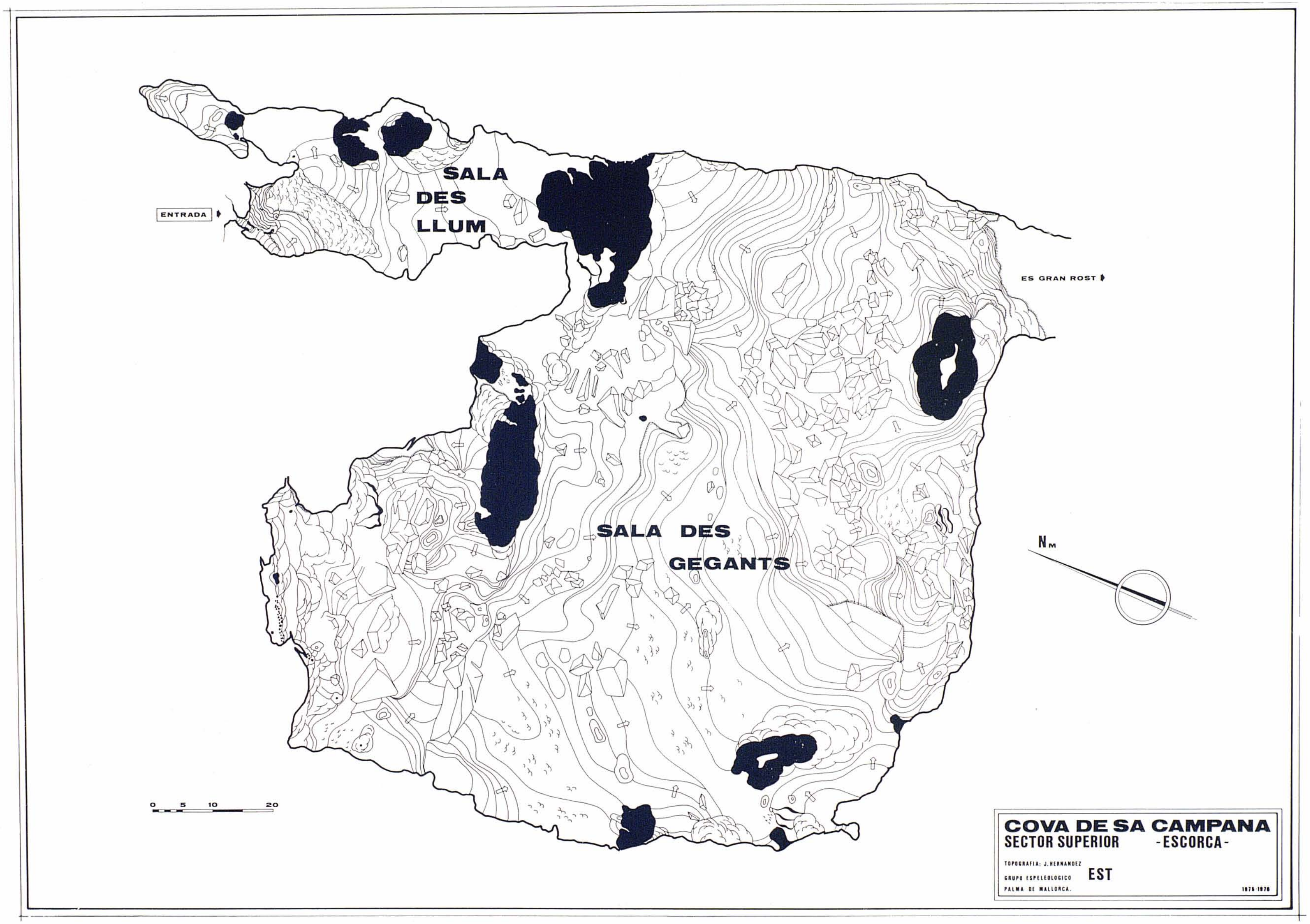

Figura 3. Fragmento de la topografía de la Cova de sa Campana (Escorca). Obsérvense las grandes dimensiones de la Sala des Gegants, que es el resultado de unos procesos clásticos de gran envergadura.

los mecanismos de descompresión que afectan a ciertos macizos calcáreos elevados, aunque los procesos de disolución y precipitación kárstica también son patentes. A veces alcanzan profundidades notables; así sucede en el Avenc de na Boira (Esporles), el Avenc des Cocons (Fornalutx), el Avenc de Son Grua (Pollença) y el Avenc de sa Pedra (Esporles).

TIPO 5. *Cavidades «tectónicas».* Grietas de despegue próximas a fuertes pendientes o influidas muy directamente por la presencia de acantilados epigeos. Incluimos en este grupo a las *fentes de décollement* de los autores franceses y a los *gouffres tectoniques* de GÈZE (1953) por considerar que muchas simas mallorquinas tienen un origen semejante: Avenc des Grau (Bunyola), Avenc de sa Cuina (Bunyola), Avenc des Coverany (Puigpunyent), etc. Son frecuentes en ellas los fondos caóticos y los falsos pisos constituidos por grandes bloques inestables. La intervención de los procesos kársticos es mínima e incluso inexistente, y cuando la hay la frontera con las simas megaclásicas se hace difícil de sostener. El calificativo de cavidades «tectónicas» parece bastante inadecuado, pero la bibliografía espeleológica lo sigue utilizando todavía y por ello se ha optado por mantener el término entre comillas.

TIPO 6. *Formas de conducción.*

TIPO 6a. *Cavidades activas y surgencias.* Formas endokársticas de conducción, actualmente activas. Son poco abundantes en Mallorca y entre ellas se cuentan la Font des Verger (Sóller), la Font de l'Algaret (Pollença), la Cova de les Rodes (Pollença), la Cova de Can Sivella (Pollença) y la Cova dets Estudiants (Sóller). Se trata de cavernas de desarrollo horizontal en las que predominan las galerías de trazado más bien rectilíneo. Están recorridas por ríos subterráneos, por lo menos en parte de su trayecto (Figura 7).

TIPO 6b. *Cavidades freáticas fósiles.* Cuevas de dimensiones variables provistas de morfologías que denotan haber sido excavadas en régimen freático (BRETZ, 1942), tales como cúpulas en forma de campana, *pendants* y anastomosis de conductos. Presentan plantas de trazado bastante diverso, tanto rectilíneas como laberínticas, pero se caracterizan por la carencia de salas de gran tamaño. La Cova des Mirador (Escorca), la Cova de Canet (Esporles), la Cova de Cal Pesso (Pollença) y la estrecha galería de la Cova del Drac (Santanyí)

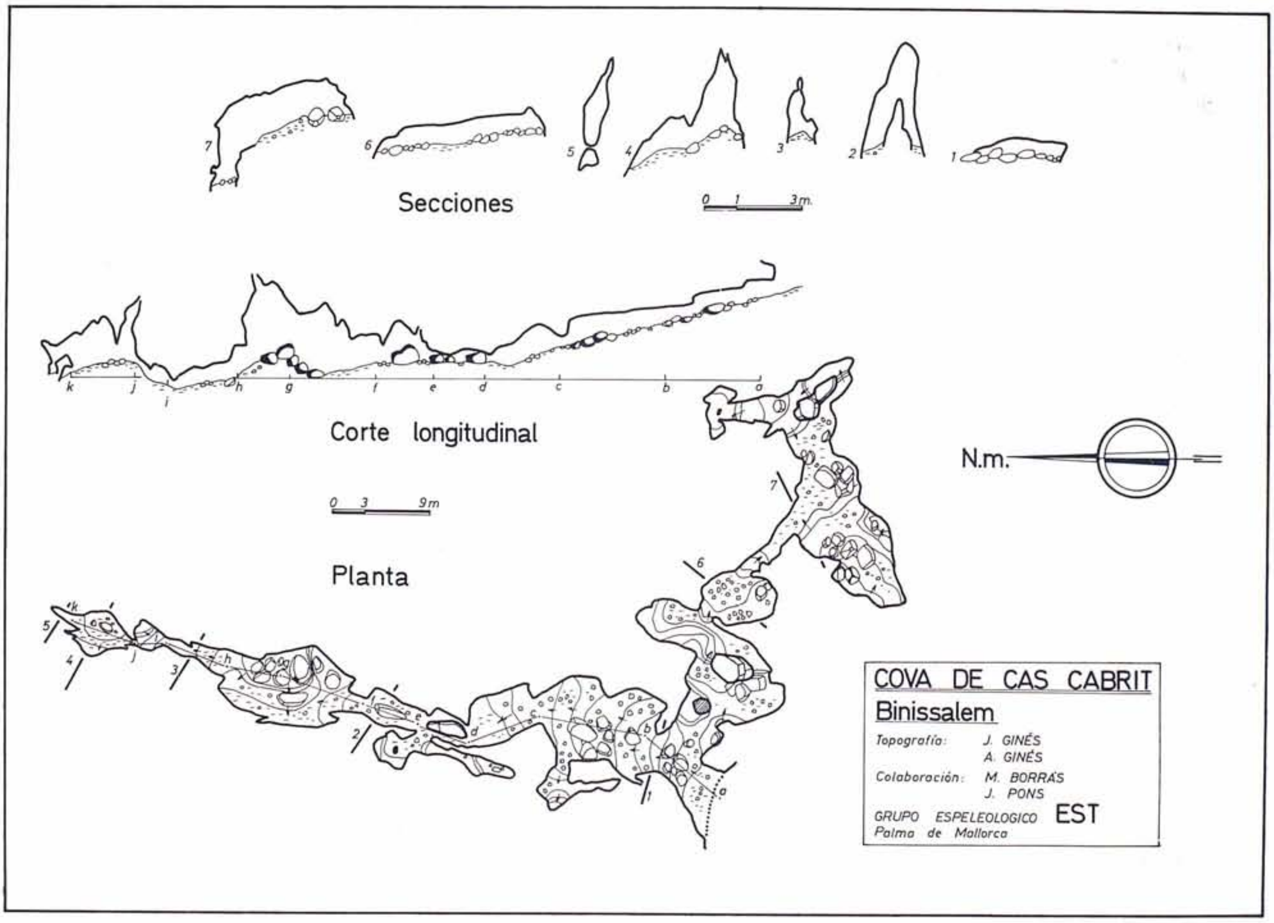

Figura 8. Topografía de la Cova de Cas Cabrit (Binissalem). Esta cueva posee morfologías que denotan un origen freático. Obsérvese la planta relativamente rectilínea de la cavidad.

pueden servir como ejemplos de cuevas freáticas rectilíneas, mientras que la Cova de Llenaire (Pollença), la Cova de Sa Teulada (Santa Margalida), la Cova den Tocahores (Petra) y el retículo de galerías de Sa Cova Figuera (Manacor) son buenos ejemplos de cuevas freáticas de estructura laberíntica. Tanto en un caso como en otro, esta clase de cavidades fósiles no muestra apenas modificaciones morfológicas importantes que hayan alterado la estructura originaria de cuando se formó la cueva (Figuras 8 y 9).

TIPO 7. *Cavidades «clásticas».* Cuevas que aparecen conformadas por una o varias unidades clásticas: salas más o menos grandes, galerías amplias en forma de bóveda o hundimientos de diversa índole. Los procesos espeleogenéticos causantes de dichos hundimientos, denominados clásticos en la bibliografía de los países latinos, podrían ser incluidos dentro del concepto de *incasion* en el sentido propuesto por BÖGLI (1980). Estas «unidades clásticas» se han conjugado unas con otras desordenadamente, sin que se observe ninguna pauta de jerarquización ni tampoco direcciones preferentes que pudieran expresar un determinado sentido de drenaje. En esta clase de cuevas no quedan apenas vestigios de las primitivas cavidades embrionarias y en cambio se aprecia un claro predominio de las morfologías clásticas; es decir, acumulaciones de bloques, grandes hemiconos derrubiales y techos casi parabólicos en busca del perfil de equilibrio (Figura 2). Con frecuencia los bloques se encuentran soldados por abundantes formaciones estalagmíticas y coladas pavimentarias (Figura 3). Las hay en gran número, distribuidas por todas la regiones kársticas de la Isla, por lo que además de las que ya se han mencionado con anterioridad se pueden citar otras muchas: Coves de Garrafa (Andratx), Cova de sa Germaneria (Calvià), Coves des Màrmol (Calvià), Coves del Pilar (Palma), Coves de Campanet (Campanet), Cova de ses Meravelles (Bunyola), Sa Cova Calenta (Felanitx), Cova dets Ases (Felanitx), Cova den Bessó (Manacor), Cova A de Cala Varques (Manacor), Cova de Can Bordils (Manacor), Avenc de Sa Vallet (Santanyí), Cova des Galliner (Escorca), etc.

TIPO 8. *Cavidades horizontales no definidas.* Fenómenos hipogeos horizontales cuya morfología no permite encuadrarlos en los dos grupos precedentes, aunque tampoco se pueden clasificar como pequeños cavernamientos ni como cuevas marinas. Éste es el caso, por ejemplo, de la cova de ses Genetes (Santanyí).

TIPO 9. *Pequeños cavernamientos.* Cavidades de tamaño reducido carentes de un especial significado morfogénico. Se incluyen aquí balmas y abrigos como la Cova de s'Aüc (Escorca), la Cova de s'Eura (Santa Maria del Camí) o la Cova des Soldat Pelut (Escorca).

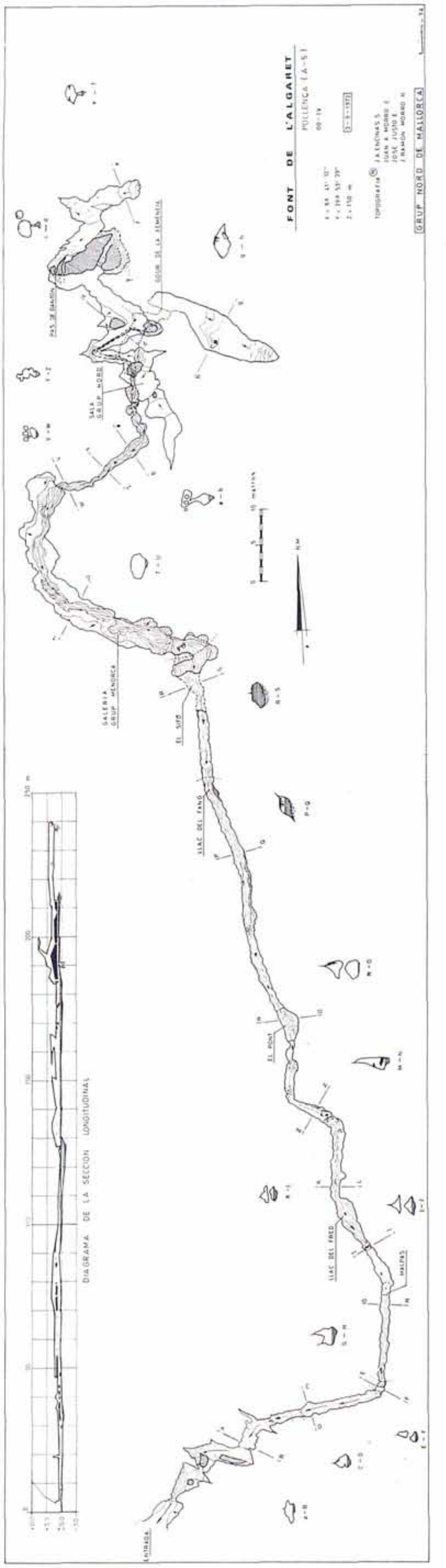

Figura 7. Topografía de la Font de l'Algaret (Pollença). Se trata de una de las escasas cavidades activas, recorridas por un río subterráneo, que hay en Mallorca (según GRUP NORD DE MALLORCA, 1973).

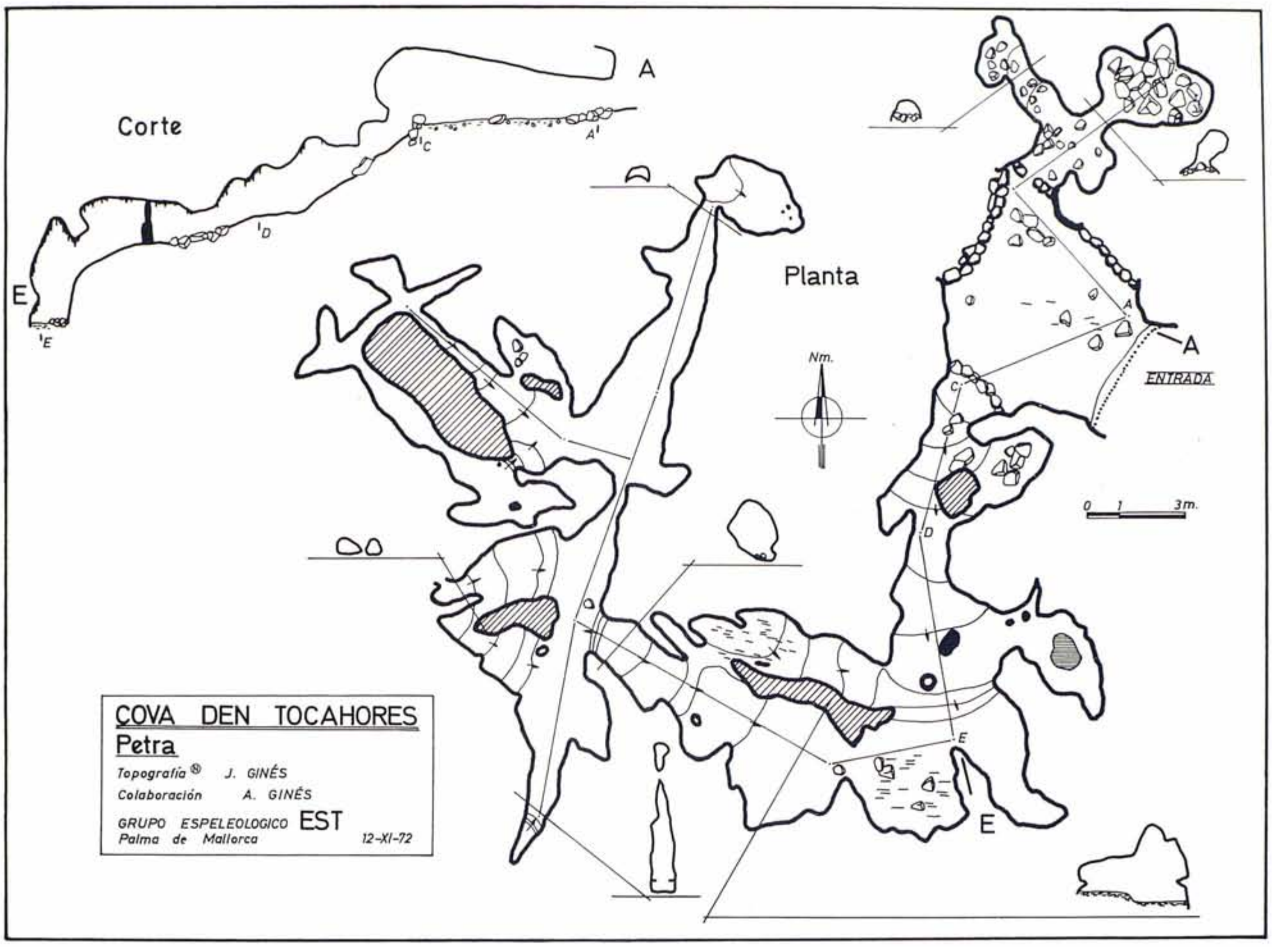

Figura 9. Topografía de la Cova den Tocahores (Petra). Pequeña cavidad de origen freático, destacable por su estructura laberíntica y por las morfologías muy representativas que posee.

TIPO 10. *Cuevas marinas.* Cavernas de abrasión marina, actuales o fósiles, así como surgencias y cavidades kársticas abiertas a nivel del mar. Lamentablemente los conocimientos geográficos sobre estas cuevas mallorquinas son todavía muy escasos e insatisfactorios.

Regiones espeleológicas de Mallorca

Las cuevas y simas son inseparables del contexto geológico y topográfico en que se hallan inscritas. Además es obvio que las características morfológicas y estructurales de las cavidades existentes en una determinada región kárstica, así como la evolución y desarrollo de las mismas, viene condicionada por la litología, la tectónica y la historia geológica que durante los últimos millones de años han ido configurando el relieve superficial. Las modalidades particulares que presenta la excavación y evolución morfológica de redes de cavidades en el interior del karst dependen estrechamente de un complejo entramado de interacciones geológicas y geográficas, las cuales confieren una notable variedad estructural a las cuevas y simas localizadas en los diferentes conjuntos kársticos de la isla de Mallorca. Por esta razón parece útil subdividir la Isla en una serie de regiones cuyas formas endokársticas se caracterizan por una cierta homogeneidad estructural y espeleomorfológica.

Un primer análisis de la tipología de las cavidades mallorquinas con referencia a su ubicación geográfica (Figura 10) fue presentado por GINÉS y GINÉS (1974b). Posteriormente los mismos autores (GINÉS y GINÉS, 1977) han sugerido una más precisa delimitación de las regiones kársticas de la Isla, teniendo en cuenta las áreas geográficas y comarcas naturales propuestas por BARCELÓ (1973) y ROSSELLÓ-VERGER (1974). En dicho trabajo se establecen las siguientes regiones y subregiones kársticas (Figura 11) en base a consideraciones de tipo litológico, geomorfológico, topográfico, climático, hidrográfico y espeleogenético:

1. SERRA DE TRAMUNTANA
   1.1. Ponent
   1.2. Muntanya
   1.3. Formentor

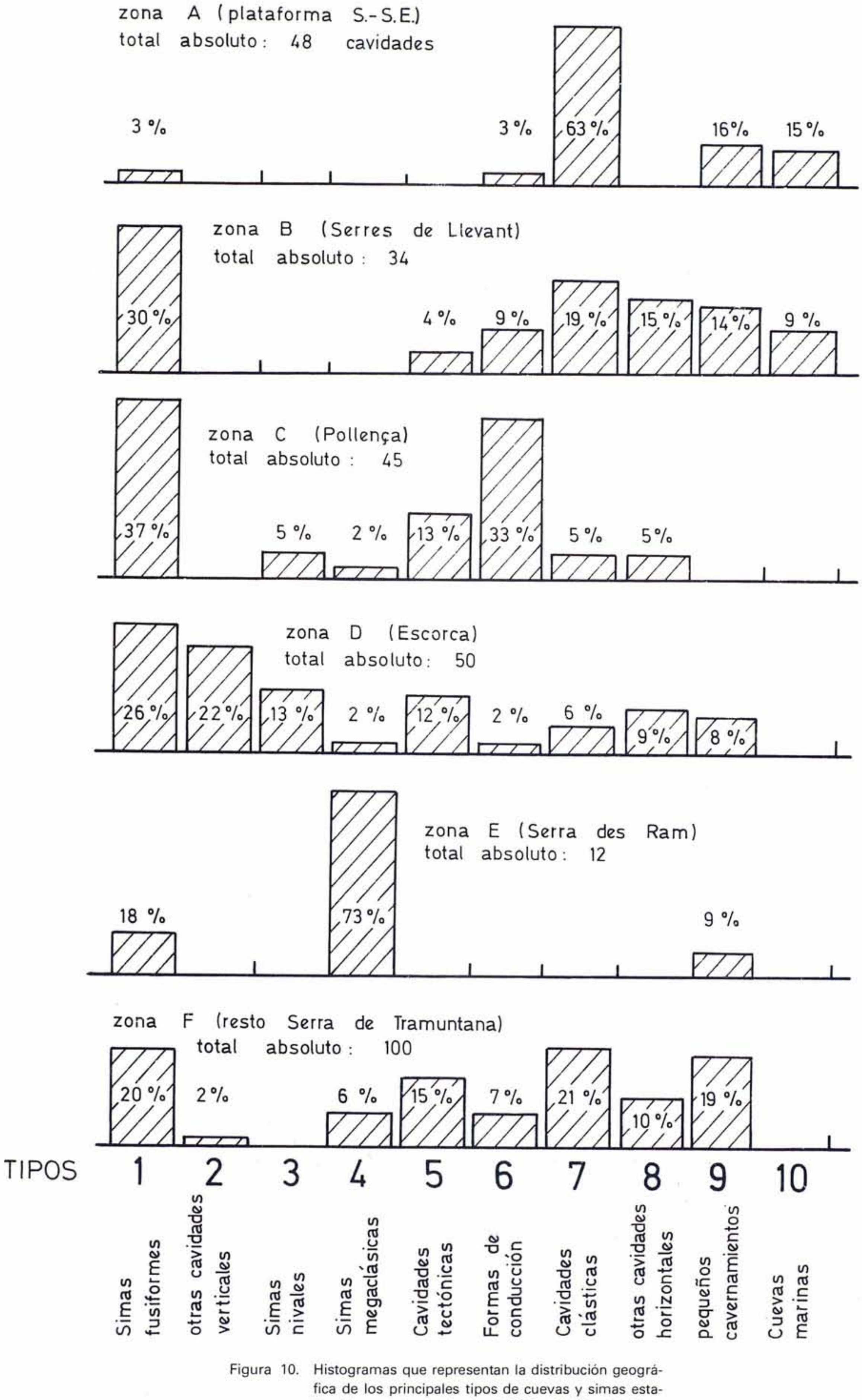

Figura 10. Histogramas que representan la distribución geográfica de los principales tipos de cuevas y simas establecidos en el texto (según GINÉS y GINÉS, 1974b).

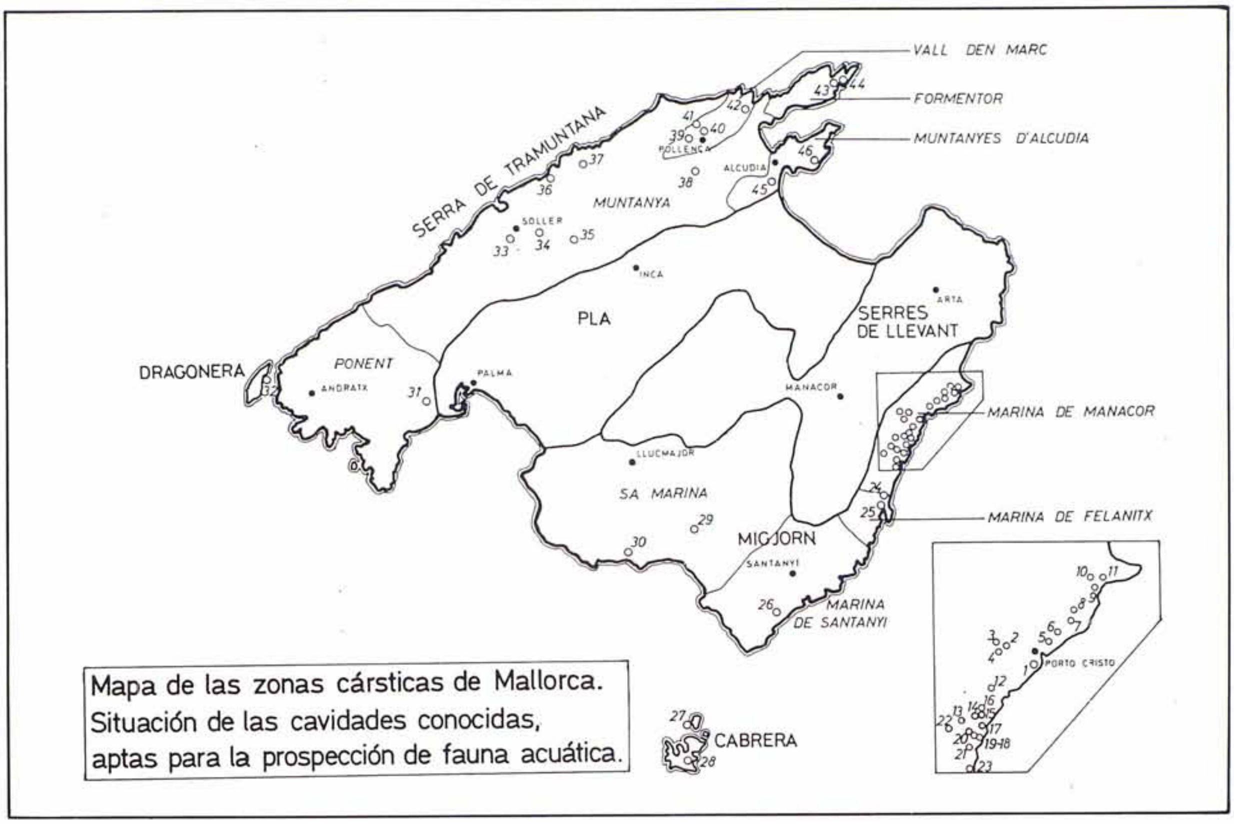

Figura 11. Regiones kársticas de Mallorca, según GINÉS y GINÉS (1977).

   1.4. Muntanyes d'Alcúdia
   1.5. Pollença/Vall den Marc
2. PLA
   2.1. Muro/Santa Margalida
3. SERRES DE LLEVANT
   3.1. Muntanyes d'Artà
   3.2. Muntanyes meridionals
4. MIGJORN
   4.1. Marina de Manacor
   4.2. Marina de Felanitx i de Santanyí
   4.3. Sa Marina

En efecto, por lo que se refiere a la estructura geológica de Mallorca, de inmediato se puede constatar una clara diferenciación fisiográfica entre las dos agrupaciones montañosas que enmarcan la Isla (Serra de Tramuntana y Serres de Llevant) y el conjunto monótono y tabular del Migjorn mallorquín. Mientras las primeras están constituidas por una amplia secuencia de rocas sedimentarias que abarcan desde el Triásico al Burdigaliense (calizas, dolomías y margas principalmente), sobre las cuales ha actuado una intensa y complicada tectónica, las calcarenitas tortonienses, dispuestas horizontalmente, dan lugar a una plataforma muy peculiar a lo largo de los terrenos costeros del Sur y Sureste e incluso de buena parte del Centro insular.

El marcado contraste que se manifiesta en la karstificación de ambos conjuntos calcáreos fue ya planteado por DARDER (1930) y ha sido desarrollado después por GINÉS y GINÉS (1977), a propósito de las características que presenta el medio acuático en las cuevas de Mallorca. En aquel trabajo se aludía, como principales aspectos diferenciadores entre ambas zonas, a la disposición transgresiva de los materiales tortonienses y sobre todo a su elevada porosidad primaria en comparación con las calizas de las montañas, cuyos estratos, plegados ya antes de la transgresión tortoniense, han sido sometidos a una importante fisuración que prevalece sobre la escasa porosidad primaria de la roca. Como el comportamiento del agua en el interior de la roca karstificable está determinado por la porosidad y transmisividad de los materiales, parece lógico suponer que las características netamente contrapuestas del conjunto calizo fisurado de la Serra de Tramuntana, con respecto a las calcarenitas muy porosas del Migjorn, pueden considerarse de entrada como un criterio válido para la delimitación de las principales regiones kársticas. Éstos y otros condicionantes imponen rasgos particulares a la espeleogénesis que ha tenido lugar en cada una de las regiones kársticas establecidas más arriba.

Las Figuras 12 y 13 permiten evaluar cómo las proporciones de formas endokársticas verticales, horizontales y pequeñas cavidades se reparten muy desigualmente entre las distintas regiones

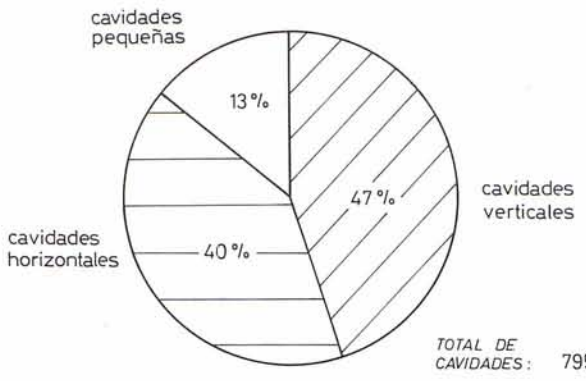

Figura 12. Diagrama que expresa las proporciones existentes entre cavidades verticales, horizontales y pequeños cavernamientos, a partir de un muestreo de casi 800 cavidades mallorquinas.

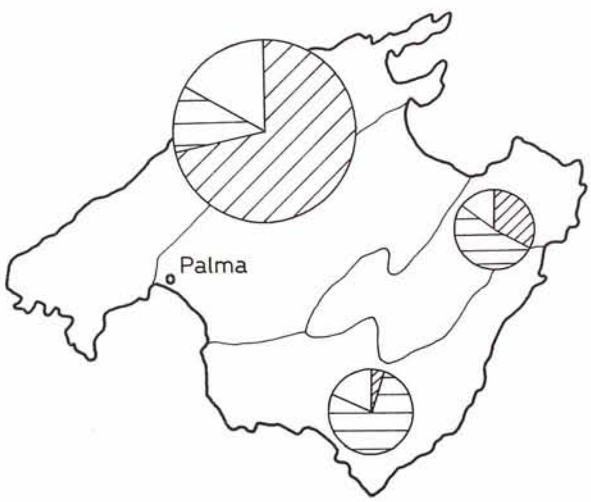

Figura 13. Diagrama que representa las proporciones existentes entre cavidades verticales, horizontales y pequeños cavernamientos en las tres regiones geográficas principales de la Isla.

calcáreas. Si en la Serra de Tramuntana destacan las cavidades verticales y las pequeñas cavidades, la región de Migjorn muestra por el contrario un acentuado predominio de las cavidades de desarrollo horizontal y las Serres de Llevant se significan por valores intermedios, menos extremados. También se constatan diferencias apreciables entre algunas subregiones en lo que se refiere a la abundancia de formas endokársticas (Figura 14) y en cuanto a la densidad de cavidades (Figura 15); sobre un muestreo de casi 800 cuevas y simas. A partir de ambas figuras se deduce que más del 80 % de las cavidades subterráneas exploradas hasta la fecha pertenecen a la Serra de Tramuntana y que las regiones calizas de Llevant y Migjorn poseen amplios sectores pobres en cavidades penetrables.

Por último, la Figura 16 proporciona una imagen bastante representativa de la densidad de cuevas y simas que presentan los distintos términos municipales. Para realizar dicha estimación tan sólo se han contabilizado las cavidades de grandes y medianas dimensiones, pertenecientes a los grupos III, IV, VI, VII y VIII del «Inventari Espeleològic de les Illes Balears» (TRIAS et al., 1979). Las mayores densidades se concentran en la extremidad septentrional de la Isla, que comprende los municipios de Pollença, Mancor de la Vall y Escorca, siendo el índice más alto el correspondiente a Pollença con casi 0,7 cavidades por kilómetro cuadrado. Un segundo grupo de términos municipales dan valores que oscilan entre 0,2 y 0,4 cavidades por kilómetro cuadrado, circunscribiéndose en dos núcleos: el que incluye Calvià, Puigpunyent, Esporles y Estellencs, por una parte, y el de Sóller y Fornalutx, que es continuación del sector septentrional antes citado. Aunque Manacor posee localmente uno de los más notables conjuntos de cavernas al Sur de Porto Cristo (Can Frasquet-Cala Varques), con un índice cercano a 14 cuevas por kilómetro cuadrado, el total de su extenso municipio sólo alcanza un valor de 0,12 cavidades por kilómetro cuadrado.

Clasificación geográfica de las cuevas y simas de Mallorca

En este apartado final se dedican unos breves párrafos a exponer los rasgos que merecen ser mencionados con relación a las cavidades existentes en cada una de las regiones y subregiones espeleológicas de Mallorca, teniendo en cuenta el nivel de conocimientos y exploraciones de que se dispone en la actualidad. Se intentarán asociar las diferentes clases de cavidades, tal como han sido definidas en un apartado anterior, con las áreas geográficas del karst insular en donde aquellas se encuentran bien representadas; un primer ensayo, realizado en este sentido, aparece en GINÉS y GINÉS (1974b) (Figura 10). Con la enumeración que sigue, las características más relevantes de las cavidades de los distintos conjuntos kársticos de Mallorca, así como su distribución y situación geográfica, podrán ser emplazadas en un contexto más preciso que el que hasta ahora nos permite la bibliografía, en la que escasean los trabajos de síntesis sobre las cuevas y simas mallorquinas.

SERRA DE TRAMUNTANA

Algunos de los datos más destacables acerca de los karst de la Serra de Tramuntana y de las cavidades localizadas en esta región kárstica aparecen comentados en GINÉS y GINÉS (1974b), en GINÉS et al. (1979) y en GINÉS (1983).

Ponent.— Abundan las cuevas y simas de estructuras muy variadas, a pesar de que las morfologías exokársticas son pobres y poco espectaculares. La frecuencia con que afloran materiales margosos no favorece el modelado de superficie propio del karst, pero sin embargo hay magníficos ejemplos de cavernas ricas en espeleotemas, como las Coves de Génova (Palma), Coves de Son Berenguer (Santa Maria del Camí) y Coves des Màrmol (Calvià). Algunos sectores poseen una notable densidad de cavidades como la Serra de na Burguesa y la Serra des Ram/Maristela. Predominan las cavidades clásticas, megaclásicas, fusiformes y tectónicas. Descripciones de algunas de las principales cavidades subterráneas que se hallan en esta región han sido publicadas en JOLY (1929), MONTORIOL-POUS (1962), MONTORIOL-POUS (1963), GINÉS y GINÉS (1972b) y CARDONA y FERRERES (1979).

Muntanya.— En este sector orográfico se encuentran las mayores alturas de la cordillera y además, en buena parte de su extensión, las formas kársticas de superficie adquieren una gran relevancia. El relieve es muy enérgico y la complicación geológica que muestran sus terrenos calizos es considerable, viéndose acentuada todavía más por una tectónica de pliegues-falla y cabalgamientos que imprimen un aire muy peculiar al paisaje. Es preciso hacer notar que la pluviosidad es intensa en esta región, rebasándose incluso los 1.200 mm en algunas localidades. La diversidad de tipos de cavidades representadas es tan grande que resulta preferible no detenerse a especificarlas grupo a grupo. No obstante, hay un claro predominio de las cavidades fusiformes mientras que varios de los escasos ejemplos de formas endokársticas de conducción se encuentran en esta región. Entre las pocas cavidades clásticas existentes allí se cuenta la Cova de sa Campana (Escorca), que es la más profunda de Mallorca con sus 304 metros de desnivel (MIR y TRIAS, 1973). También se localizan en estas montañas del centro de la Serra de Tramuntana las mayores simas de la Isla, como el Avenc des Gorg Blau (Escorca) que llega a 172 metros de profundidad. Descripciones de algunas de las principales cavidades subterráneas de esta región han sido publicadas en ESCOLÀ (1970), GINÉS y GINÉS (1971,1972a), MIR y TRIAS (1973), GINÉS y QUINTANA (1973), RIPOLL y ROCA (1974), ROMERO (1975), BARRERES et al. (1975-76), TRIAS (1979), GINÉS et al. (1980-82), GRUP ESPELEOLÒGIC EST (1982), GINÉS et al. (1985) y GRUP ESPELEOLÒGIC EST (1986).

Formentor.— Han sido exploradas unas cuantas cavidades, casi todas ellas fusiformes, de entre las cuales cabe mencionar el Avenc del Pla de les Basses (Pollença) que supera los 130 metros de desnivel (MEDIAVILLA, 1980) y fue ya citado por DARDER (1930) en un trabajo precursor sobre los fenómenos kársticos de Mallorca.

Muntanyes d'Alcúdia.— Se conocen un grupo de cavidades de estructura bastante singular, provistas casi todas de interesantes depósitos de espeleotemas. Descripciones de algunas de estas cavernas se pueden encontrar en ESCUDERO (1974), GINÉS y GINÉS (1974a) y TRIAS (1986).

Pollença/Vall den Marc.— La Vall den Marc y su prolongación natural, la Vall de Cala Sant Vicent, se hallan recorridas por una importante corriente de aguas subterráneas, observable a través de varias cavidades que jalonan su curso y que constituyen además elementos integrantes del sistema de drenaje. De entre estas cuevas se pueden citar el Avenc de na Borrassa, la Cova de Can Sivella y la Cova de les Rodes; todas ellas ubicadas en el término municipal de Pollença. A parte de estas cavidades activas, los alrededores de Pollença poseen toda una gama de formas endokársticas: cuevas fósiles bien concrecionadas, simas megaclásicas, cavidades tectónicas y simas fusiformes que actúan como unidades absorbentes dentro de este sistema kárstico tan bien caracterizado. Entre la bibliografía que incluye descripciones de cuevas y simas de esta región se pueden citar los trabajos de

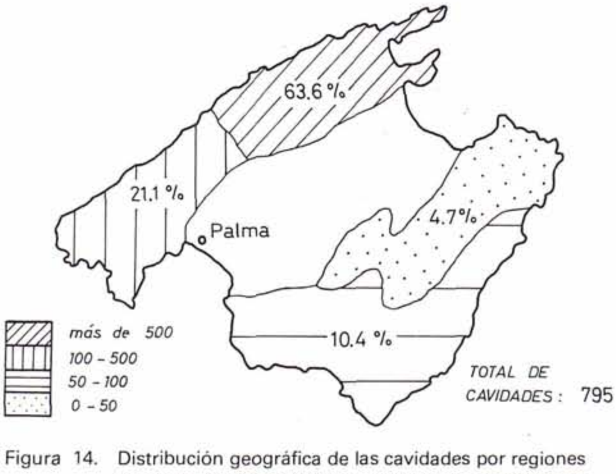

Figura 14. Distribución geográfica de las cavidades por regiones kársticas. Se aprecia cómo la Serra de Tramuntana registra una concentración muy importante de formas endokársticas.

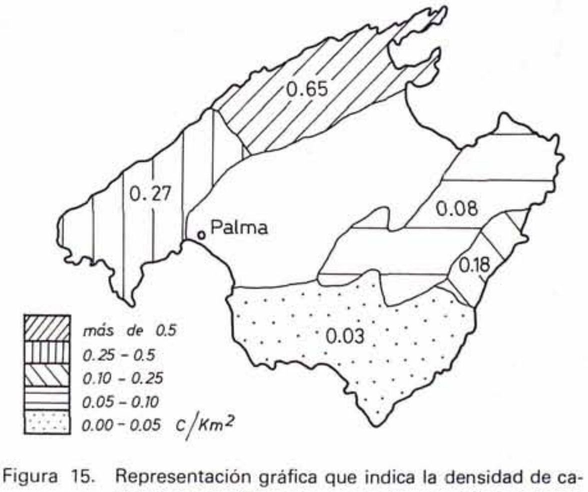

Figura 15. Representación gráfica que indica la densidad de cavidades por kilómetro cuadrado en varias regiones kársticas significativas. Los datos proceden de un muestreo de casi 800 cuevas y simas.

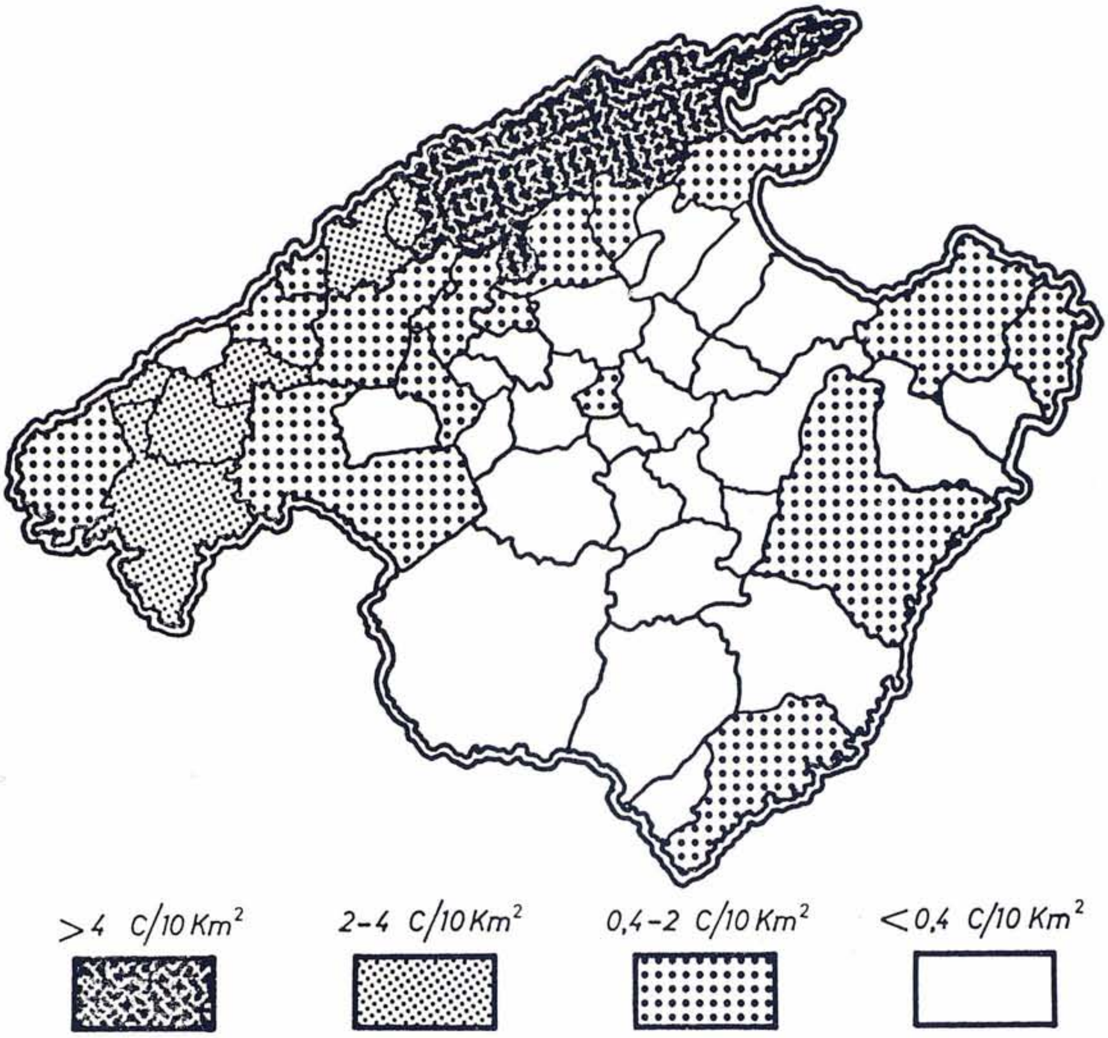

Figura 16. Mapa que expresa los valores de densidad de cavidades que corresponden, según datos del Inventari Espeleològic de les Balears (TRIAS et al., 1979), a los diferentes términos municipales de la Isla.

JOLY (1929), ENCINAS et al. (1972), MORRO y MORRO (1972), GRUP NORD DE MALLORCA (1973), MORRO y LLOBERA (1973) y GINÉS y GINÉS (1979).

PLA

La comarca central de la Isla consta de grandes mantos de aluviones, extendiéndose paralelamente al curso de la Serra de Tramuntana entre las bahías de Alcúdia y de Palma. Incluye, asimismo, los terrenos calizos que prolongan el Pla hacia el Este.

Muro/Santa Margalida.— Una pequeña zona karstificable se sitúa a lo largo de los términos municipales de Muro y Santa Margalida. Se trata de calcarenitas tortonienses en las cuales se han explorado varias cavidades freáticas. La más sobresaliente es la Cova de Sa Teulada (Santa Margalida) con sus 1.100 metros de recorrido laberíntico (THOMAS-CASAJUANA y MONTORIOL-POUS, 1953).

SERRES DE LLEVANT

Esta zona kárstica comprende el marco montañoso de la comarca de Artà y las alineaciones de colinas bajas y montañas aisladas que se extienden hacia Felanitx, en el Sureste, y hacia las inmediaciones de Llucmajor, en dirección Suroeste. Su uniformidad geológica se debe sobre todo a criterios de índole tectónica, puesto que a pequeña escala presenta aún mayor complejidad que la Serra de Tramuntana. Sus cavidades son variadas pero de dimensiones modestas.

Muntanyes d'Artà.— Abundan las simas, tanto fusiformes como megaclásicas, cuya profundidad es bastante reducida si exceptuamos el gran pozo del Avenc des Travessets (Artà), con su vertical absoluta de 145 metros (GINÉS, 1975). En la costa de Capdepera son frecuentes las cuevas intensamente concrecionadas (GINÉS, 1973 y GINÉS et al., 1975) y además se han explorado varias cuevas marinas.

Muntanyes meridionals.— Tanto en los Puig de Randa, Bonany y Sant Salvador, como en las colinas de los alrededores de Porreres y Manacor se encuentran interesantes cavernas fósiles, varias de las cuales han sido citadas en JOLY (1929) y en GINÉS (1983). La Cova Nova de Son Lluís (Porreres) y la Cova des Diners (Manacor) son las más relevantes, debido a sus grandes dimensiones (TRIAS, 1979b).

MIGJORN

Algunas de las principales características del karst y de las cavidades de esta amplia región ya han sido expuestas en los trabajos de GINÉS y GINÉS (1974b), GINÉS y GINÉS (1977) y GINÉS (1983).

Marina de Manacor.— Hay un absoluto predominio de las cuevas clásticas, en tanto que las cavidades verticales de aspecto fusiforme son casi inexistentes. Abundan también las cuevas marinas o relacionadas con la zona de erosión litoral, donde estos procesos dan origen a interesantes fenómenos kárstico-costeros. Las cavernas de esta región son notables por su uniformidad estructural, en la que resultan extraordinariamente frecuentes las salas y galerías abovedadas, y por los bellos conjuntos de espeleotemas que contienen. Por el contrario, muy pocas cavidades conservan vestigios de sus primitivas fases de excavación; circunstancia que dificulta la identificación de los mecanismos espeleogenéticos que las han engendrado. Descripciones de cuevas representativas de esta región kárstica se pueden consultar en MARTEL (1903), MAHEU (1912), JOLY (1929), DARDER (1930), GINÉS y GINÉS (1976), TRIAS y MIR (1977) y GINÉS y GINÉS (1977).

Marina de Felanitx y de Santanyí.— Hasta la fecha son pocas las cuevas exploradas en esta región, pero se comprueba un neto predominio de las cavernas de origen clástico. Se trata de un karst similar al de la Marina de Manacor, aunque la densidad de cavidades es mucho menor.

Sa Marina.— Poco se puede generalizar sobre las formas endokársticas de Sa Marina de Llucmajor/Campos, por ser todavia insuficientemente conocidas además de escasas en número. Junto a cuevas clásticas como la Cova des Pas de Vallgornera (Llucmajor) hay cavidades que muestran un sorprendente desarrollo vertical, como sucede con la Cova de Ses Sitjoles (Campos) y la cova de Sa Guitarreta (Llucmajor) descrita por MIR (1974).

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APUNTS SOBRE ELS AVENCS DEL PUIG MAJOR (Escorca, Mallorca)

per Miquel TRIAS
de la Secció d'Espeleologia del G.E.M.

Resum

Presentam aquí la descripció de quatre cavitats inèdites ubicades prop del cim del Puig Major, zona poc coneguda espeleològicament per albergar una base militar. La més notable d'elles, l'Avenc des Mamuts, té una fondària de 105 m. Una altra, el Clot des Teixos, amb els seus 1.360 m d'altitud, és la localitat més alta de la rata-pinyada *Myotis myotis* de Mallorca.

Abstract

The description of four pot-holes situated near the top of the Puig Major is presented. Very few speleological data were known because this area is a military base. The most outstanding of the pots is Avenc des Mamuts, 105 m deep. Another one, Clot des Teixos, 1.360 m high, is the highest majorcan site of the big bat *Myotis myotis*.

Introducció

El Puig Major de Son Torrella o de Torrelles és la muntanya més alta de Mallorca i la més destacada dins el conjunt de la Serra de Tramuntana. No tan sols és la més alta sinó també la més bella, amb els accesos més espectaculars, i la possibilitat de molts d'itineraris excursionistes, incloent travessies no massa cansades i ben variades. Amb la popularització de l'excursionisme a l'Illa, la seva pujada s'havia convertit en una clàssica, cantada per un dels poetes de l'Escola Mallorquina (OBRADOR, 1964). Els itineraris més fets partien de Son Torrella o de Montnàber per la Coma de n'Arbona seguint el camí dels nevaters. Un caminet ben construït feia més còmode el trajecte per l'aspre roquissar.

Dissortadament a finals dels anys cinquanta s'hi construeix una estació de radar militar, i la muntanya es fa inaccessible als excursionistes, almenys les parts properes a les construccions. Unes grandioses esferes ben visibles al cim demostraven fins a quin punt havia arribat la destrucció del paisatge mallorquí. Si bé que amb el temps alguns excursionistes agosarats començaren a trescar el Puig i a atracar-se a les instal·lacions militars, la prospecció espeleològica no hi va arribar, i poques notícies teníem de cavitats properes al cim i a la carretera d'accés.

Una bona excepció a aquest panorama era precisament l'Avenc des Mamuts, que per esser molt aprop d'un dels edificis de la base era conegut, i amb molt poc seny, emprat com a abocador. Havent tengut notícies d'aquesta cavitat i de la seva presumible fondària, l'Speleo Club Mallorca va sol·licitar permís a les autoritats militars per visitar-lo, i el 16 de març de 1975 va efectuar una exploració fins a −60.

Per diverses causes l'avenc va romandre ignorat durant onze anys fins que recentment, i aprofitant la bonissima disposició de l'actual comandament de la base, hem tengut ocasió de completar l'exploració i fer prospecció per les proximitats del cim. Fruit d'aquesta activitat és la nota que presentam i que no pretén ser un estudi de les cavitats del Puig Major en conjunt, sinó només d'un grup d'elles definides per esser fàcilment accessibles des de les instal·lacions militars i que foren explorades amb l'Avenc des Mamuts, objectiu principal de les activitats de la Secció d'Espeleologia del G.E.M. de finals de 1986 i principis de 1987.

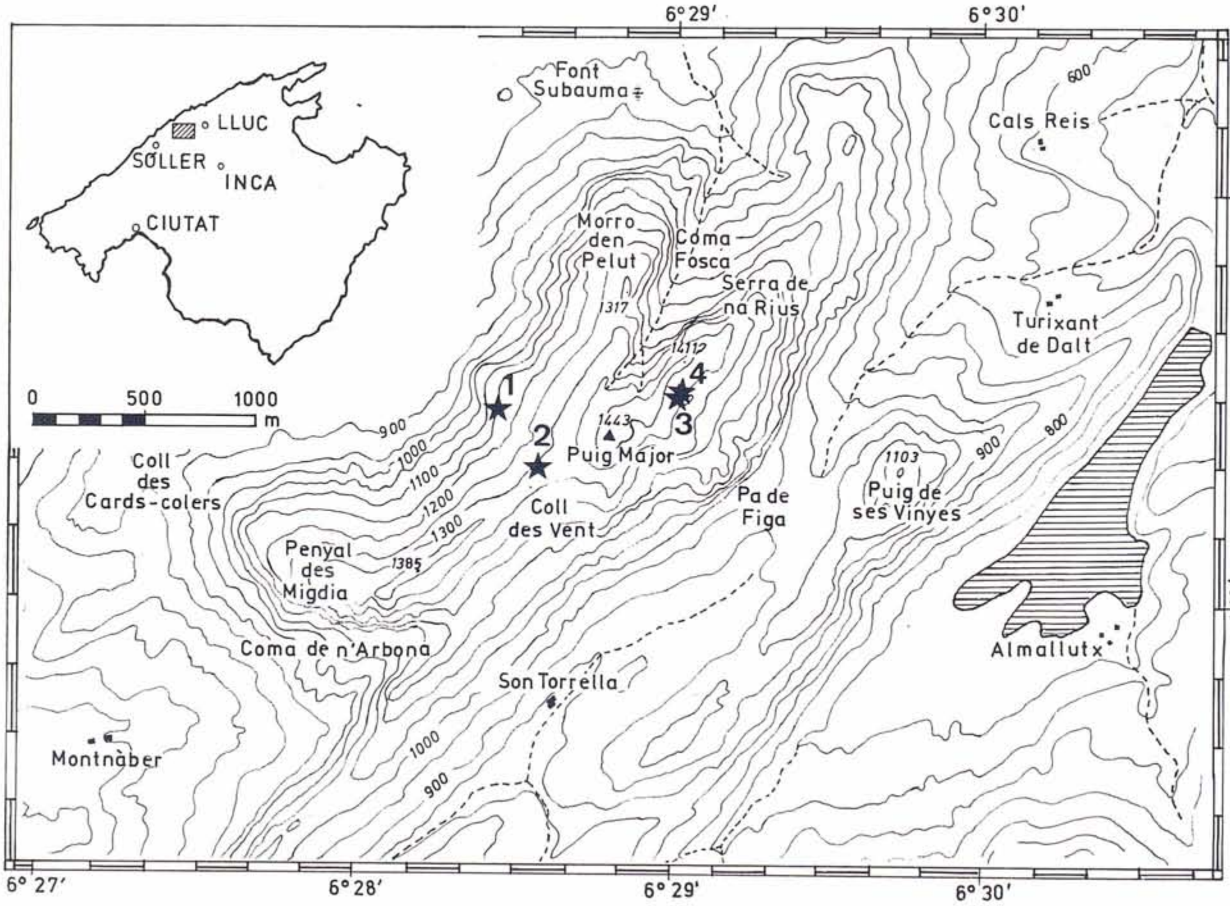
Volem agrair al Sr. Joan Oliver qui està al càrrec de les instal·lacions militars, el permís per accedir-hi, a més de la seva magnífica col·laboració que ens ha facilitat extraordinàriament la nostra tasca. Igualment hem de manifestar el nostre reconeixement a tot el personal de la base, de qui no hem rebut més que atencions en tot moment i ajuda quan l'hem haguda de mester.

No podríem deixar de fer menció dels companys del G.E.M. que han intervengut en aquestes exploracions, començant per l'entusiasta J.M. Álvarez, autèntic motor de la campanya, en la què han pres part també amb plena dedicació B. Company, V. Flores, A. Nadal i P.L. Cantó. Hem d'agrair també a J.A. Alcover la identificació del material quiropterològic esmentat més avall.

Aspectes geogràfics

Situat equidistant entre Lluc i Sóller, en el bell mig de la Serra Nord, el Puig Major forma un massís allargassat en direcció NE-SO, dominat a 1.443 m per la piràmide del cim (l'altitud és discutible ja que va esser aterrassat per construir-hi la base de radar). Dins aquest massís hi podem distinguir diverses parts amb entitat pròpia: cap al NE, el cim es continua per la Serra de na Rius, separada del Morro den Pelut per la Coma des Ribell o Coma Fosca que arriba pràcticament fins al cim. A poc més d'un quilòmetre del cim cap al SO, el Penyal des Migdia aixeca el seu imposant cingle dominant la Vall de Sóller. A l'altra banda de la Coma de n'Arbona, la Serra de Son Torrella continua el massís cap al SO. Més avall en direcció SE i clarament separat pel Coll de ses Escudelles hi trobam el contrafort del Puig de ses Vinyes.

Geològicament tot el conjunt és un paquet de calcàries massives grises del Lias inferior, part culminant de la cúpula anticlinal de la segona sèrie dels plecs que seguint una empenta del SE han format la Serra Nord (COLOM, 1975). La complicació tectònica i l'acció erosiva han donat origen als característics perfils piramidals del Puig Major amb timbes a totes les seves cares; recordem que la majoria de muntanyes de la Serra presenten una



Mapa general del massís del Puig Major amb la situació dels avencs. Els números són els mateixos del text.
El mapa ha estat idealitzat, suprimint-hi totes les construccions modernes.

vessant SE de pendent suau i una cara NO molt rosta, prop de la vertical.

Les formes càrstiques superficials, com és habitual a les parts altes de la Serra, en general no són gaire desenvolupades: rossegueres, lapiaz de diàclasi de poca fondària i algunes zones de relles petites dominen el paisatge. Contrastant amb la tònica general, la zona on s'obri el Clot dels Teixos presenta un bon modelatge càrstic. Aquella és el principi del coster que des del cim de la Serra de na Rius davalla en direcció al Puig de ses Vinyes, per acabar caient per l'imponent espadat del Pa de Figa fins al Coll de ses Escudelles. Aquí hi trobam excavada qualque dolina, no gaire extensa però de destacable fondària, alguns rellars i especialment notables exemplars d'avencs orbs i corredors càrstics, dels quals n'és un bon exemple el mateix Clot des Teixos.

Descripció dels avencs

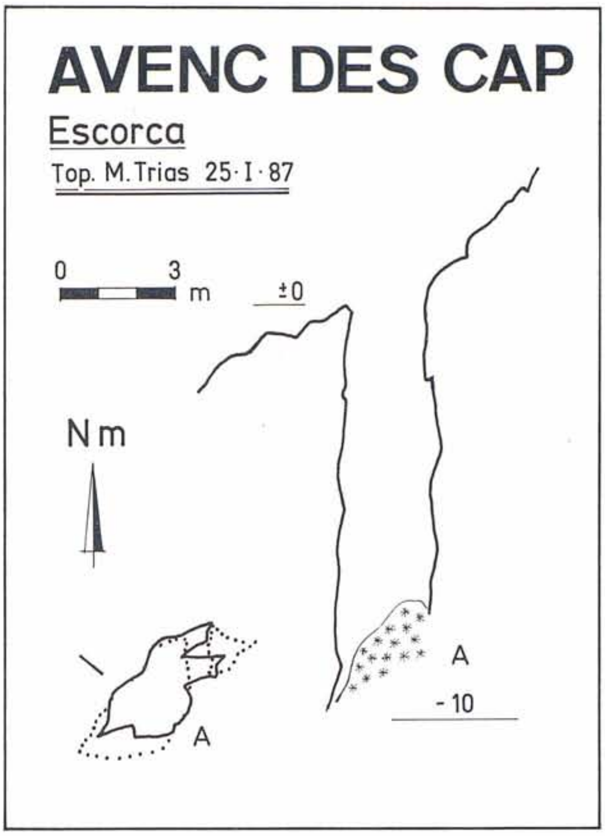
En conjunt les cavernes que descrivim en aquestes planes, presenten la característica comú d'esser cavitats verticals com és pràcticament general a les parts altes dels massisos, enfora dels nivells de base. Ara bé, dins aquest conjunt, presenten diferències prou notables per oferir-nos una casta de mostruari tipològic de cavitats verticals.

Dues d'elles (Avenc des Cap i Avenc Meu) són poca cosa més que formes de superfície, genèticament associades als esquetjars on s'obrin. Per ventura, l'Avenc des Cap presenti els trets típics dels *tessereft* (GINÉS et alia, 1980), cavitats d'evolució nival. És interessant que ens fixem que un dels aspectes d'aquests avencs, les parets solcades per canals de dissolució les trobam també a l'Avenc Meu.

Per altra part l'Avenc des Mamuts és un típic avenc de dissolució; els diferents pous que el formen s'han originat a partir de cavitats fusiformes, excavades sobre diverses fissures privilegiades per l'aigua infiltrada a la superfície d'una manera difusa. En canvi el Clot des Teixos s'ha originat gràcies a un aport hídric més concentrat, ja que ha funcionat com a engolidor d'una enclotada dins un esquetjar, si bé que els fusos coalescents de la seva zona interior semblen excavats per aigua d'infiltració zenital.

1. AVENC DES CAP

És un pou de 10 m de fondària sobre diàclasi NE-SO. La boca subdividida en dues parts desiguals, és lleugerament més grossa que el fons. Aquest fet i el modelatge de les parets formant canals i arestes molt marcats, fa que pensem que aquesta petita cavitat s'hagi fet fonda gràcies a l'acumulació de



neu, mecanisme que com hem vist més a dalt és típic dels *tessereft* algerins (GINÉS, et al., op. cit.).

2. AVENC DES MAMUTS

La cavitat s'obri a la cara Nord del Puig, 10 m per davall del Coll des Vent. La seva boca de 2 × 1 m ens posa en comunicació amb un pou de 70 m, el **Pou Major**. La part inicial d'aquest està sobre diàclasi NO-SE, a partir de −10 en segueix una altra de direcció NE-SO. Sobre aquests dos sistemes s'organitza tota la cavitat.

La davallada del **Pou Major** està animada per diversos accidents, a −28 hi trobam **Es Canteranos**, dos grandiosos blocs de roca *in situ* que l'excavació del pou seguint dues diàclasis paral·leles ha deixat a l'aire. Davall d'ells hi ha **Es Nínxol**, un bon refugi contra la caiguda de pedres, ben necessari en aquest pou. Pocs metres més avall d'**Es Nínxol** la planta del pou es fa rodonenca, per eixamplar-se passat el **Cul Fals**, replà rost cobert de pedres inestables, per sort fàcilment evitable. D'aquí la baixada és aèria fins al fons del pou a −72 m.

Aquest té planta en escaire seguint els dos sistemes de diàclasis, i un fort pendent. Des de la seva part alta podem accedir a través d'una finestra per davall d'un bloc pla d'aparença ominosa, al **Pou de sa Llosa** de 10 m de fondària, sense massa interés, tret del bufador que hi trobam abaix, a −72 i que pensam que pugui comunicar amb la part inferior del **Pou des Cans**.

Al darrer citat hi penetram pel **Pas des Vent**, situat entre els enderrocs de la part baixa del fons del **Pou Major**, a −75. Es tracta d'un buit de planta respectable: al principi té 8 × 3 m, en el fons assoleix els 20 × 7, formant una sala de direcció major NE-SO. Amb els seus 28 m de fondària el **Pou des Cans** en porta a −105, cota més baixa de l'avenc.

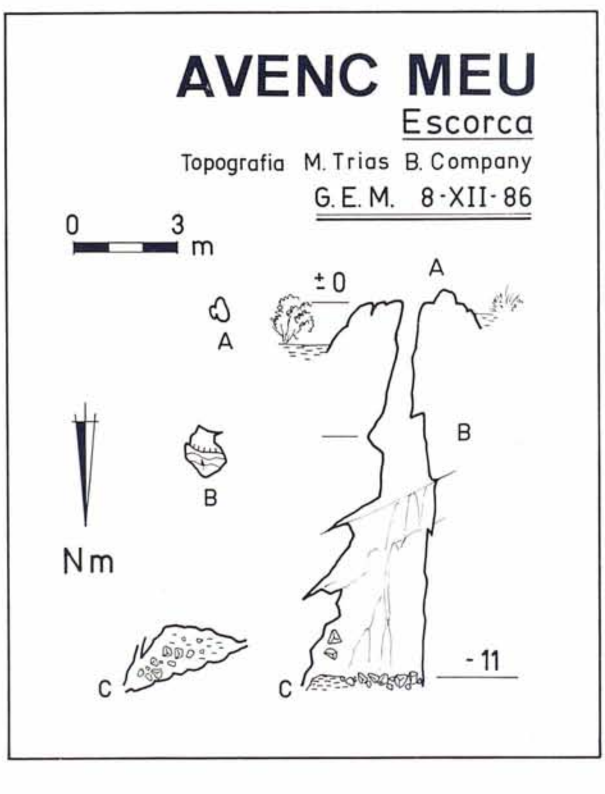
Tornant al **Nínxol**, ben davant d'ell hi tenim el **Pou de s'Artista**. Hi accedim amb una travessia començada desde l'ancoratge situat a 5 m per damunt del **Nínxol**. Aquest pou de 10 m de fondària sobre diàclasi NE-SO, es continua per una galeria de sòtil inabastable situada aproximadament damunt del **Pou des Cans**, enc que sens indicis de comunicació.

Morfològicament el predomini correspon a la dissolució, amb algunes zones on els procesos clàstics tenen una certa significació (sala al fons del **Pou des Cans**); més poc important volumètricament és la litogènesi, si bé que els recobriments parietals són molt abundants.

En el curs de les nostres visites collirem bastants d'ossos de quiròpters, pertanyents a l'espècie *Myotis myotis,* rata-pinyada de mida grossa que actualment sembla que no habita la cavitat, una dada més en el registre dramàtic de la desaparició d'aquests mamífers.

Com hem dit abans, la proximitat de l'Avenc des Mamuts a les instal·lacions militars ha fet que, com passa massa sovint, hagi estat aprofitat com a abocador per tota classe de deixalles, fins i tot bidons grossos. Entre les coses que s'hi han tirat es troben dispositius d'emissió i conducció de microones dels aparells de radar i de comunicacions de la base. El fet que aquestes peces emiteixin en funcionament radiacions perilloses, ha permès especular que a l'avenc s'hi llançaven materials radioactius, idea que ha estat recollida per la premsa regional en un article, per altra part ple de desbarats en l'aspecte espeleològic (*Última Hora* del dia 18-7-1985).

Malgrat la poca base d'aquestes suposicions, l'assumpte ha estat comprovat tant per interès dels responsables de les instal·lacions com pel propi interés dels exploradors. De fet ni l'ambient del pou on s'acaramullen les restes, ni les peces sospitoses han mostrat, exposades al comptador Geiger-Müller, nivells de radioactivitat distingibles de l'ambiental.



3. AVENC MEU

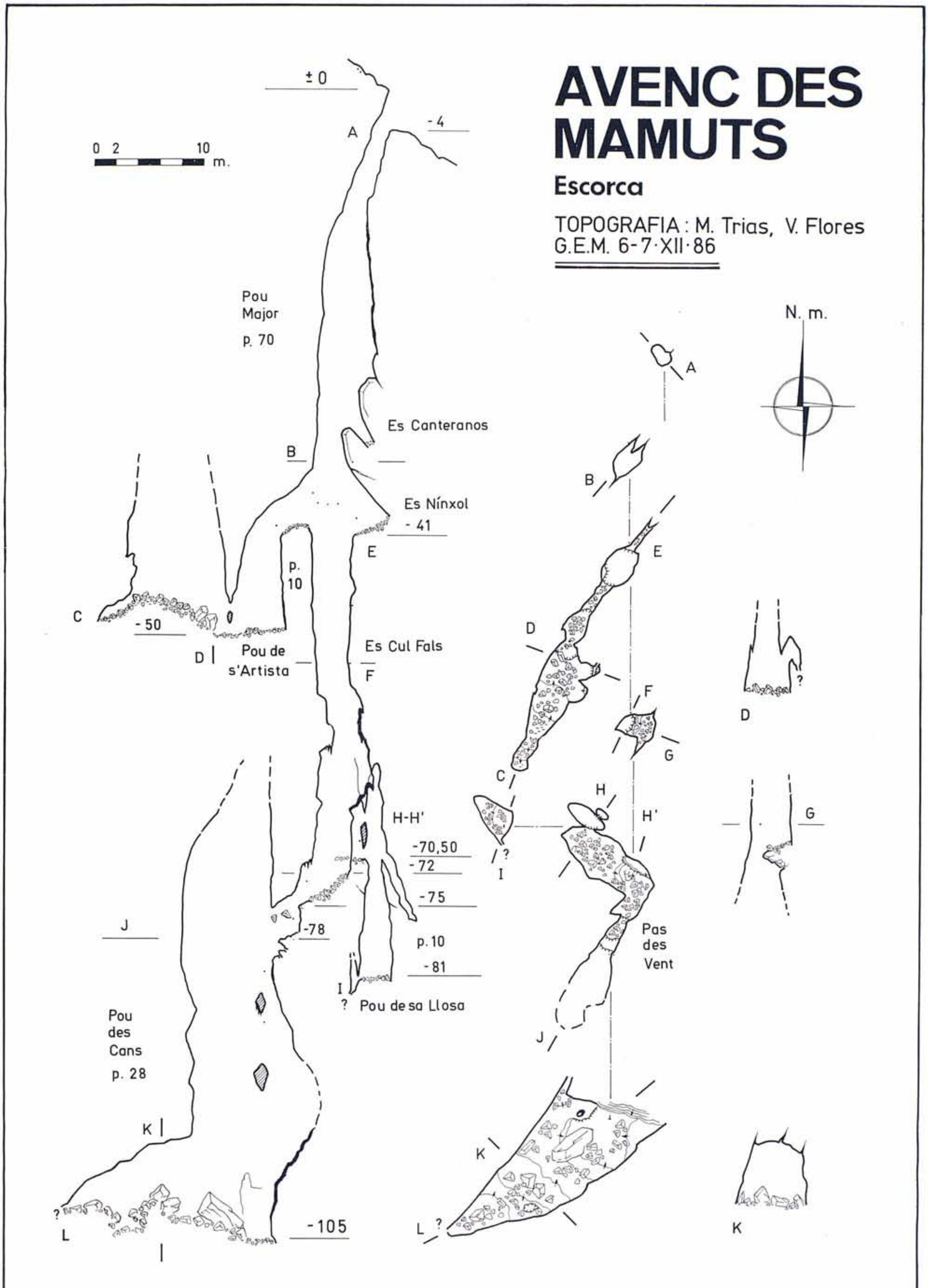
Petita cavitat de 11 m de fondària situada entre la dolina que trobam davall del Clot des Teixos i una altra dolina més a Ponent. Al seu únic pou hi entram per una boca de 60 × 40 cm; al principi subvertical, el pou mentres davalla es va eixamplant i girant fins a fer-se acampanat seguint diàclasi NE-SO. El fons de terra i pedres té unes dimensions de 4 × 1 m. Dins l'apartat morfològic, destacarem les canals de corrosió que solquen les parets de la seva zona inferior, del tot similar a l'esquetjar exterior.

4. CLOT DES TEIXOS

Com ja hem dit, davallant des del cim de la Serra de na Rius, i una mica més a Ponent, trobam una zona molt carstificada superficialment; dins ella i molt vistable, una petita dolina presenta la seva paret Sud coberta d'eura. Per damunt el costat NE de la dolina, uns arbres ens mostren la situació del Clot des Teixos.

Aquest s'ens apareix com a un *corredor càrstic,* fenomen també conegut amb el nom de *bogaz* què és el que se li dóna en el Carst (MAIRE, 1980). De fet aquesta forma càrstica es diferencia d'un avenc de diàclasi, en que és una forma de superfície de poca fondària. En el nostre cas, el corredor comunica amb un autèntic avenc a la seva part Oest. La zona hipogea consta de dues parts ben diferenciades: un pou de 19 m amb un replà a la meitat, la segona és un rosari de petits fusos escalonats sobre diàclasi NO-SE, que davallen fins a −36, mínima cota de la cavitat. La morfologia de dissolució té un predomini quasi absolut a tot l'avenc.

Tal com ja hem dit, podem suposar una gènesi diferenciada: els pous s'haurien excavat a partir de


AVENC DES MAMUTS
Escorca
TOPOGRAFIA : M. Trias, V. Flores
G.E.M. 6-7·XII·86
N. m.
0 2 10 m.
± 0
- 4
A
Pou
Major
p. 70
Es Canteranos
B
Es Nínxol
- 41
E
p.
10
C
- 50
D
Pou de
s'Artista
Es Cul Fals
F
H-H'
-70,50
-72
-75
J
-78
p. 10
- 81
I
? Pou de sa Llosa
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des
Cans
p. 28
K
L
- 105
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Pas
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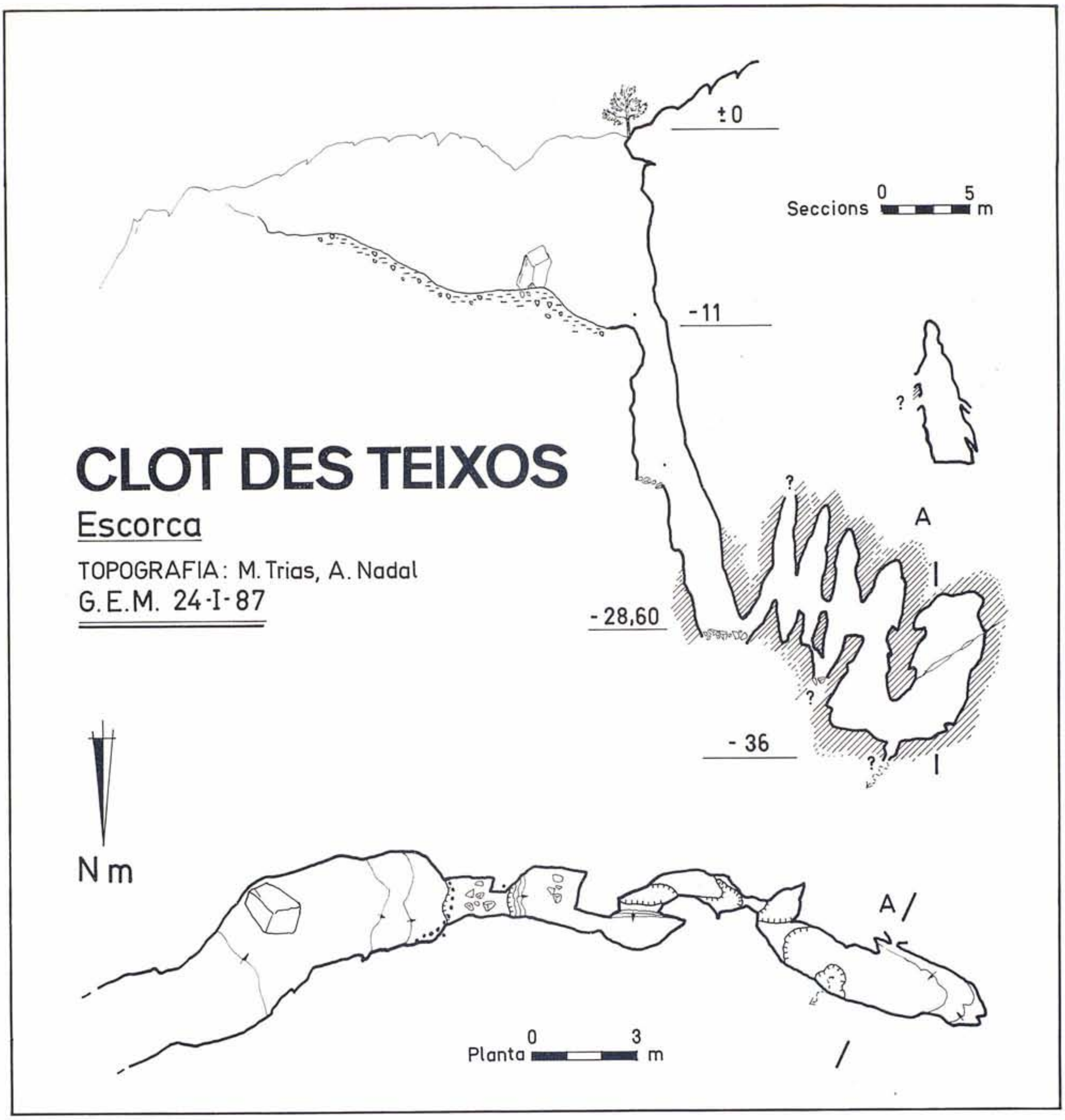

l'aigua recollida en el corredor, què en temps passat en podria replegar més (ara és a una eminència del terreny, però podria haver estat enclotat); en la gènesi dels fusos tendrien més importància els aports difusos de l'esquetjar que tenen a damunt.

Aquí també trobàrem restes de *Myotis myotis;* per tant aquest avenc, situat a 1.360 m d'altitud, és la localització més alta de la dita espècie a Mallorca.

Aquestes enclotades són amb els penyals, per les seves condicions d'ombra i humitat, excel·lent refugi per a les espècies vegetals relictes de temps més freds i que ara són pròpies de regions centreuropees. Hi trobam teixos *(Taxus baccata)* junt amb els arbres de fulla caduca, rotaboc *(Acer granatensis)* i pomera borda *(Sorbus aria).*

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OBSERVACIONES SOBRE LA CONCENTRACIÓN DE DIÓXIDO DE CARBONO EN LA ATMÓSFERA DE LA COVA DE LES RODES (Pollença, Mallorca)

por Ángel GINÉS, Justo HERNÁNDEZ, Joaquín GINÉS y Andreu POL
del Grup Espeleològic EST. Palma de Mallorca.

Resum

Les dades obtengudes en l'atmosfera de la Cova de les Rodes (Pollença) mitjançant 14 sèries d'observacions, que foren realitzades entre Abril de 1982 i Març de 1983, han permès comprovar l'existència d'una important oscil·lació cíclica anual del contingut en diòxid de carboni.

La informació que s'ha aconseguit reunir correspon a un total de 40 mesures fetes amb la tècnica Draeger, havent-se triat com a estacions de medició 6 llocs suficientment representatius de la topografia de la cavitat, que endemés tenen l'avantatge d'estar distribuïts al llarg d'un recorregut de quasi 400 metres: és a dir, des de prop de l'entrada fins al punt més allunyat d'ella.

Es constata que els valors de la concentració de diòxid de carboni registrats en l'atmosfera de la Cova de les Rodes fluctuen entre 4,9 % i menys de 0,1 % en volum, i presenten un màxim a l'estiu i un mínim durant els mesos de Març-Abril. Són especialment significatives les 5 sèries d'observacions que van des del 23 de Maig fins l'11 de Juliol de 1982, ja que posen de manifest la rapidesa amb què es produeix l'ocupació de l'atmosfera de la cavitat per l'aire enriquit en diòxid de carboni, provinent de les escletxes que enrevolten la cova. Malgrat que els coneixements disponibles sobre la dinàmica de l'aire i sobre les característiques microclimàtiques de la Cova de les Rodes són encara escassos, s'han pogut elaborar algunes conclusions sobre el comportament del diòxid de carboni en les escletxes i coves dels sistemes càrstics de Mallorca.

Abstract

Data obtained from the atmosphere of the Cova de les Rodes (Pollença) through 14 series of observations, accomplished between April 1982 and March 1983, give evidence that there is an important annual cyclic oscillation in carbon dioxide contents.

All information assembled is a result of 40 measurements using the Draeger technique. Measurement stations choosed were 6 places sufficiently representative of the topography of the cavity. Moreover, there is the advantage that they are allocated over a distance of nearly 400 metres, that is, from the immediate area of the entrance to the far end of the cave.

It is proved that carbon dioxide concentration values recorded from the atmosphere of the Cova de les Rodes oscillate between 4.9 % and less than 0.1 % in volume, peaking a maximum in summer and a minimum in March-April. The 5 series of observations from 23th May 1982 to 11th July 1982 are specially significant as they show how quickly the atmosphere of the cave is occupied by carbon dioxide enriched air, originated in the fissures surrounding the cavity. Despite of the lack of knowledge available by now on the air dynamics and microclimatic characteristics of the Cova de les Rodes, some conclusions on the carbon dioxide behaviour in the fissures and caves of the karstic systems in Mallorca have been reached.

Introducción

El dióxido de carbono desempeña un papel fundamental en los procesos de karstificación debido a su capacidad para disolverse en el agua y producir ácido carbónico. De hecho, la cantidad total de caliza que puede ser disuelta en forma de bicarbonato cálcico por unidad de volumen de agua es función de la presión parcial de CO_2 (pCO_2) disponible en el aire que se halla en contacto con ella o, lo que es lo mismo, de la concentración de dicho gas en el medio. Las principales fuentes de aprovisionamiento de CO_2 están constituidas por la atmósfera y sobre todo por la actividad metabólica de la vegetación y de los seres vivos que habitan en el suelo. Mientras las concentraciones de CO_2 atmosférico son bastante uniformes, pudiéndose evaluar en torno al 0,03 % en volumen, los niveles de dióxido de carbono existentes en el aire del suelo son variables y casi siempre mucho más altos, como consecuencia de la respiración de las raíces de las plantas y de la degradación de materia orgánica llevada a cabo por los microorganismos edáficos.

En la actualidad, el dióxido de carbono de origen «biogénico» es considerado por muchos investigadores como el principal factor que controla la disolución de la caliza y, por consiguiente, los procesos de karstificación (JAKUCS, 1977; JENNINGS, 1985 y TRUDGILL, 1985; entre otros). Parece bien establecido que la zona edáfica es ciertamente la responsable de la mayor parte de la agresividad química de las aguas que ingresan en el karst, debido al importante aporte de CO_2 biogénico con el que éstas tienden a equilibrarse durante su permanencia temporal en el suelo. Cuando, más tarde, el agua que se ha infiltrado a través de las fisuras de la roca aparece en el techo de una caverna, la concentración de su CO_2 disuelto resulta superior a la del aire circundante y una cierta proporción del CO_2 se desprende por difusión pasando a enriquecer la atmósfera de la cavidad en gas carbónico.

Este mecanismo de transporte de gas carbónico, disuelto en las aguas de infiltración, se verifica no tan sólo a nivel de las cuevas penetrables por el hombre sino que también ocurre, según parece a mayor escala, a nivel de la red de grietas y fisuras que rodea las cuevas, tal como lo sugiere BAKALOWICZ (1979). Es preciso tener en cuenta además los desplazamientos de dióxido de carbono que se realizan en estado gaseoso, pues las circulaciones de aire que afectan a grietas y cavidades de mayor tamaño, especialmente en las zonas de vertiente (RENAULT, 1972), y los fenómenos de difusión o decantación por gravedad que pueden suceder en el interior del karst, son capaces de movilizar masas de aire subterráneas dentro de la zona de infiltración de una manera extremadamente compleja.

Las observaciones cuantitativas sobre la composición química del aire de las cuevas comenzaron a ser abordadas probablemente a partir de TROMBE (1952) y han aumentado mucho en los últimos tiempos como resultado de los trabajos de DELECOUR et al. (1968), EK et al. (1968), RENAULT (1971, 1972), JAMES (1975, 1977), EK (1979) y RENAULT (1979). Las investigaciones recientes, aunque localizadas sobre todo en cuevas de Bélgica, Francia y Australia, se han ido progresivamente generalizando a otros terrenos kársticos de diferentes características bioclimáticas, de tal manera que hoy se dispone de abundantes datos cuantitativos que han permitido elaborar interpretaciones de más amplio alcance.

En algunas publicaciones como las de JAMES y DYSON (1981) o CHOPPY (1983) se encuentra resumida con mucho acierto la problemática del comportamiento del CO_2 en la atmósfera de las cuevas, desde un punto de vista exclusivamente espeleológico. Por otra parte, varios autores han intentado considerar la distribución del dióxido de carbono en el karst como si toda la zona de infiltración (zona vadosa) constituyera un vasto reservorio de CO_2, el cual intervendría activamente en los equilibrios químicos que afectan al agua durante su trayecto subterráneo. Estas modernas perspectivas de la karstogénesis parten del concepto de pCO_2 equilibrante desarrollado por ROQUES (1963) y se encuentran formuladas, junto con nuevos enfoques, en ATKINSON (1977) y BAKALOWICZ (1979).

El dióxido de carbono en las cuevas de Mallorca

Por lo que concierne a Mallorca (Figura 1) la primera referencia a elevadas concentraciones de CO_2 en cuevas de la Isla aparece en BOVER (1839), con relación a la Cova Nova de Son Lluís (Porreres). Sin embargo publicaciones posteriores llegaron a crear cierta confusión, pues mientras MARTEL (1903) señala, aunque sin visitar la cueva, que su propietario le había confirmado la existencia de aire irrespirable en algunos sectores, JOLY (1929), habiéndola explorado personalmente, niega que ello fuera cierto. Las mediciones efectuadas el 28 de Febrero de 1982 han permitido demostrar de modo concluyente que el contenido en CO_2 de la Cova Nova de Son Lluís es ciertamente considerable, incluso durante la época invernal, alcanzando magnitudes de hasta 3,5 % en volumen (GINÉS, 1983).

Las informaciones disponibles a partir de la década de los sesenta, a medida que la espeleolo-

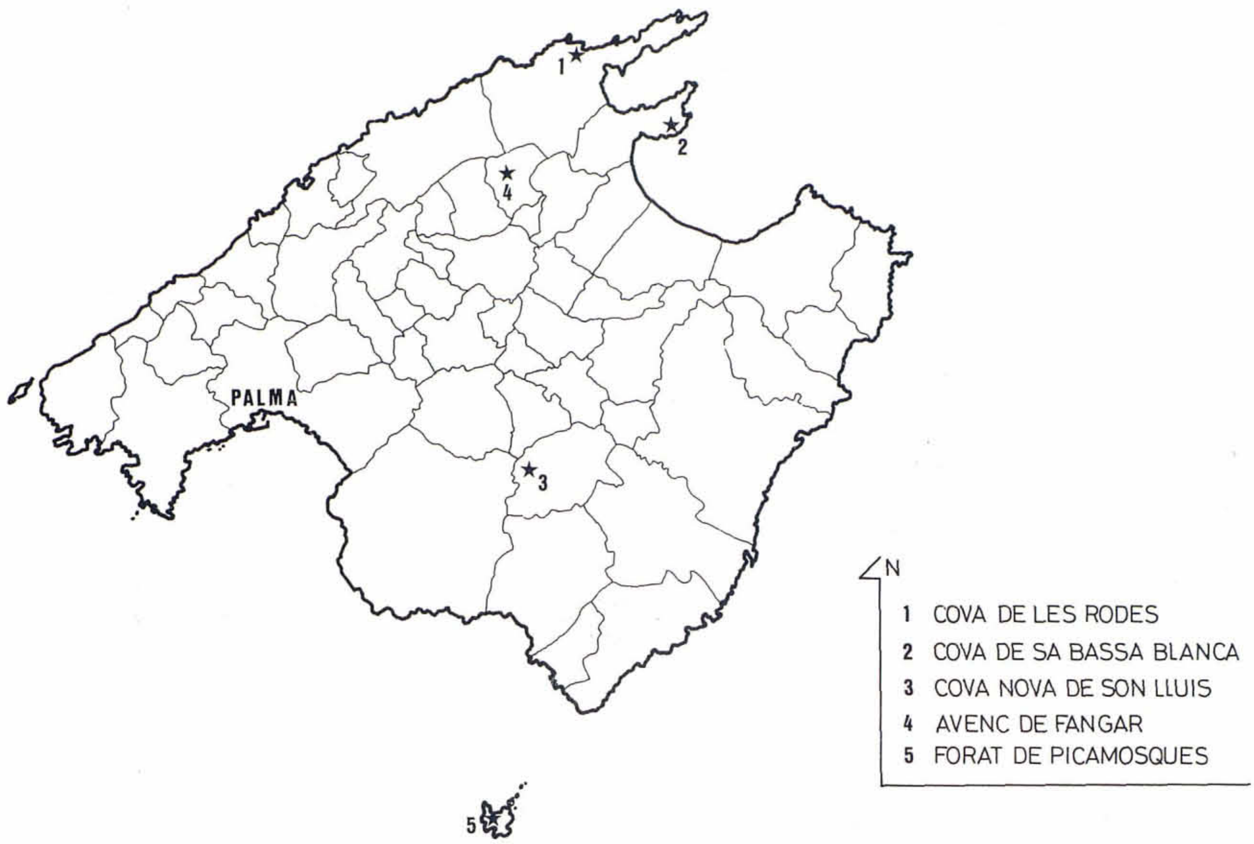

Figura 1. Localización de las cavidades más significativas citadas en el texto.

gía comienza una considerable expansión en nuestro país, están centradas sobre todo en los problemas de exploración planteados en algunas simas por niveles anormalmente altos de CO_2. MONTORIOL-POUS (1961) indica la presencia en el Forat de Picamosques (Isla de Cabrera) de una «notable cantidad de anhídrido carbónico que llega a apagar las lámparas de acetileno haciendo la exploración peligrosa» y constata que en aquella sima la cantidad de CO_2 aumenta con la profundidad. Por su parte, ASTIER y VILLA (1967) exponen las dificultades con que se encontraron durante la exploración parcial del Avenc de Fangar (Campanet) como consecuencia de una importante acumulación de dióxido de carbono, aunque exageran tanto en la profundidad que atribuyen a la sima como en la casi imposibilidad de explorarla sin medios técnicos especiales. Datos cualitativos mucho más fiables y precisos son proporcionados por ESCOLÀ (1970), al comentar detalladamente la distribución del CO_2 en el Avenc de Fangar desde los 80 metros de profundidad hasta las cotas inferiores de la sima, establecidas en torno a los −163 metros. Entre tanto otras observaciones similares, pero no publicadas, se iban reuniendo por grupos espeleológicos mallorquines sobre cavidades en las que cerillas, velas y lámparas de acetileno funcionaban irregularmente o donde se apreciaban condiciones de respiración dificultosa, como es el caso del Avenc Cremat (Puigpunyent), Avenc de Son Forté (Artà), Avenc de Son Mas (Valldemossa) y Cova de Sa Bassa Blanca (Alcúdia) entre otras.

Los primeros datos cuantitativos obtenidos sobre concentraciones de dióxido de carbono en la atmósfera de cuevas mallorquinas se deben a MESTRE (1980), quien realizó varias mediciones con detector Draeger en la Cova de les Rodes (Pollença). Sus observaciones, tanto las efectuadas en Febrero de 1979 (en las que se registraron valores que apenas superaban el 0,1 %) como las que llevó a cabo en Octubre del mismo año (alcanzándose concentraciones comprendidas entre el 3,1 % y 4,2 %) permitían comprobar la existencia de fluctuaciones estacionales que ya habían sido advertidas con anterioridad por algunos espeleólogos a lo largo de repetidas visitas a la cueva (J.A. Encinas, com. pers.). También mediante la utilización del detector Draeger, MAROTO y FONT (1981) dan cuenta de niveles de CO_2 superiores al 2 % en la Cova de Sa Bassa Blanca (2 de Marzo de 1981), aunque mediciones todavía inéditas han llegado a detectar hasta 2,5 % en Agosto de 1984. Más recientemente, GINÉS (1983) ha presentado los resultados de 33 mediciones del contenido en CO_2 de varias cuevas de Mallorca, así como algunas interpretaciones provisionales dentro de un enfoque ecológico. La mayor parte de dichas mediciones son un avance de los datos que sirven de base al presente trabajo y han sido efectuadas en la Cova de les Rodes (Pollença).

Medidas realizadas

Las mediciones de dióxido de carbono que han hecho posible el seguimiento y estudio de la evolución de la atmósfera de la Cova de les Rodes, durante un ciclo anual completo, fueron obtenidas mediante la utilización de una bomba manual Draeger cuya denominación en el mercado es «Auer Gas Tester». Se necesitó dedicar 14 visitas a la cueva con el fin de conseguir una cuantificación suficientemente afinada de los cambios estacionales en su pCO_2, de tal manera que se cumpliera como mínimo una frecuencia mensual, además de completar la campaña con otras dos exploraciones adicionales en las que se buscó coincidir con momentos en que se preveían modificaciones bruscas en las concentraciones de CO_2.

El detector Draeger que fue empleado en las mediciones consiste en un aparato portátil, ligero y nada frágil, que permite evaluar con bastante precisión el porcentaje de gas carbónico contenido en el aire del entorno, sirviéndose de indicadores coloreados específicos para el CO_2. Este detector consta de una pera aspiradora de goma, calibrada para un volumen de 100 centímetros cúbicos y dotada de un elemento central de material plástico que sostiene la pieza porta-tubos, en donde se han de insertar los tubos colorimétricos. Después de comprimir y soltar la pera de goma, la longitud de la coloración que se alcanza en la columna interior del tubo proporciona una lectura directa, expresada en tanto por cien en volumen, de la concentración de dióxido de carbono que está presente en la muestra de aire analizada. El fundamento químico de los tubos colorimétricos del aparato Draeger se basa en la absorción del CO_2 por las aminas. El desplazamiento en el valor del pH ocasiona el cambio de color de un indicador ácido-base.

Las 40 mediciones efectuadas en el curso de la campaña se repartieron a lo largo de 6 estaciones escogidas previamente en base a dos objetivos prioritarios: 1) las estaciones debían reflejar la complejidad topográfica de la cavidad, localizándose cerca de los más importantes estrechamientos o desniveles que presenta la galería principal de la cueva, obstáculos que quizás pudieran tener alguna significación en los movimientos de aire que renuevan periódicamente su atmósfera; y 2) las estaciones debían espaciarse con una cierta regularidad desde la entrada hasta el fondo de la caverna, jalonando su recorrido, a fin de intentar captar la procedencia interna o externa de los cambios estacionales en el contenido de CO_2 del aire subterráneo y para poder delimitar al mismo tiempo los gradientes de pCO_2 que pudieran aparecer.

La localización de las 6 estaciones que fueron seleccionadas aparece indicada en la Figura 2, sobre una topografía esquemática que procede de la bibliografía existente (ENCINAS, 1972). La estación

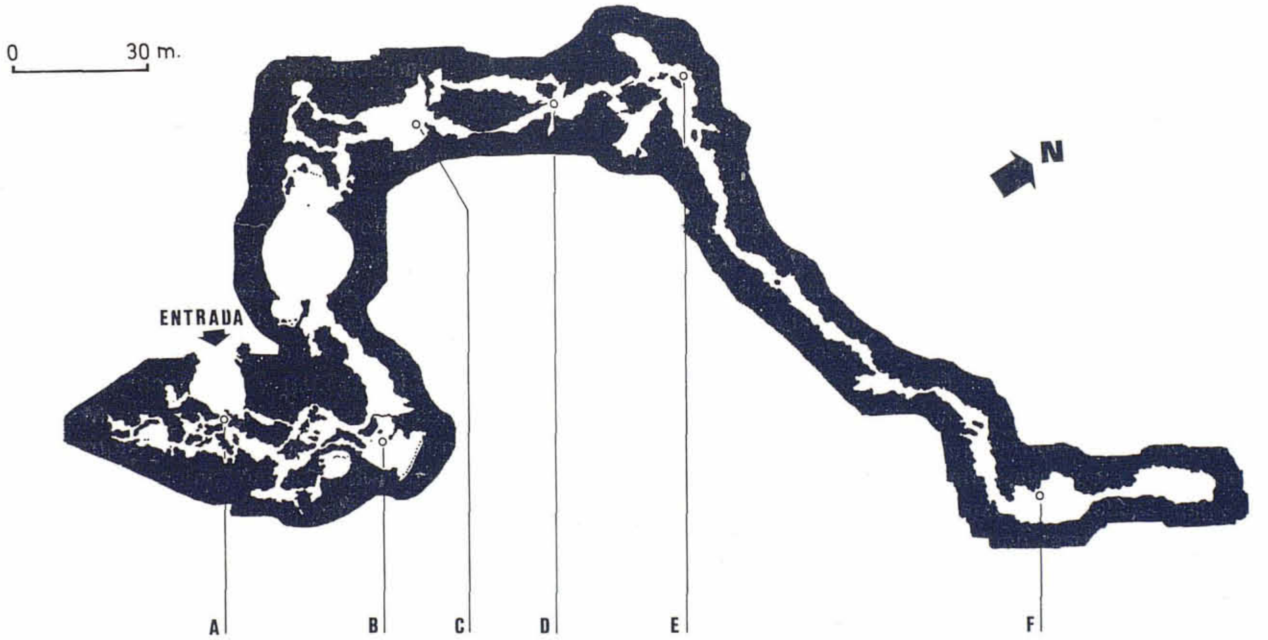

Figura 2. Emplazamiento aproximado de las estaciones de medición sobre una topografía esquemática de la Cova de les Rodes.

A se sitúa muy cerca de la entrada, al fondo de la primera sala, donde su trayectoria tuerce hacia el Norte para dar inicio a la galería principal. La estación **B** está emplazada en la sala del primer pozo, justo en el lugar en el que desemboca la galería de acceso. La estación **C** corresponde a la orilla del primer pequeño lago que presenta la cueva; se trata de un lago que interrumpe frontalmente la galería y obliga a sortearlo remontando por una pendiente arcillosa que permite comunicar con un tramo de conductos fósiles de techo bajo. La estación **D** se encuentra en el fondo del segundo pozo, antes de iniciar la sucesión de pasos estrechos en los que comienza a oírse el ruido del río subterráneo. La estación **E** ha sido ubicada deliberadamente en un ramal, que se desvía hacia el Oeste, de cuya pared brota buena parte del caudal del río formando una pequeña cascada. Por último, la estación **F** se halla en el extremo más alejado de la galería principal de la caverna, poco antes de llegar al sifón terminal y bajo unas cúpulas que muestran interesantes formas de corrosión.

Debido a que sólo disponíamos de un limitado número de tubos colorimétricos, fue necesario administrar convenientemente la cantidad de mediciones a realizar y distribuirlas en las 6 estaciones de tal modo que por lo menos se consiguieran varios datos significativos de todas ellas, sin detrimento de que algunas estaciones fueran muestreadas con mucha mayor regularidad. Precisamente era mediante estas observaciones, reiteradas con una frecuencia superior en determinadas estaciones, como se pretendía poder cuantificar el ciclo de oscilación anual que, según informaciones aportadas por las exploraciones de espeleólogos y de acuerdo con las medidas publicadas por MESTRE (1980), se suponía que caracterizaba a la atmósfera de la Cova de les Rodes. Para tal fin y considerando sus emplazamientos respectivos, se escogieron de entre los 6 puntos de observación las estaciones **B** (cercana a la entrada), **C** (representativa del tramo medio de la cavidad) y **F** (en las galerías finales) para la realización en ellas de muestreos regulares. Así, de entre las 40 mediciones verificadas durante la campaña, 11 pertenecen a la estación **B** y otras 11, aunque de fechas no necesariamente coincidentes, han sido obtenidas en la estación **C**. Los escasos datos procedentes de la estación **F** son consecuencia de las elevadas pCO_2 que se registran desde finales del mes de Mayo, haciendo peligrosa la exploración de este tramo de la cueva durante el verano por alcanzarse valores superiores al 4,5 %. Las restantes estaciones, aunque insuficientemente muestreadas, proporcionan sin embargo datos puntuales interesantes: la estación **A** permitió detectar en Julio valores de hasta 4 % a menos de 15 metros de distancia del exterior; la estación **D** ayudaba a establecer posibles gradientes; y la estación **E** posee la cualidad de estar situada en un punto de contacto con el río subterráneo, pudiendo informar sobre el papel del agua del río en los intercambios gaseosos con la atmósfera de la cueva.

Los resultados obtenidos (Tabla I) denotan en todas las estaciones una clara pauta de oscilación anual. Ninguna de las estaciones muestreadas es ajena a esa tendencia cíclica. Para mejor evidenciar este hecho, la Figura 3 representa gráficamente los valores registrados durante todo el año en las estaciones **B, C, D** y **F**. Así, en la Figura 3a se percibe con gran nitidez el incremento de la concentración de CO_2 que comienza a producirse desde principios del mes de Abril, así como su progresiva disminución durante los meses de otoño. Debido al menor número de mediciones efectuadas, la Figura 3b es mucho menos precisa, aunque informa suficientemente sobre la tendencia que predomina a lo largo del ciclo anual. Si se comparan entre sí las gráficas correspondientes a esas 4 estaciones, se comprueba la existencia de un fuerte paralelismo que sólo resulta distorsionado por ligeros desfases. La forma de los picos que aparecen en la Figura 3a pone de manifiesto las diferencias en el comportamiento del dióxido de carbono a nivel de las estaciones **B** y **C**, presentando además la ventaja de que ambas gráficas están basadas en un conjunto de mediciones (11 en cada estación) relativamente significativo. La mayor frecuencia con que se repitieron las observaciones en la estación **B** durante el curso de los meses de Mayo a Julio, obedece a la oportunidad excepcional que se nos ofreció de registrar la fase de «crecida» del CO_2 en la atmósfera de la cueva. En cambio, una mayor atención fue prestada, en la estación **C**, al proceso de «retirada» del gas carbónico durante los meses de invierno. Las gráficas pertenecientes a las otras dos estaciones (Figura 3b) son menos rigurosamente comparables ya que, mientras la estación **D** fue muestreada en 6 ocasiones, sólo se pudieron realizar 4 medidas en la estación **F** (localizada en el punto más profundo y lejano de la cueva) a causa de las mencionadas dificultades de exploración y de los pocos tubos de medición que poseíamos. No obstante, ambas gráficas parecen indicar una progresiva suavización de su perfil cuanto mayor es la distancia que separa las estaciones respecto de la entrada de la caverna.

En la Figura 4a se puede seguir el desenvolvimiento de la fase de «crecida» en el conjunto de las 6 estaciones que jalonan el recorrido de la Cova de les Rodes. Se aprecia cómo los valores registrados el 23-V-82 delimitan un gradiente muy acusado, que va desde 0,2 %, junto a la entrada, hasta 3,5 % en el fondo de la cueva; se trata de un gradiente sobre todo longitudinal puesto que los desniveles de la cueva no son demasiado relevantes.

Mediciones del contenido en dióxido de carbono de la Cova de les Rodes (Pollença)

Fecha de la observación	Estaciones A	B	C	D	E	F
4-IV-82		ND	ND			
23-V-82	0,2 %	0,2 %	1,5 %	2,0 %	2,2 %	3,5 %
5-VI-82		0,7 %				
13-VI-82		2,8 %	2,9 %	3,5 %		
20-VI-82	2,7 %	2,8 %				
11-VII-82	4,0 %	4,5 %	4,2 %	4,3 %		
8-VIII-82		3,3 %	3,9 %	4,1 %		
5-IX-82	2,8 %	3,5 %	4,2 %			
10-X-82		1,0 %	4,0 %	4,0 %		4,9 %
14-XI-82		0,2 %	2,7 %			
26-XII-82		0,1 %	0,2 %	0,3 %	3,0 %	1,2 %
23-I-83			0,1 %		0,3 %	
20-II-83					1,5 %	0,8 %
27-III-83			0,1 %			
18-II-79		0,15 %	0,1 %		según MESTRE (1980)	
13-X-79		3,1 %	4,2 %	3,6 %		

Mediciones del contenido en dióxido de carbono de otras cuevas mallorquinas

2-III-81	Cova de Sa Bassa Blanca (Alcúdia), 30 mts. prof.	2 %
27-II-82	Cova de Sa Guitarreta (Llucmajor), 25 mts. prof.	ND
28-II-82	Cova Nova de Son Lluís (Porreres), 35 mts. prof.	3,5 %
12-VIII-84	Cova de Sa Bassa Blanca (Alcúdia), 30 mts. prof.	2,5 %

ND = valores de pCO_2 no detectables

Tabla I

Datos posteriores, especialmente los obtenidos el 11-VII-82, parecen sugerir una estabilización gradual de la concentración de CO_2 alrededor de valores próximos al 4,5 %. La secuencia de lecturas verificada con periodicidad casi quincenal en la estación **B**, durante las exploraciones de los días 23-V-82, 5-VI-82, 13-VI-82 y 11-VII-82 (Tabla I), terminan de ilustrar la rápida invasión de la zona de entrada por aire enriquecido considerablemente en dióxido de carbono.

El proceso inverso, que refleja la fase de «retirada» del CO_2, ha podido ser documentado con amplitud en la Figura 4b, donde un grupo de datos conseguidos en las visitas de fecha 11-VII-82, 8-VIII-82 y 10-X-82 señalan una reaparición e intensificación del gradiente en las inmediaciones de la boca de la cueva. Si estas tres representaciones son confrontadas con la que describe, en la misma Figura 4b, los datos procedentes de la exploración del 26-XII-82, queda patente hasta qué punto la disminución del contenido en CO_2 se ha llegado a propagar en esta época del año hasta la estaciones **C** y **D**, donde ya no se rebasa el 0,3 %. Incluso la estación **F** registra simultáneamente descensos notables, bajando desde 4,9 % en Octubre hasta sólo 1,2 % a finales de Diciembre.

Otro aspecto importante del comportamiento del CO_2 en la atmósfera de la Cova de les Rodes se pone de manifiesto en la Figura 4c. Ésta consiste en una sencilla gráfica que pretende expresar el amplio margen de variación experimentado por la concentración de dióxido de carbono en todas las estaciones, mostrando la notable semejanza existente entre sus valores extremos a pesar de que las estaciones se encuentran espaciadas a lo largo de casi 400 metros de recorrido. De hecho, se han podido reunir medidas que van desde 0,05 % a más de 4 % en las estaciones **A**, **B** y **C** (Tabla I), siendo interesante constatar la lectura de 4 % registrada el 11-VII-82 en la sala de entrada, a menos de 15 metros del exterior. Las fluctuaciones son considerables también en las estaciones **D** y **F**, al abarcar desde 0,8 % hasta 4,3 % para el sector que comprende los doscientos metros más distantes respecto de la boca. Los datos de la estación **E**, aunque incompletos, no contradicen la amplitud de variación previsible en ese tramo de la galería principal puesto que faltan mediciones en dicho punto durante la temporada de máximo enriquecimiento en CO_2. Serían necesarias observaciones adicionales en los sectores más profundos de la cavidad para conocer si el máximo de 4,9 %, registrado en la estación **F**, es superado en el transcurso del verano o si, por el contrario, la atmósfera de la Cova de les Rodes tiende a estabilizarse en torno a valores cercanos al 5 %.

Por último conviene indicar que, además de los datos incluidos en las Figuras 3 y 4, varias mediciones no utilizadas en la confección de las gráficas aparecen recopiladas en la Tabla I, junto con

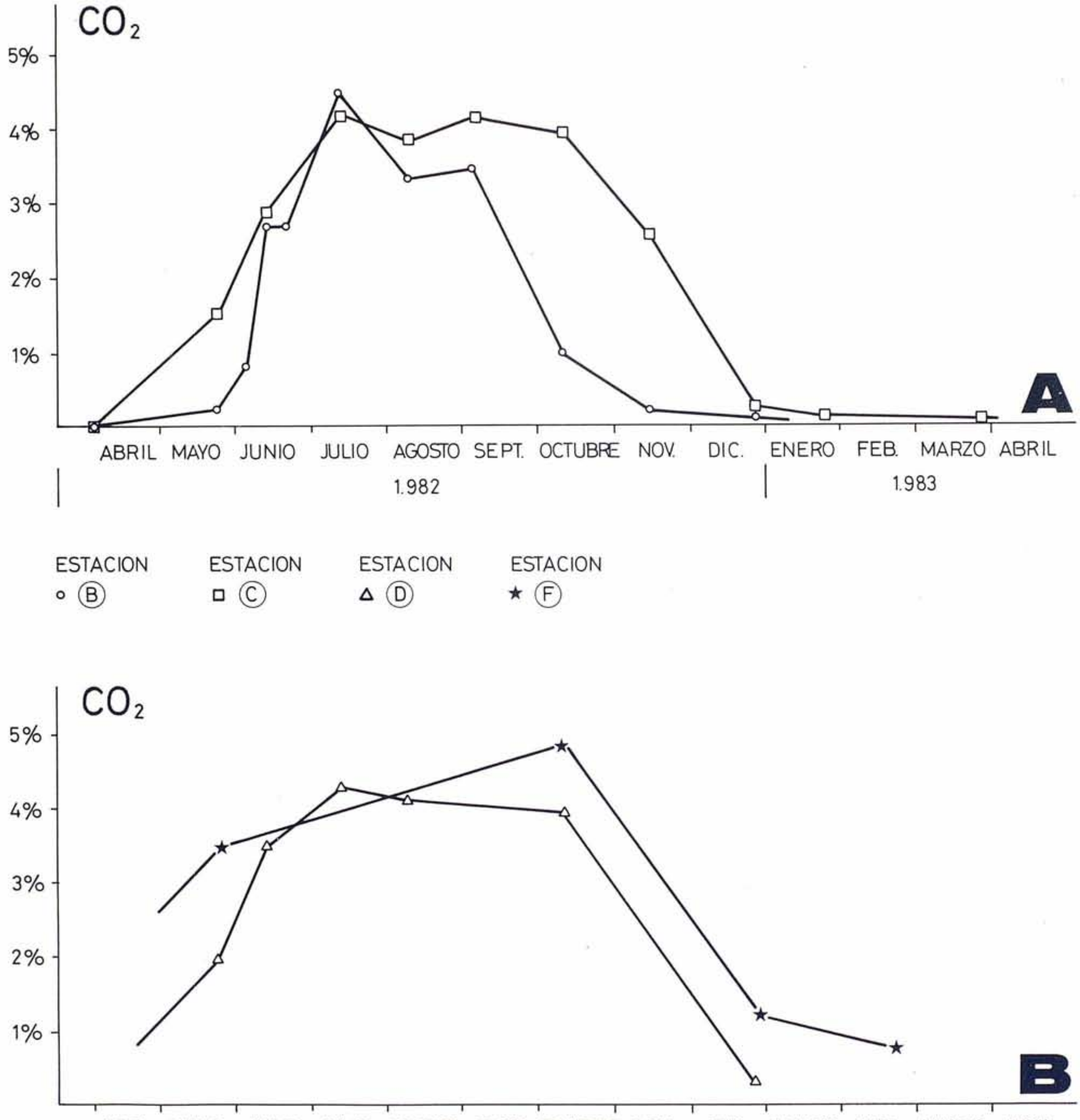

Figura 3. a) Oscilación anual de la concentración de dióxido de carbono en las estaciones B y C.
b) Oscilación anual de la concentración de dióxido de carbono en las estaciones D y F.

otras informaciones complementarias. Entre ellas se han incorporado también algunos datos procedentes de MESTRE (1980), los cuales pueden ser tabulados en sus respectivas columnas por coincidir aproximadamente con tres de las estaciones que sirvieron de base para la elaboración del presente estudio.

Interpretación de los resultados

Son varios los problemas que quedan planteados al examinar el grupo de datos en los que se resume la campaña de mediciones efectuada en la Cova de les Rodes. Fundamentalmente es necesario explicar la procedencia del dióxido de carbono, junto con los procesos que intervienen en su formación, y discernir las causas de su comportamiento tan peculiar en la atmósfera de esta cueva, especialmente en lo que concierne a los mecanismos que provocan las fases estacionales de aumento y disminución de los contenidos en CO_2. También hay que proponer ideas que justifiquen los valores tan altos que se registran en algunas estaciones, relacionando los datos cuantitativos con apreciaciones sobre los condicionantes topográficos que desempeñan un importante papel en el microclima de la cueva y en la generación de gradientes. Por último, no deben disociarse las observaciones realizadas en la propia caverna del contexto más amplio en que ésta se inscribe, como es en este caso el sistema subterráneo de la Vall den Marc. Se trata de un sistema kárstico cuya superficie está ocupada por una activa cubierta edáfica y vegetal, mientras que por debajo la circulación de aguas subterráneas, que toma contacto con la cueva en varios puntos, se desplaza siguiendo el fondo del valle hacia Cala Sant Vicent.

Varias hipótesis se han propuesto para explicar el origen del dióxido de carbono que se acumula dentro de las cavidades kársticas: 1) desprendimiento de CO_2, a partir de las aguas que transitan por el interior del karst, como consecuencia de reajustes en su equilibrio químico al entrar en contacto con la atmósfera subterránea; 2) difusión de CO_2 en estado gaseoso, procedente del suelo donde se forma en grandes cantidades, hacia las galerías de las cuevas a través de la red de fisuras que presenta la roca; 3) producción de CO_2 debido a la actividad degradativa de los microorganismos que descomponen los restos vegetales y otros materiales orgánicos acarreados por las aguas de infiltración; y 4) otras causas diversas y sin duda excepcionales, como la contaminación ocasionada por el hombre, las emisiones de gases volcánicos, las acumulaciones de guano y la respiración de murciélagos o raíces de plantas.

Los resultados de la campaña de medidas, junto con otras observaciones hechas sobre el terreno, parecen indicar que es la difusión de aire enriquecido en CO_2, proviniente de las grietas que rodean las cuevas, la fuente principal del dióxido de carbono detectado en las cavernas mallorquinas. Anteriores estudios ya apuntaron esa posibilidad (ESCOLÀ, 1970; GINÉS, 1983) mientras que, por el contrario, no se han encontrado pruebas a favor de que la descomposición de materia orgánica o la presencia de murciélagos tengan influencia alguna en nuestro caso. Más difícil resulta descartar por completo el papel jugado por el agua en la transferencia de dióxido de carbono si nos atenemos a los argumentos desarrollados por BAKALOWICZ (1979) sobre los mecanismos responsables de la movilidad del CO_2 en la zona de infiltración. De cualquier modo, la mayor parte del transporte directo de gas carbónico es atribuible básicamente a los intercambios que tienen lugar entre la heterogénea atmósfera (pero rica en dióxido de carbono) de la red de grietas y el aire que ocupa los conductos y galerías de mayor tamaño, en los cuales los procesos de ventilación son mucho más eficaces. En lo que se refiere a la Cova de les Rodes, todavía falta por detallar el modo cómo se propaga la invasión de aire enriquecido en CO_2 desde el fondo de la caverna (Figura 4a), durante la temporada de primavera en que parece extinguirse la ventilación procedente de la zona de entrada.

Es difícil deducir cual es el motivo de la relativa reiteración con la que ciertas cuevas mallorquinas exhiben contenidos de CO_2 bastante apreciables. Los datos cuantitativos siguen siendo escasos y quizás, a medida que se generalicen, tenderán a demostrar cómo este fenómeno es incluso más frecuente de lo esperado. Cabe suponer que los elevados valores de CO_2, puestos en evidencia por las medidas efectuadas, no son más que la expresión a nivel de las cuevas de las importantes concentraciones de dióxido de carbono que predominan en la red de grietas y fisuras existente en la zona de infiltración. Valores tan altos como los 3,5 % ó 4,9 % registrados en la Cova Nova de Son Lluís y en la Cova de les Rodes respectivamente, denotan un considerable grado de confinamiento del aire en estas cavidades, el cual puede estar relacionado con la intensidad de los procesos de estalagmitización que tanto caracterizan a los sistemas kársticos de Mallorca, limitando el intercambio del aire subterráneo con el exterior.

Las particularidades del comportamiento del gas carbónico en la atmósfera de la Cova de les Rodes son inseparables de los fenómenos de ventilación que la afectan y de sus modificaciones estacionales; siendo controlados ambos por los cambios de temperatura que rigen en el exterior de la cavidad. Es muy probable que algunos de los rasgos más definitorios de las Figuras 3a y 4b, tales

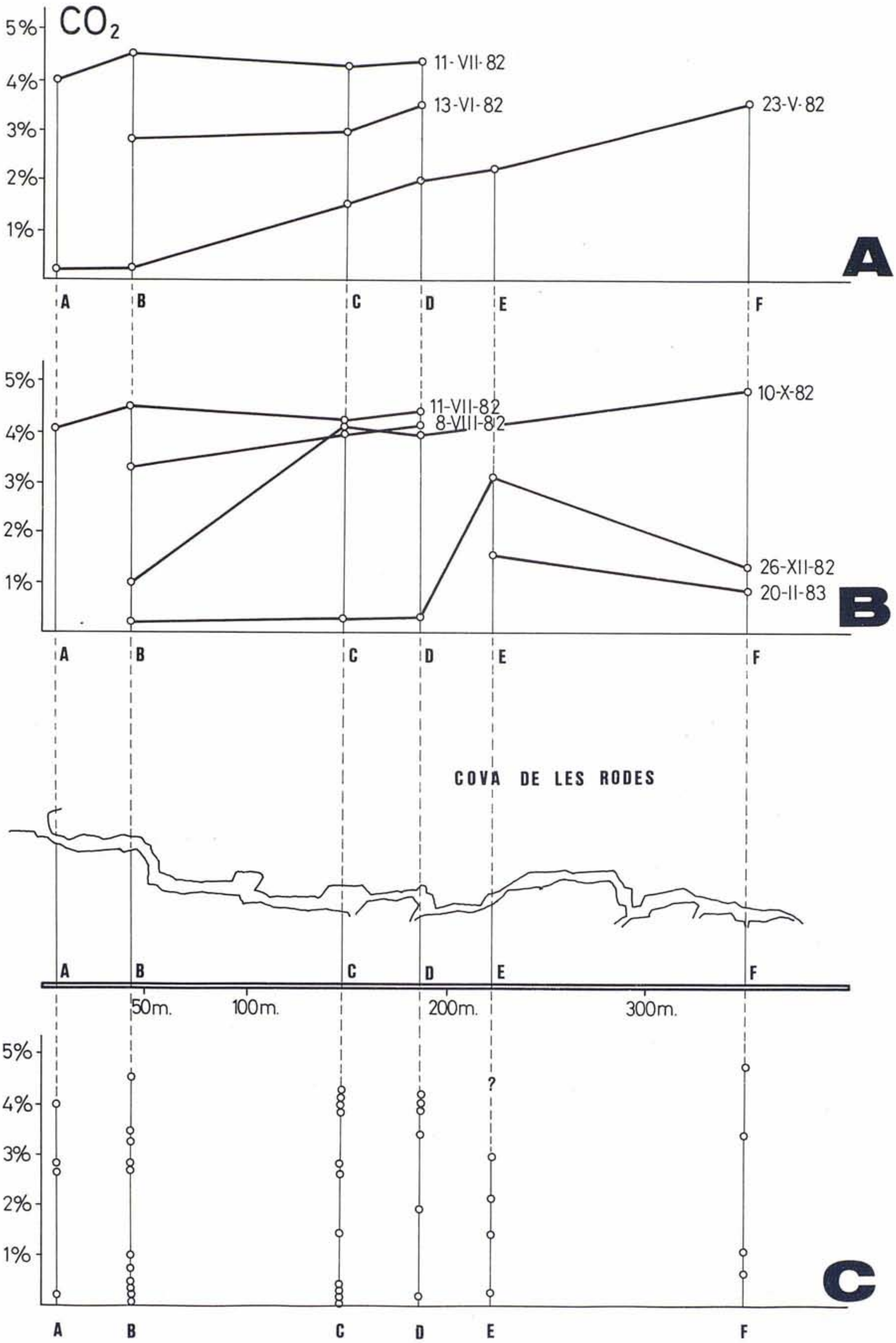

Figura 4. a) Comparación entre los valores de pCO_2 registrados en las 6 estaciones durante una secuencia de medidas que comprende desde Mayo hasta Julio.

b) Comparación entre los valores de pCO_2 registrados en las 6 estaciones durante una secuencia de medidas que comprende desde Julio hasta Febrero.

c) Comparación entre los valores extremos de pCO_2 registrados en cada estación a lo largo de la campaña.

(Algunos datos cuyos valores se solapaban han sido intencionadamente separados en esta gráfica para facilitar su interpretación.)

como el súbito incremento de la concentración de CO_2 en la estación **B** durante los meses de Mayo-Junio o la disminución de ésta entre el 10-X-82 y el 26-XII-82, respondan a mecanismos de ventilación promovidos a partir de la entrada de la caverna. Sin embargo sería necesario llevar a cabo un estudio microclimático detallado para intentar resolver estos interrogantes, ya que las circulaciones de aire pueden adquirir una gran complejidad en cuevas con topografías tan accidentadas como ésta. Tampoco hay que olvidar la interferencia de las variaciones de la presión atmosférica externa, tanto en el previsible efecto de «bombeo» de CO_2 desde las fisuras hacia el interior de la galería principal (durante los momentos de bajas presiones) como en otras observaciones más localizadas. En este sentido, es probable que el peculiar ritmo de ascenso de la pCO_2 registrado en la estación **B** entre el 5-VI-82 y el 20-VI-82 pueda achacarse a circunstancias barométricas de este tipo: es sorprendente que en ese intervalo de quince días sólo haya una subida muy intensa en el curso de la primera semana (desde 0,7 % hasta 2,8 %) sin que sea detectable ningún aumento en los días siguientes, a pesar de que la tendencia prosigue todavía hasta mitad del mes de Julio.

Otro aspecto estrechamente relacionado con los problemas de ventilación o confinamiento del aire subterráneo radica en la propia fisiografía externa del sistema kárstico. Cuanto mayor es la altitud y el desnivel del terreno más importantes son las corrientes de aire que se generan y más eficaz la labor de su renovación. Por el contrario, las concentraciones de CO_2 más notables halladas en Mallorca corresponden a colinas de baja altura, incluso inferiores a los 300 metros s.n.m., cuyos relieves son suaves y poco enérgicos. Lamentablemente nuestro desconocimiento de la globalidad del sistema kárstico de la Vall den Marc, desde un punto de vista geoquímico, impide trasladar a un ámbito más general las observaciones puntuales obtenidas dentro de la Cova de les Rodes. Otro tanto sucede con las otras cavidades isleñas donde hasta ahora se han citado situaciones semejantes, con altos niveles de CO_2.

Distintos e incluso contradictorios tipos de gradientes de pCO_2 han sido evidenciados con bastante precisión en cuevas kársticas, por lo que RENAULT (1971), basándose en datos de diversa procedencia, se encuentra en condiciones de establecer 4 situaciones posibles: gradientes normales, gradientes horizontales (longitudinales), ausencia de gradientes y gradientes inversos; considerándose como normales aquellos gradientes en los que el contenido de dióxido de carbono en el aire subterráneo tiende a aumentar con la profundidad como consecuencia de su mayor densidad y de la limitada ventilación. Buenos ejemplos de gradientes de uno y otro tipo aparecen en DELECOUR et al. (1968), RENAULT (1972), JAMES (1977) y CHOPPY (1983). Por lo que respecta a las observaciones verificadas en cavidades mallorquinas destacan: 1) la ausencia de gradientes significativos que parece apreciarse en el Avenc de Fangar, donde se nota una desigual y aparentemente arbitraria distribución del CO_2 entre las cotas -70 y -160 metros; y 2) los buenos ejemplos de gradiente longitudinal que ofrece la Cova de les Rodes durante algunos estadios de su ciclo anual, circunstancia condicionada por la topografía de la cueva cuya profundidad apenas sobrepasa los 30 metros de desnivel. Las figuras 4a y 4b permiten distinguir gradientes longitudinales muy netos que denotan un claro incremento de las concentraciones de CO_2 a medida que la distancia con relación a la entrada se hace mayor. Los datos obtenidos en Mayo y en Octubre son especialmente ilustrativos en este sentido. En ambas situaciones, que se podrían calificar de transicionales dentro del ciclo anual, se acentúa la manifestación del gradiente pareciendo indicar con ello la existencia de una fuente de CO_2 profundamente radicada en el interior del sistema kárstico (véanse los datos del 23-V-82 en la Figura 4a) y por otra parte se deduce que el drenaje de ciertas cantidades de CO_2 hacia el exterior es más eficaz conforme aumenta la proximidad a la entrada de la cueva (véanse los datos obtenidos los días 11-VII-82, 8-VIII-82 y 10-X-82 en la Figura 4b).

La última interpretación que conviene sugerir aquí, con todas las precauciones que resultan de nuestro excesivo desconocimiento de las condiciones climáticas que posee la Cova de les Rodes, consiste en justificar las causas principales que pueden ser responsables de la importante oscilación que caracteriza a los niveles de CO_2 de su atmósfera a lo largo del año. Fluctuaciones periódicas de carácter anual en las pCO_2 de cuevas kársticas han sido frecuentemente referidas en la bibliografía, como lo atestiguan los trabajos de RENAULT (1971), JAMES (1977), RENAULT (1979), JAMES y DYSON (1981), CHOPPY (1983) y VILLAR et al. (1985) entre otros. Para explicar tales oscilaciones estacionales han sido postuladas varias hipótesis. Las más generalizadas se fundamentan en la posible generación de circulaciones de aire debidas a diferencias térmicas (existentes en determinadas épocas del año) entre el aire exterior y el aire subterráneo que ocupa la atmósfera de la cavidad. Estas corrientes de aire realizarían una labor de ventilación, renovando el aire subterráneo y sustituyéndolo en parte por aire externo empobrecido en CO_2. Durante el comienzo de la estación cálida, cuando las temperaturas del exterior no llegan a decrecer por debajo de la media anual, sería cuando el aire relativamente frío y denso de la atmósfera de la caverna permanecería atrapado en las zonas internas de la cueva, cesando de esta forma la ventilación activa por termocirculación. Los intercambios mediante difusión desde las grietas circundantes así como las variaciones de presión atmosférica (especialmente las bajas barométricas) se encargarían entonces de enriquecer en CO_2 la atmósfera de la cavidad, aportando aire procedente del enrejado de fisuras que la rodea.

Otras posibles explicaciones alternativas, que han sido propuestas en la bibliografía como causantes de oscilaciones anuales de la pCO_2 en casos muy concretos, no parecen ser aplicables a los datos y mediciones proporcionados por la Cova de les Rodes. Ni las crecidas estacionales experimentadas por las aguas de infiltración después de las temporadas de lluvias, ni las llegadas de materiales orgánicos acarreados por el agua, que pudieran desencadenar la actividad degradativa de microorganismos, ni las variaciones estacionales en la fabricación biógena de CO_2 en el suelo pueden dar cuenta de la información reunida sobre las fluctuaciones del CO_2 en la atmósfera de la Cova de les Rodes. La estación **E**, situada junto al río no ha llegado a expresar nada destacable si se exceptúa la medición efectuada el 26-XII-82 (ver Figura 4b) en la que quizás se evidencia un desprendimiento de CO_2, al margen del ciclo anual que afecta a la totalidad de la caverna. Tampoco parece que la tardía irrupción de dióxido de carbono entre Mayo y Junio (Figura 3a), con su perfil excesivamente abrupto, pueda ser atribuida a los cambios estacionales de la concentración de CO_2 en el medio edáfico cercano a la cueva. Por consiguiente, la renovación parcial de la atmósfera de la Cova de les Rodes ocasionada por corrientes de aire de origen térmico (termocirculación) parece configurarse como la explicación que resulta más coherente con los datos disponibles hasta la fecha.

Conclusiones

Todavía es muy incompleto el conocimiento que poseemos sobre la dinámica del dióxido de carbono en nuestras cuevas y sería aún más aventurado cualquier intento de resituar lo poco que sabemos dentro del marco más amplio de los procesos de karstificación. Sin embargo, el análisis de los datos y mediciones, que se han podido reunir hasta la fecha, permite establecer las siguientes conclusiones:

1. En Mallorca son bastante frecuentes las cavidades que albergan elevadas concentraciones de CO_2, probablemente como consecuencia del considerable grado de fosilización que han experimentado muchos de los sistemas kársticos de la Isla en el transcurso del Pleistoceno.

2. Observaciones llevadas a cabo en el Forat de Picamosques, Avenc de Fangar y Cova de Sa Guitarreta, entre otras cavidades, parecen descartar que el enriquecimiento en CO_2 sea debido a la degradación de materia orgánica o causado por acumulaciones de guano de murciélago en su interior.

3. Valores superiores al 2,5 % en volumen son detectables en algunas cuevas como la Cova de les Rodes, Cova de Sa Bassa Blanca y Cova Nova de Son Lluís, emplazadas en parajes cuya topografía exerior se caracteriza por colinas suaves y relieves moderados.

4. Las interpretaciones de ciertos datos, sobre todo los provinientes del Avenc de Fangar y Cova de les Rodes, sugieren que el principal lugar de origen del CO_2 es la red de fisuras que rodea las cuevas, debiendo alcanzarse en ella contenidos superiores al 5 %.

5. Las medidas periódicas obtenidas en varias estaciones de la Cova de les Rodes, durante un ciclo anual completo, han aportado un registro muy preciso y esclarecedor de los drásticos cambios estacionales, en la concentración de CO_2, que muestra la atmósfera de esta caverna.

6. Variaciones temporales en la composición química del aire de ciertas cuevas, como las que se han podido ejemplificar en la Cova de les Rodes, plantean la posibilidad de que algunos ritmos climáticos exteriores lleguen a manifestarse de este modo en el interior de las cavidades kársticas, incidiendo quizás en alguna medida sobre las comunidades de organismos troglobios.

Agradecimientos

La realización de este trabajo ha sido posible gracias a la ayuda económica que nos fue concedida por el Institut d'Estudis Baleàrics (organismo dependiente de la Conselleria d'Educació i Cultura de les Illes Balears) con la intención de ampliar los conocimientos que se tenían sobre la Cova de les Rodes, debido a su interés ecológico y a su notable singularidad dentro del conjunto de cavidades kársticas de Mallorca. Agradecemos al Institut d'Estudis Baleàrics la sensibilidad mostrada al subvencionar esta campaña de recogida de datos, que ha requerido la visita a la cueva en 14 ocasiones durante un ciclo anual completo.

Nuestra gratitud se extiende asimismo a los compañeros del Grup Espeleològic EST que nos han acompañado durante las exploraciones y muy especialmente a Benet Morey.

También debemos manifestar nuestro agradecimiento al Departament d'Ecologia y al Departament de Geologia de la Universitat de les Illes Balears

por habernos facilitado el equipo Draeger necesario para la obtención de las mediciones.

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THE STATUS OF *BOGIDIELLA BALEARICA* DANCAU, 1973, A STYGOBIONT AMPHIPOD FROM MALLORCA

by Jan H. STOCK (*) & Thomas M. ILIFFE (**)

Resumen

Se presenta la redescripción de *Bogidiella balearica* Dancau, 1973, un anfípodo estigobionte de las cuevas anquihalinas de Mallorca. Queda demostrado que se trata de una buena especie, clasificable dentro del subgénero *Bogidiella* s. str., y que se puede diferenciar fácilmente de *Bogidiella chappuisi* Ruffo, 1952 (con la cual se intentó sinonimizar con anterioridad), perteneciente a otro subgénero, *Medigidiella*.

Abstract

Redescription of *Bogidiella balearica* Dancau, 1973, a stygobiont amphipod from anchihaline caves in Mallorca. It proves to be a good species, to be classified with the subgenus *Bogidiella* s. str., and it is well-distinguished from *Bogidiella chappuisi* Ruffo, 1952 (with which it was tentatively synonymized in the past), belonging to a different subgenus, *Medigidiella*.

Introduction

Bogidiella balearica was described by D. Dancau (1973) after specimens from two caves in Mallorca, Coves del Drac and Cova des Pont.

The status of *B. balearica* was discussed by Karaman, 1979: 25, who regarded it as a «possible synonym» of *B. chappuisi* Ruffo, 1952. This statement was repeated by Karaman (in Ruffo, 1982: 253).

In a series of Amphipoda collected early 1986 in Mallorcan caves by the junior author, two male specimens of a *Bogidiella* were encountered, which were morphologically in good agreement with Dancau's description of *B. balearica*. Moreover, one of the specimens came from the same cave (Coves del Drac) as Dancau's type-material. On the basis of the new material, the taxonomic status of *B. balearica* is clarified; it appears to be a good species.

(*) Institute of Taxonomic Zoology, University of Amsterdam, P. O. Box 20125, 1000 HC Amsterdam, The Netherlands.

(**) Bermuda Biological Station for Research, Ferry Reach 1-15, Bermuda.

Bogidiella balearica Dancau, 1973

Dancau, 1973: 114-119, figs. 1-4; Karaman, 1979: 24-25 (synonymy discussed); Stock, 1981: 354 (cited only); Karaman, in Ruffo, 1982: 253 (cited only).

Material.— 1 ♂, Mallorca 86-002, Coves del Drac (Manacor), in upper layers of 2nd lake of commercial cave; surface salinity 3 ppt, surface temperature 18.8° C; 10 Jan. 1986.

1 ♂, Mallorca 86-004, Coves dels Hams (Manacor), in upper layers; surface salinity 14 ppt, surface temperature 19.6° C; 11 Jan. 1986.

The following notes may serve to supplement Dancau's description, which is in general quite satisfactory.

Body length 2.2 and 2.4 mm. Head (fig. 1): Ocular lobe narrow, rounded; antennal sinus shallow but distinct.

First antenna (fig. 2): First peduncle segment with medioventral spine. Aethetasks on all 8 flagellum segments, each as long as corresponding segment. Accessory flagellum rather long, 3-segmented; short aesthetask on tip of segment 3.

Second antenna (fig. 3): Gland cone elongatetriangular, rather short. Flagellum 5-segmented, aesthetasks on segments 2 and 5, subequal to lenght of corresponding segment.

Upper lip as illustrated (fig. 4).

Mandibles (figs. 5, 6): Molar seta present both left and right. Left lacinia mobilis with 5 coarse teeth, right lacinia finely toothed (9 teeth).

Lower lip (fig. 7), contrary to Dancau's description with well-developed inner lobes.

First maxilla (fig. 8): Outer lobe with 7 spines (2 pluridentate, 1 with 3 denticles, 2 with 2 denticles, 2 with 1 denticle).

Second maxilla as illustrated (fig. 9).

Maxilliped: Inner lobe (fig. 11) with bicuspidate spines on distal margin. Outer lobe (fig. 10) with 3 finely denticulated, simple spines.

First gnathopod (fig. 12): Coxal plate trapezoidal, wider than long. Posterior margin of basis with 1 short and 2 long setae. Palmar index (sensu Ruffo, 1973) 0.46. Palmar margin with 5 bifid spines, some setae, and 2 rows of fine denticles: an Angle row (A in fig. 13) and a row at the Base of the claw (B in fig. 13); the B-row is short and the A-row is implanted in a very shallow palmar angle sinus. Three setule-tipped palmar angle spines.

Second gnathopod (fig. 14): Coxal plate wider than long. Posterior margin of basis with 1 short and 1 long seta. Palmar index 0.46. Palmar margin fig. 15) with 6 bifid spines, some setae, and short rows of A- and B-spinules. Two setule-tipped palmar angle spines.

Third pereiopod (fig. 16): Basis with 4 spines on anterior margin, 3 on posterior margin. Merus 3.5 times as long as wide. Propodus with 3 setae on posterior margin.

Fourth pereiopod (fig. 17): Almost identical to P3. Coxal plate very short. Coxal gills on P4 - P6, ovate, with short peduncle.

Fifth pereiopod (fig. 18): Coxal plate vaguely equilobate. Merus 4.2 times as long as wide.

Sixth pereiopod (fig. 19) much longer than fifth. Coxal plate slightly anterolobate. Four spines on posterior margin of basis. Merus 5.1 times as long as wide. Anterior margin of propodus with 2 setules.

Seventh pereiopod (fig. 20) longer than sixth. Coxal plate hardly lobate. Posterior margin of basis with 5 spines. Merus 4 times as long as wide. Some setae on anterodistal end of carpus. Very long setae on propodus.

Lentiform organs small, rounded, slightly elleptical, smooth-edged, in basal part of basis of P3 - P7.

Epimeral plates (fig. 21) unarmed. Posteroventral corner produced into small tooth.

Pleopods 1 to 3 similar, without endopodite. Second pleopod (fig. 22) not modified in male. Two retinacula on inner side of peduncle of each pleopod, anchor-shaped, with 3 pairs of hooks (fig. 23).

First uropod (fig. 24): Peduncle with strong proximoventral spine. Margins of rami unarmed. Exopodite slightly shorter than endopodite, each ramus with 4 distal spines.

Second uropod (fig. 25): Endopodite longer than peduncle and longer than exopodite. Exopodite with 4 distal spines (3 short, 1 long). Endopodite with 4 shorter and 1 longer distal spines, non of them modified in male.

Third uropod (fig. 26): Rami slender, at least 2.5 times as long as peduncle. One of the distal spines of each ramus very long (>33 % of length of ramus).

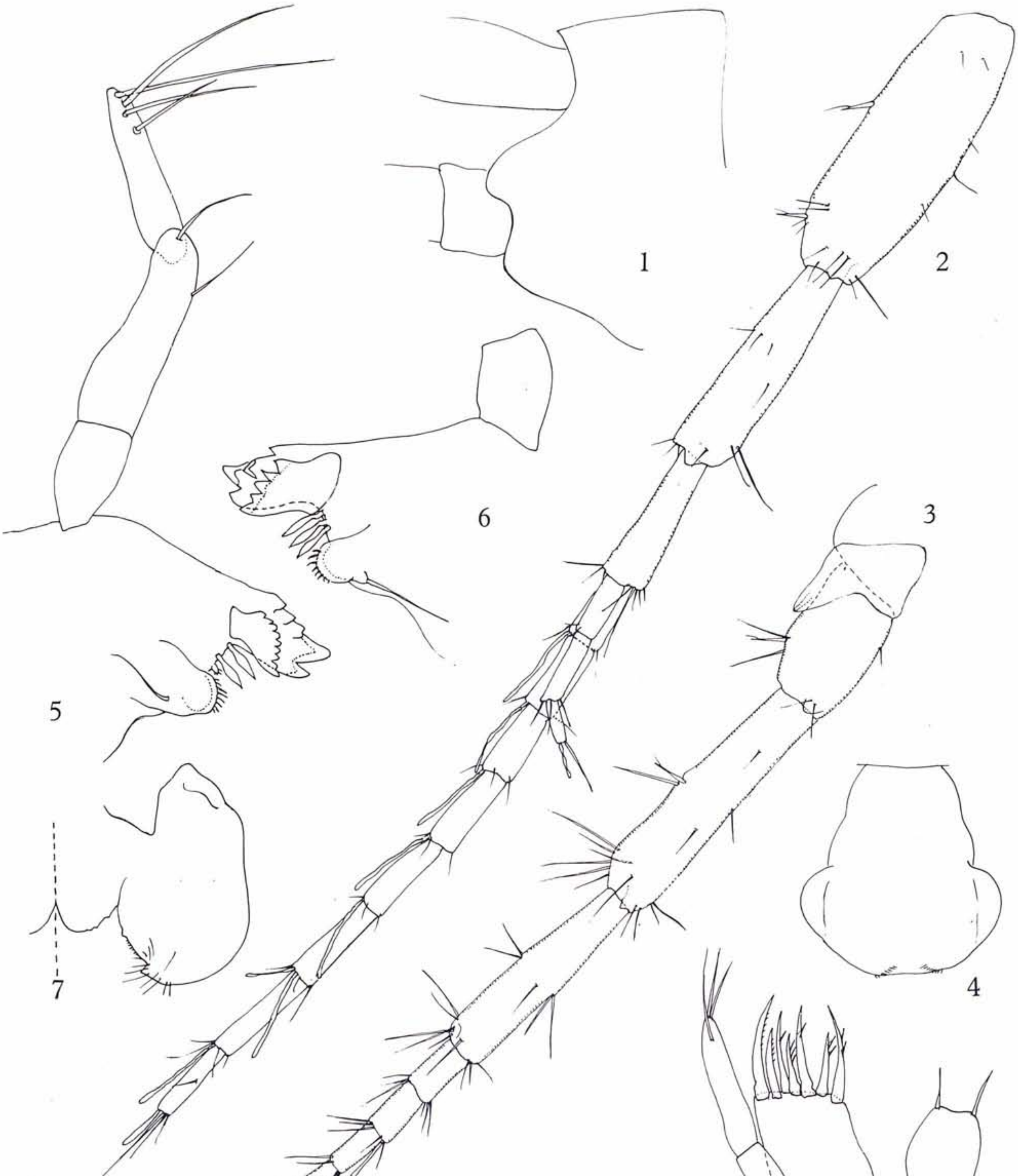
Telson (fig. 27): Rather deep, widely V-shaped distal cleft. Two plumose sensorial setae on either side. Each telson lobe with 2 long distal spines (longest spine longer than telson, shortest spine about 5/6 of length of longest spine).

Discussion

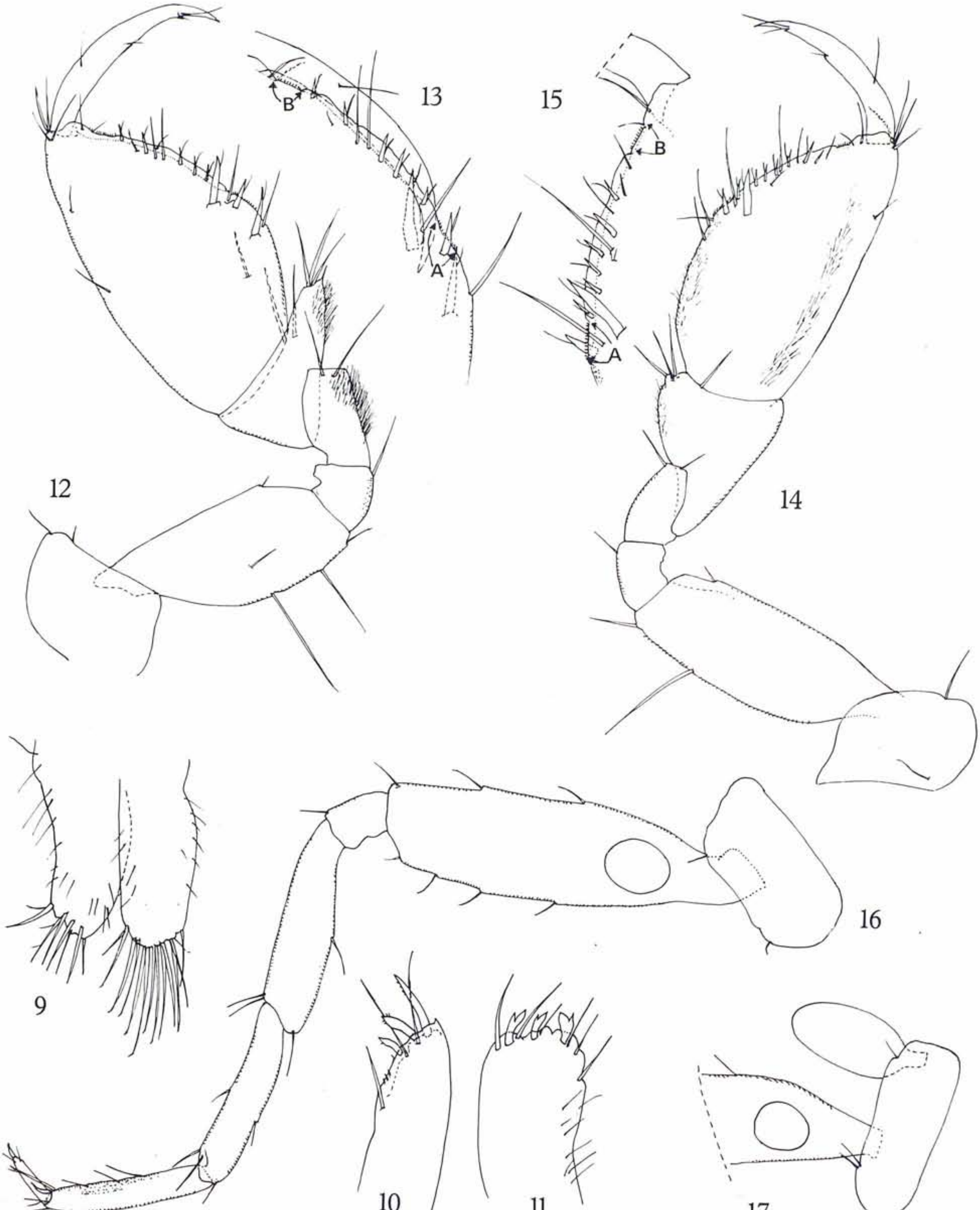
The absence of modified elements (spines, setae) on the endopodite of the second uropod and the exopodite of the second pleopod in the male of the Mallorcan taxon, show that it belongs to the subgenus *Bogidiella* s. str. (see Stock, 1981, and Karaman, 1982). Its alledged senior synonym, *B. chappuisi* Ruffo, 1952 (see Karaman, 1979) belongs to the subgenus *Medigidiella,* since it possesses modified spines, presumably serving for sperm transfer, on the second male uropod.

We have compared the Mallorcan material with a sample of *B. (M.) chappuisi* from the type area (littoral interstitial waters, Roussillon coast, France), and have observed several additional characters, allowing separation of both sexes of *balearica* and *chappuisi.* Some of these are shown in figs. 28-34 of the present paper; moreover the correct illustrations in Karaman, 1979, figs. I-IV, and in Karaman (in Ruffo), 1982, in particular fig. 171, based on topotypes, may serve very well for comparison.

The discriminating characters are: (1) The greater elongation of several appendages (peduncle of first antenna, mandible palp, pereiopods 3 through 7, third uropod) in *balearica.* For instance, the merus of P3, P5, and P6 is 2.5, 2.15, and 2.8 times as long as wide in *chappuisi,* against 3.5, 4.2, and 5.1 times, respectively, in *balearica.* (2) The presence of 3 bicuspidate spines on the inner lobe of the maxilliped (2 bicuspidate spines and an unarmed swelling in *chappuisi,* fig. 28). (3) The presence of 3 setae (2 long, 1 short) on the posterior margin of the basis of gnathopod 1 (1 long and 1 short in *chappuisi,* fig. 29). (4) Palmar margin of gnathopod 1 with ca. 6 bifid spines (0-3 in *chappuisi,* fig. 30). (5) The palmar angle sinus of gnathopod 1 is shal-



Figs. 1-8. *Bogidiella (B.) balearica* Dancau, 1973, ♂ (Manacor, Mallorca).
1, cephalosome, from the left (scale WX); 2, first antenna (WX); 3, second antenna (WX); 4, upper lip (WY); 5, right mandible (WZ); 6, left mandible, palp omitted (WZ); 7, lower lip (WZ); 8, first maxilla (WZ). Scales below fig. 19.



Figs. 9-17. *Bogidiella (B.) balearica* Dancau, 1973, ♂ (Manacor, Mallorca).

9, second maxilla (scale WZ); 10, outer lobe of maxilliped (WZ); 11, inner lobe of maxilliped (WZ); 12, first gnathopod (WX); 13, palmar margin of first gnathopod (WY) [A = angle row of spinules, implanted in angle sinus; B = row of spinules at base of claw]; 14, second gnathopod (WX); 15, palmar margin of second gnathopod (WY) [symbols as in fig. 13]; 16, third pereiopod (WX); 17, basal part of fourth pereiopod (WX). Scales below fig. 19.

low (deeper in *chappuisi,* fig. 30). (6) The B-row of spinules on the palma of gnathopod 2 is short (long in *chappuisi,* fig. 31). (7) Pereiopods 3 to 5 bear a short seta (P3, P4) or a spine (P5) in the middle of the anterior margin of the merus (absent in *chappuisi,* fig. 32). (8) The propodus of pereiopods 3 and 4 bears 3 shorts setae, that of P5 a spine (absent in *chappuisi,* fig. 32). (9) The posterior margin of the basis of P7 bears several spinules (only 1 in *chappuisi).* (10) The propodus of P7 bears longer setae and the claw is more slender in *balearica* than in *chappuisi* (fig. 33). (11) The longest telson spine is longer than the telson (shorter than the telson in *chappuisi).*

Study of a large series (>70 specimens) of *B. chappuisi* (from interstitial waters of a gravel bank at the mouth of La Baillorie, Banyuls, France, chlorinity 24696 mg/l), has revealed a broad range of variation in the expression of certain characters (number of segments in accessory flagellum of A1, length of spines on uropod 3, slenderness of pereiopods, length of telson spines, number of telson spines...) in what is presumed to be a monospecific population. Similar variations have been noticed by Karaman (1979) elsewhere in the Mediterranean belt. It remains to be seen if these populations are indeed monospecific, or whether they consist of a mixture of sibling species. At any rate, the characters 1 to 11 enumerated above, all fall outside the range of variation observed in the alledged *B. chappuisi,* and of course the apomorphic sexual dimorphism in the armature of the endopodite of uropod 2 in *chappuisi* forms already sufficient ground for placing *B. balearica* as a distinct species in a different subgenus.

Within the subgenus *Bogidiella* s. str., with which *balearica* is to be classified, the Mallorcan taxon is closely related to *aprutina* Pesce, 1980, *dalmatina* S. Karaman, 1953, *niphargoides* Ruffo & Vigna, 1977, *semidenticulata* Mestrov, 1961, and *vomeroi* Ruffo & Vigna, 1977. These species all share the combination of the following characters with *balearica:* (1) telson with II + II apical spines; (2) presence of lentiform organs on the pereiopods; (3) absence of endopodite in the pleopods.

These species can be distinguished from *balearica* as follows:

— *aprutina:* posterior margin of basis of Gn.1 with 1 long and 1 short seta; lentiform organs crenulated; spines of outer lobe of maxilla 1 with 0-3 denticles;

— *dalmatina:* basis of Gn.1 as in *aprutina;* telson cleft narrow; telson longer than wide; telson spines very unequal in length; spines on outer lobe of maxilla 1 with 1-2 denticles;

— *niphargoides:* basis of P1 with 1 short and 3 long setae; telson cleft shallower; flagellum of first antenna 18-segmented; palmar margin of Gn.1 and Gn.2 with numerous bifid spines;

— *semidenticulata:* basis of P1 as in *aprutina;* lentiform organs much larger; P3 - P6 very scantily armed; proximoventral spine of uropod 1 located in the middle of the ramus; spines of outer lobe of maxilla 1 with 1 denticle;

— *vomeroi:* basis of Gn.1 as in *aprutina;* lentiform organs located in distal part of basis of pereiopods; uropod 1 without proximoventral spine; antennae less slender; spines of outer lobe of maxilla 1 all pluridentate.

Moreover, all 5 species listed above have only 2 (instead of 3) bifid spines on the inner lobe of the maxilliped.

Other *Bogidiella* material from Mallorca

A damaged specimen of *Bogidiella,* probably a male, was collected from the underflow in the gravel bed of the Torrent de Pareis, near La Calobra (Mallorca), at ca. 1000 m from the sea, 2 Jan. 1978, chlorinity 800 mg/l (ZMA Amph. 108.099). This specimen, devoid of its P6 and P7, resembles *B. (B.) balearica* in the slenderness of the appendages, but has the distal telson armature reduced to I + I spines. Certain other characters of this specimen (armature of basis of Gn.1, armature of P3 - P5) are better in agreement with *B. (M.) chappuisi* than with *B. (B.) balearica.* This specimen was briefly mentioned by Stock, 1978: 89. Its taxonomic status must remain uncertain for the moment, awaiting more material from this locality. It appears to be rare, or at least very localized, since repeated sampling in 1983 and 1985 has failed to produce any further specimens.

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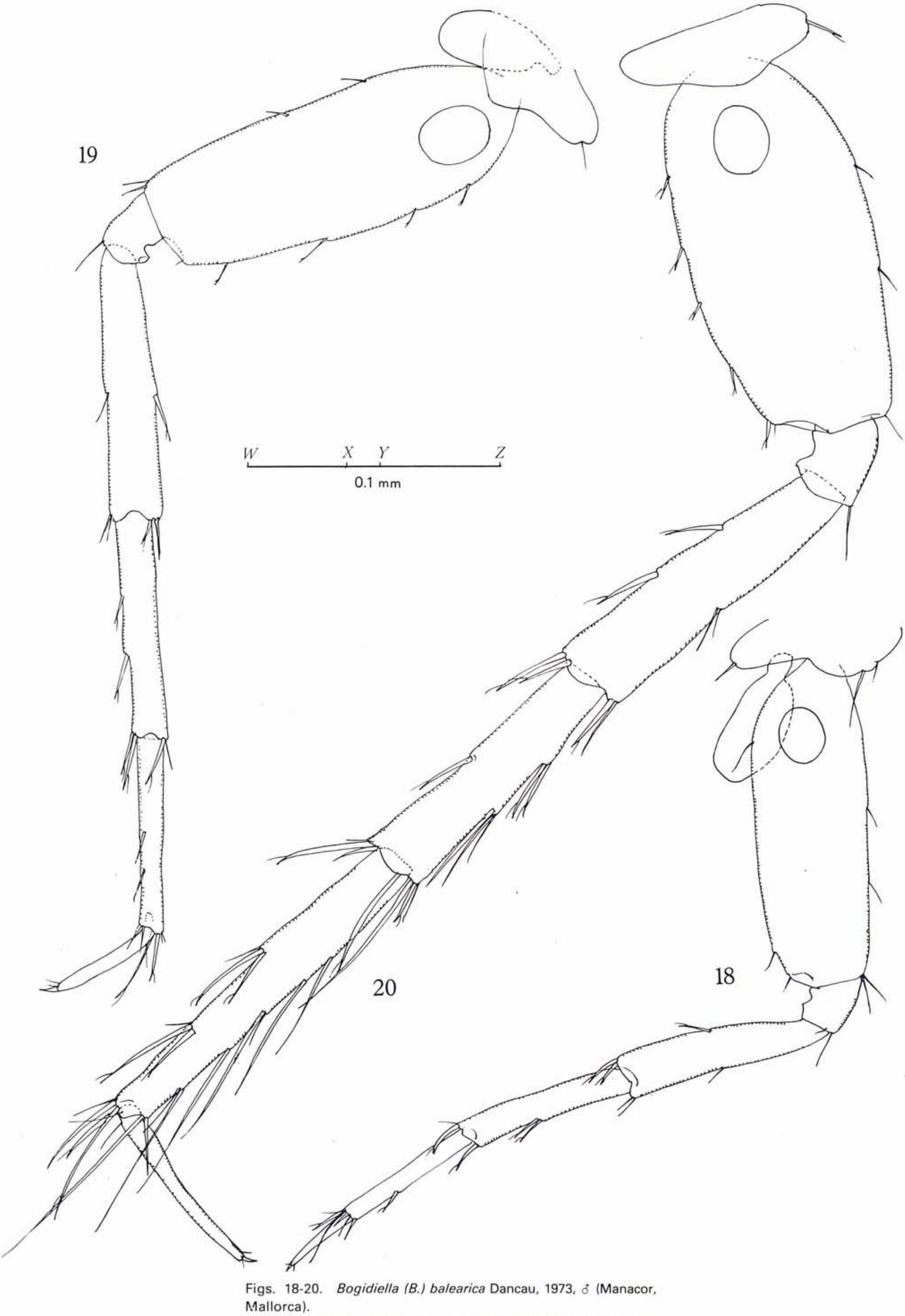
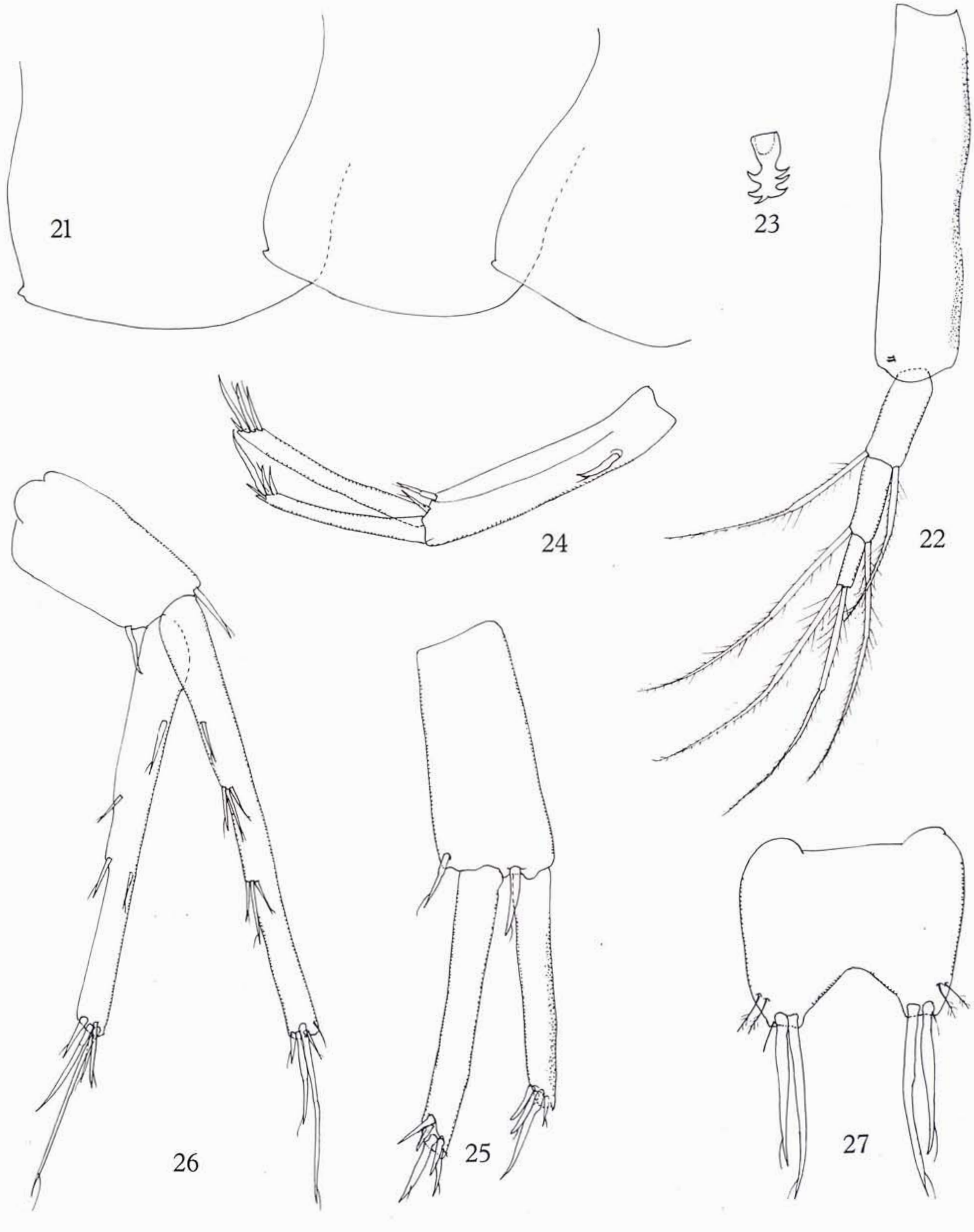
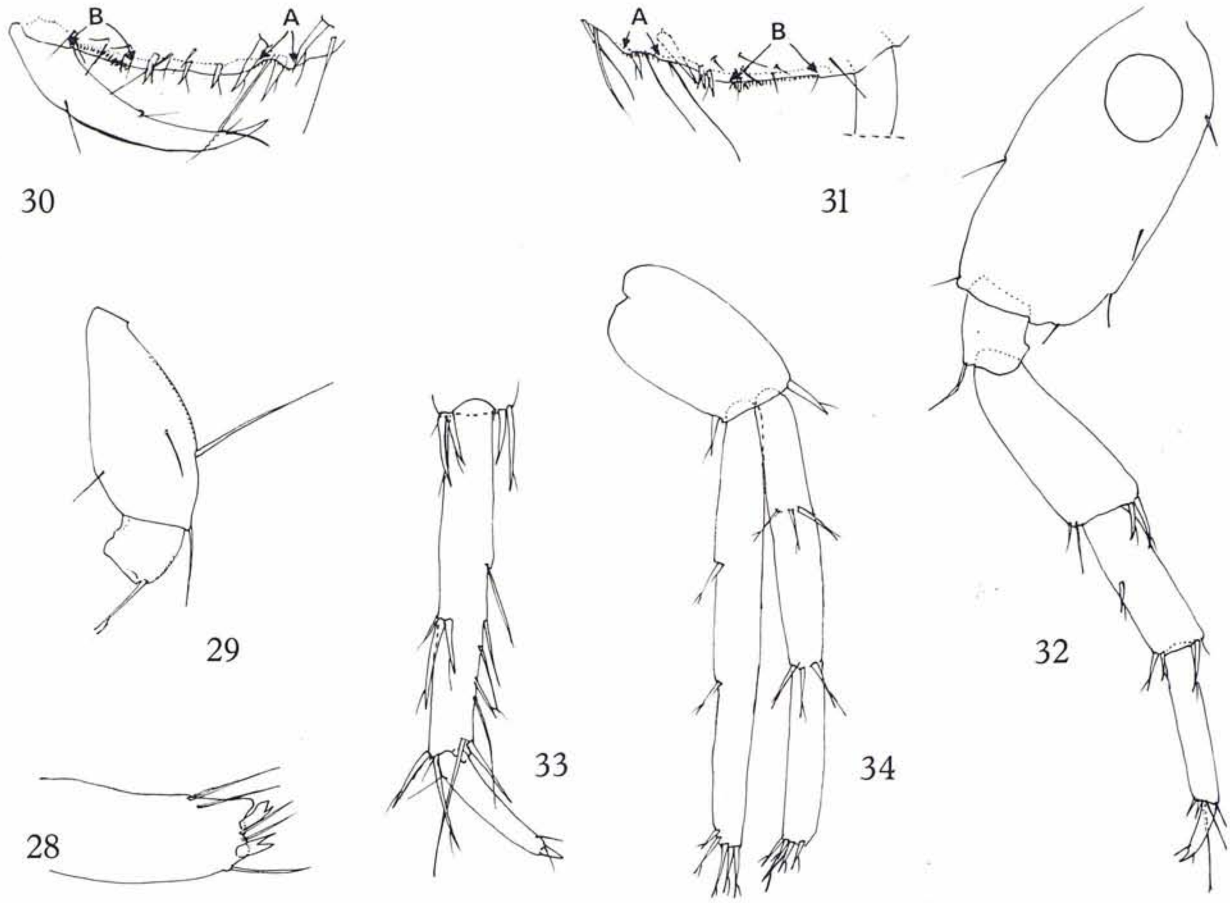


Figs. 18-20. *Bogidiella (B.) balearica* Dancau, 1973, ♂ (Manacor, Mallorca).
18, fifth pereiopod (scale WX); 19, sixth pereiopod (WX); 20, seventh pereiopod (WX). All scale elements (WX, WY, WZ) correspond to 100 μm.



Figs. 21-27. *Bogidiella (B.) balearica* Dancau, 1973, ♂ (Manacor, Mallorca).
21, epimeral plates 1 to 3, from the right (scale WX); 22, second pleopod (WX); 23, retinaculum of first pleopod (free-hand sketch); 24, first uropod (WX); 25, second uropod (WY); 26, third uropod (WX); 27, telson (WZ). Scales below fig. 19.



Figs. 28-34. *Bogidiella (Medigidiella) chappuisi* Ruffo, 1952, ♀ (mouth of La Baillorie, Banyuls, France).
28, inner lobe of maxilliped (scale WZ); 29, basis of first gnathopod (WX); 30, palmar margin of first gnathopod (WY) [A = angle row of spinules, implanted in deep sinus; B = row of spinules at base of claw]; 31, palmar margin of second gnathopod (WY) [A and B as in fig. 30]; 32, fifth pereiopod (WX); 33, distal part of seventh pereiopod (WX); 34, third uropod (WX). Scales below fig. 19.

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UNIÓ GEOGRÀFICA INTERNACIONAL
Grup d'Estudi sobre l'Impacte Humà en el Carst
Actes de la reunió de 1986
Palma de Mallorca.

INTERNATIONAL GEOGRAPHICAL UNION
Study Group on Man's Impact in Karst
Proceedings of the 1986 Meeting
Palma de Mallorca.

Preàmbul

Les àrees càrstiques ofereixen un ampli camp d'investigació pel que fa a les peculiaritats de l'ocupació humana en elles. Les especials característiques geomorfològiques de les zones càrstiques donen lloc a una interessant i variada incidència de l'activitat de l'home, en la seva adaptació a les condicions particulars imposades per un medi geogràfic tan especial.

Les conseqüències del desenvolupament de les activitats humanes en les zones càrstiques foren l'objecte d'una reunió del Grup d'Estudi sobre l'Impacte Humà en el Carst, que se celebrà a Palma del dia 25 al 30 d'Agost de 1986; amb aquest motiu vingueren a la nostra Illa un reduït grup de carstòlegs de diversos països, interessats en aquesta temàtica específica. Aquesta trobada era part de les activitats de la Conferència Regional sobre els Països Mediterranis de la UNIÓ GEOGRÀFICA INTERNACIONAL, que tingué lloc a Barcelona durant el mes de Setembre d'aqueix mateix any.

En l'esmentada reunió foren presentades 12 comunicacions que s'ocupen d'una àmplia gamma d'interaccions entre l'activitat humana i el carst. Sobresurt la gran diversitat de temes tractats, abraçant tant plantejaments globals de gestió ambiental en terrenys càrstics, com previsió d'enfonsaments, problemes de deforestació, drenatge de poljes, efectes geomorfològics lligats a utilitzacions agrícoles pretèrites o possibles deterioracions produïdes per la pluja àcida en els espeleotemes de certes coves. Les comunicacions ofereixen també una àmplia panoràmica des del punt de vista geogràfic ja que, endemés d'aquelles que tracten sobre el carst clàssic de Iugoslàvia i Centre-Europa, les aportacions referides als carsts de Gran Bretanya, Tasmània, Japó, Xina, Tailàndia i Àfrica del Sud, permeten contrastar les conseqüències de l'impacte de l'home sobre regions càrstiques de tot el món.

La FEDERACIÓ BALEAR D'ESPELEOLOGIA acceptà l'encàrrec de la publicació de les comunicacions d'aquesta recent reunió dins un número especial d'ENDINS, el qual ara presentam. Aprofitam aquesta ocasió per agrair al Dr. Ivan GAMS, president del Grup d'Estudi, i al Professor Pere RIPOLL, del Departament de Geografia de la Universitat de les Illes Balears, el fet d'haver-nos confiat l'edició de les actes d'aquesta trobada.

Pretenem amb aquesta publicació contribuir al coneixement de la incidència de l'ocupació humana en els països càrstics, a la vegada que es dóna difusió als resultats d'un fet científic desenvolupat en la nostra Illa. Volem des d'aquí desitjar una fructífera i continuada labor al Grup d'Estudi de la U.G.I. sobre l'Impacte Humà en el Carst.

Preamble

Karstic countries offer a wide field for investigation with regard to the peculiarities of man's occupation of these areas. Singular geomorphological characteristics of karstic zones originate a very interesting and plural incidence of man's activity in his adaptation to the particular conditions that such an especial geographical environment imposes.

The consequences of human activities development in karstic areas were the object of a meeting of the Study Group on Man's Impact in Karst, that took place in Palma de Mallorca from 25th to 30th August 1986. On that occasion, a reduced group of karstologists from different countries interested in this specific subject met in Mallorca. This event was a part of the tasks of Regional Conference on Mediterranean Countries of the INTERNATIONAL GEOGRAPHICAL UNION, celebrated in Barcelona in September 1986.

In the mentioned meeting, 12 papers dealing on a wide range of interactions between human activity and karst were presented. It stands out the great diversity of the subjects discussed covering, among other topics, global approaches on environmental planning in karstic lands as well as collapse forecast, deforestation problems, drainage and hydrological regulation of poljes, geomorphological effects related to agricultural uses in the past, or possible damages produced by acid rain on speleothems in certain caves. The papers also give a wide approach from the geographical point of view since in addition to those treating the classic karst in Yugoslavia and Central Europe, the reports on the karst in Great Britain, Tasmania, Japan, China, Thailand and South Africa allow to contrast the consequences of man's impact in karst regions all over the world.

The FEDERACIÓ BALEAR D'ESPELEOLOGIA accepted to be in charge of publishing the proceedings of this recent meeting in a special edition of ENDINS that we now present. We would like to acknowledge Dr Ivan GAMS, chairman of the Study Group, and Prof Pere RIPOLL, from the Departament de Geografia de la Universitat de les Illes Balears, for having charge us the publication of the proceedings of this meeting.

With this volume we intend to contribute to know human occupation incidence in karstic countries as well as to spread the results of a scientific event developed in our Island. We finally would like to wish a fruitful and a long life task to the I.G.U.'s Study Group on Man's Impact in Karst.

Joaquín GINÉS
FEDERACIÓ BALEAR D'ESPELEOLOGIA

TRACES OF EFFECTS OF ACID RAIN (SEDIMENTATION) IN THE RE-DISSOLUTION OF CAVE DRIPSTONES

by László JAKUCS (Hungary)

Resum

Des del 1980 vaig començar a observar que certs espeleotemes (especialment estalagmites) de coves càrstiques d'Hungria presentaven fenòmens de redissolució, els quals no havien estat visibles en aquestes coves 5-10 anys abans. Aquestes deformacions inqüestionablement es deuen als efectes corrosius de les aigües càrstiques que alimenten els esmentats espeleotemes. Amb la intenció de clarificar les causes d'aquest efecte, els meus companys i jo mateix començàrem les investigacions no tan sols a Hungria sinó també en coves de Txecoslovàquia, Romània, Bulgària, Iugoslàvia i Austria. Fou possible establir que l'extensió del fenomen és universal a Europa Central, encara que en diversos graus depenent de les particulars condicions naturals de cada cova.

Signes de la síndrome de degradació recent dels espeleotemes: cràters irregulars de voreres agudes i dentades; calderes amb els costats soscavats; solcs de drenatge poc fondos, amb voreres tallants; redissolució superficial de l'espeleotema en la zona d'esquits produïts per degotaments des d'una certa altura; sovint, el subsegüent reblaniment del material dels espeleotemes, que presenten, així, un aspecte cremós.

Les investigacions que he realitzat fins ara indiquen que una gran gruixa de la coberta edàfica bioactiva i permeable que reposa sobre la roca carstificable, així com la major profunditat de les arrels de la macrovegetació (arbres de fulla caduca) desenvolupada sobre l'esmentat sòl, són responsables d'una gran incidència i extensió d'aquest nou tipus de redissolució d'estalagmites i espeleotemes en general. En base a les dades disponibles, pareix probable que els boscos de pins tinguin un paper una mica diferent en aquest aspecte, en comparació amb el paper desenvolupat pels boscos d'arbres de fulla caduca, per exemple, roures, faigs, etc.

Es pot comprovar un cert grau de proporcionalitat inversa entre la freqüència de la síndrome de degradació dels espeleotemes i la profunditat de la cova en qüestió respecte de la superfície. A una cova situada a menys profunditat amb relació a la superfície, li correspon una presència més probable d'aquest nou tipus de degradació d'espeleotemes.

Subsegüentment, vaig realitzar una sèrie d'anàlisis per establir de quina manera la síndrome de degradació observada es correlaciona amb el pH del sòl càrstic i amb els paràmetres microbiològics i de composició del sòl. Foren documentades les tendències en els canvis químics de les aigües càrstiques que penetren en les coves.

Es pot constatar que, en comparació amb les dades d'anàlisis d'aigües realitzats el 1929, els quals foren emprats com a base de referència, hi ha hagut un increment del 400-600 % en el contingut de sulfats de les aigües càrstiques que gotegen en idèntics punts de les coves; foren observats també petits increments en els continguts de nitrats i clorurs. En aqueixes coves i, en particular, en les zones on la redissolució dels espeleotemes era especialment intensa, el contingut de sulfats de les aigües càrstiques era més alt que la mitja.

Les meves investigacions suggereixen, per tant, que *aquesta degradació dels espeleotemes pot ser induïda pel recent i fort increment de la concentració de sulfats en les aigües càrstiques, o indirectament per qualsevol dels factors responsables de l'esmentat increment en el contingut de sulfats.*

Summary

From 1980 on, I began to discover that certain dripstones (mainly stalagmites) in karstic cave systems in Hungary were exhibiting re-dissolution phenomena which had not been visible in the caves 5-10 years previously. These deformations unquestionably arise from the corrosional effects of karst-waters permeating onto the dripstones. With a view to clarifying the causes of this effect, my colleagues and I commenced researches in situ not only in Hungary, but also in caves in Czechoslovakia, Rumania, Bulgaria, Yugoslavia and Austria. We established that the spreading of the phenomenon is universal throughout Central Europe, though to different extent in caves with different natural features.

Signs of the recent dripstone degradation syndrome: sharp, jagged-edged, irregular-shaped craters; «calderas» with undermined sides; sharp-edged, basin-like drainage trenches; areal dripstone

surface re-dissolution in the splash-spray zone of the water drops falling from the heights; in certain cases almost total dripstone dissolution; often, the subsequent softening of the material of the dripstones, which become cream-like.

My investigations to date indicate that, the thicker the bioactive and permeable soil layer covering the karst rock, and the deeper the roots of the macrovegetation (deciduous trees) growing in this soil, the more frequent or the more extensive the new type of dripstone re-dissolution. On the basis of the available data, it seems probable that pine woods play a somewhat different role in this correlation system from the role of deciduous woods, e.g. oak, beech, hornbeam, etc.

A certain degree of inverse proportionality can be documented between the frequency of occurrence of the dripstone degradation syndrome and the depth of the cave zone in question beneath the surface. The smaller the depth of a cave system beneath the surface, the more likely the occurrence of this new type of dripstone degradation in it.

I subsequently made a wide-ranging analysis of how the observed degradation syndrome is correlated with the pH of the karst soil and with the microbiological and soil-composition parameters. The trends in the chemical changes of the karst-waters entering the caves were documented.

It turned out that, compared to the water analysis data from 1929, which were used as reference basis, there had been an increase of 400-600 % in the sulphate content of the karst-water dripping in at the same points of the caves; smaller increases were also observed in the nitrate and chloride contents. In those caves and on those dripstones where the dripstone re-dissolution was particularly extensive, the sulphate content of the karst-water was higher than average.

My researches therefore suggested the result that the recent dripstone degradation may be induced *either by the recent strong increase in the sulphate concentration of the karst-waters, or indirectly by one or other of the factors responsible for the increase in the sulphate content.*

In karst caves one can encounter extensive signs of dripstone degradation processes induced by some form of corrosion, i.e. the re-dissolution of the material of the dripstone. There may naturally be numerous causes of corrosional dripstone degradation, and the system of the mechanism of action, involving the correlations between the inducing factors and the resulting degradation symptoms, are fairly well known. A number of types of corrosional dripstone degradation are known which have *age-independent* genetics, i.e. which may occur in *all phases* of the development of a cave system; the system of conditions for their formation were present in the distant past of the cave (or in certain periods in the distant past) in the same way as in the present day. Unfortunately, however, the results of my researches indicate that there are also certain corrosional processes which are causing the degradation of cave dripstones *only in the present;* prior to the period covering the past 10-20 years, these processes have not been manifested anywhere or at any time in cave formations.

The first group, i.e. the group of corrosion variants manifested *independently of the age,* include corrosion by *unsaturated cave waters, mixing corrosion, humidity condensation dripstone corrosion,* the *corrosion of cave soils and karst-water clay, guano corrosion* and the corrosion of dripstones of cave entrances. These are the *traditional* or *permanent* types of corrosional dripstone degradation.

Photo 1. A stalagmite that has been degrading seriously for several years in the chamber «Magyarok-bejövetele» in the Baradla Cave in Hungary. The recent corrosion by the continuously dripping karst-water has etched away the outermost (youngest) dripstone layers.

These may be clearly distinguished from a characteristic group of symptoms of dripstone degradation which were earlier *never* observed anywhere in caves. The latter have appeared in the second half of the twentieth century, and I have therefore named this phenomenon the *recent dripstone degradation syndrome.*

From 1980 on, I began to discover that certain dripstones (mainly stalagmites) in karstic cave systems in Hungary were exhibiting re-dissolution phenomena which had not been visible in the caves 5-10 years previously. These deformations unquestionably arise from the corrosional effects of karst-waters permeating onto the dripstones. With a view to clarifying the causes of this effect, my colleagues and I commenced researches in situ not only in Hungary, but also in caves in Czechoslovakia, Rumania, Bulgaria, Yugoslavia and Austria. We established that the spreading of the phenomenon is universal throughout Central Europe, though to different extents in caves with different natural features.

Signs of the recent dripstone degradation syndrome

Sharp, jagged-edged, irregular-shaped craters; «calderas» with undermined sides; sharp-edged, basin-like drainage trenches; areal dripstone surface re-dissolution in the splash-spray zone of the water drops falling from the heights; in certain cases almost total dripstone dissolution; often, the subsequent softening of the material of the dripstones, which become cream-like (See Photos 1-3).

It must repeatedly be emphasized that the recent dripstone degradation syndrome I have investigated and described involves damage to dripstones that has occurred for at most few years (possibily around a decade). This damage is observed virtually exclusively at those points in the dripstone caves that are subject to the most continuous dripping; similar changes are never to be seen in or on the long ago formed layers or surfaces of the same formations. This correlation can be checked particularly easily in those caves which have long been known and visited, and in which, in the period of visits by torchlight (right up to the beginning of the twentieth century), a layer of soot of various thicknesses was deposited from the torch smoke onto the dripstone and the rock surfaces. To outline the essence: *the dripstone degradation syndrome I was studying is not present anywhere under the soot layer.* This means that in the course of development of these caves *a clear distinction may be made between a «pre-soot», symptom-free developmental period lasting for many thousands of years and very brief, «post-soot» active degradation period lasting at most a few decades* (but in my view probably rather only a few years), which has left active recorrosional (re-dissolution) traces on the surfaces of many cave dripstones, and which has even led in one or two cases to the total destruction of the dripstone formation (see Photo 4).

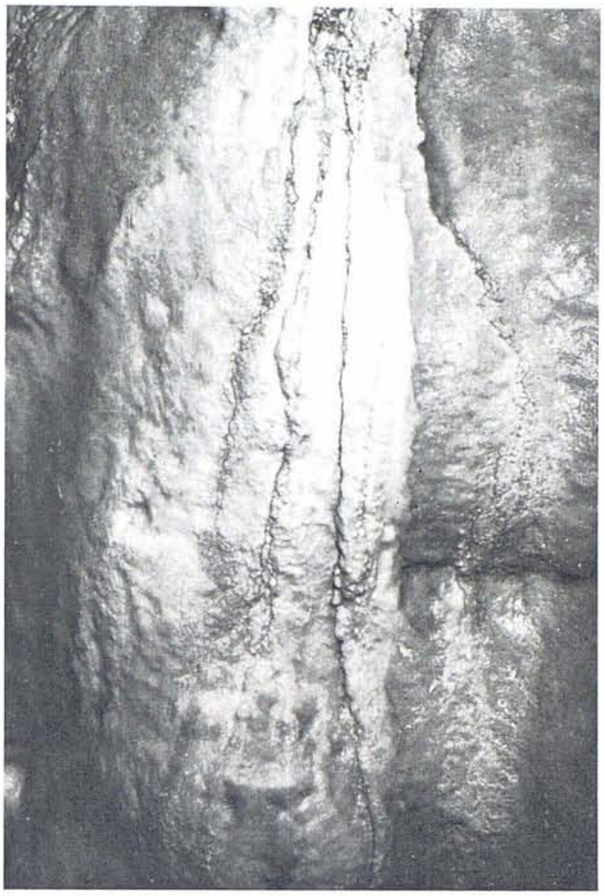

Photo 2. The altered character and effects of the water dripping onto the dripstones are indicated by the sharp-edged corrosion pits at several sites on the sides of the stalagmites. The photo was taken in the «Meseország» section of the Aggtelek Cave in Hungary.

Research into the causes of the degradation syndrome

This recent dripstone re-dissolution is generally displayed by the youngest dripstone formations, which are still active as regards water-dripping, and which in the vast majority of the cases are light in colour (frequently white). The phenomenon is to be observed only in certain zones of the caves. The degradation usually exhibits group occurrence, but stalagmites not showing signs of re-dissolution may be encountered in the immediate vicinity of degrading dripstones. Research into the causes of the symptoms is still continuing, but

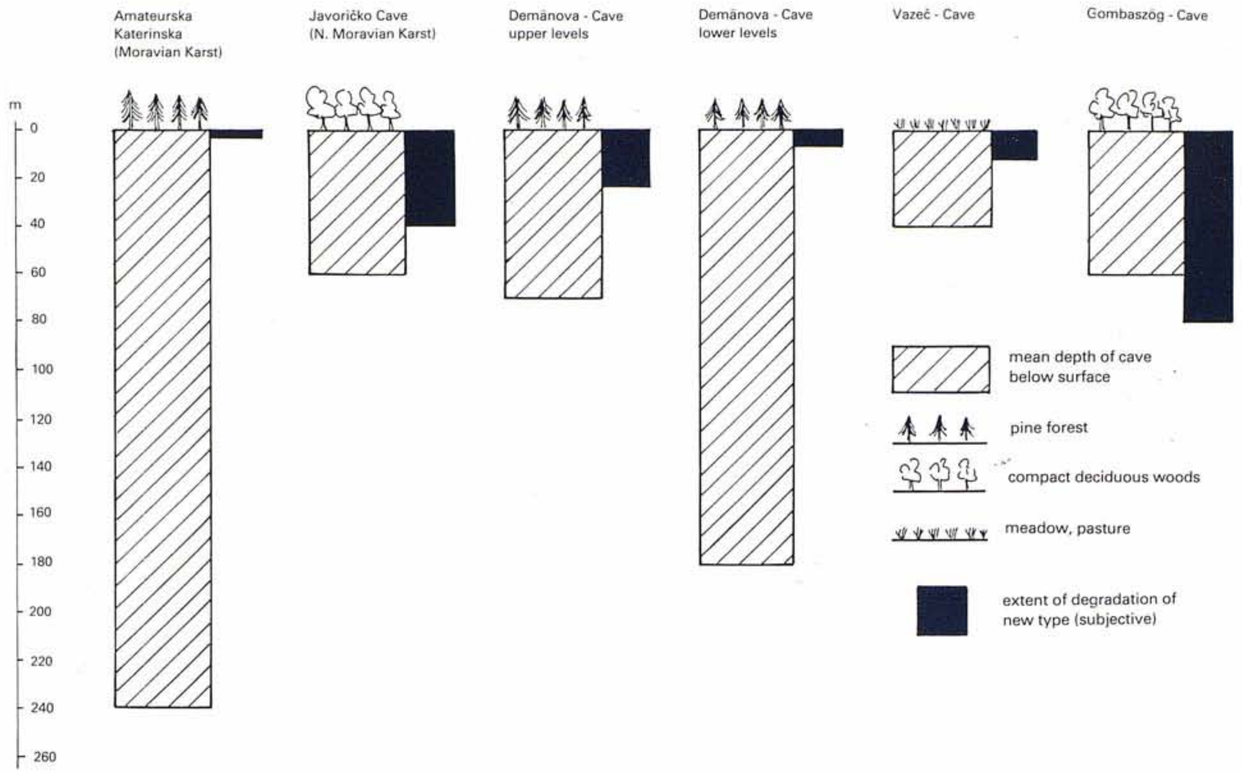

Figure 1. Assumed correlation system between depths of some czechoslovak cave systems below the surface, the type of surface vegetation, and the degree of present dripstone degradation (original).

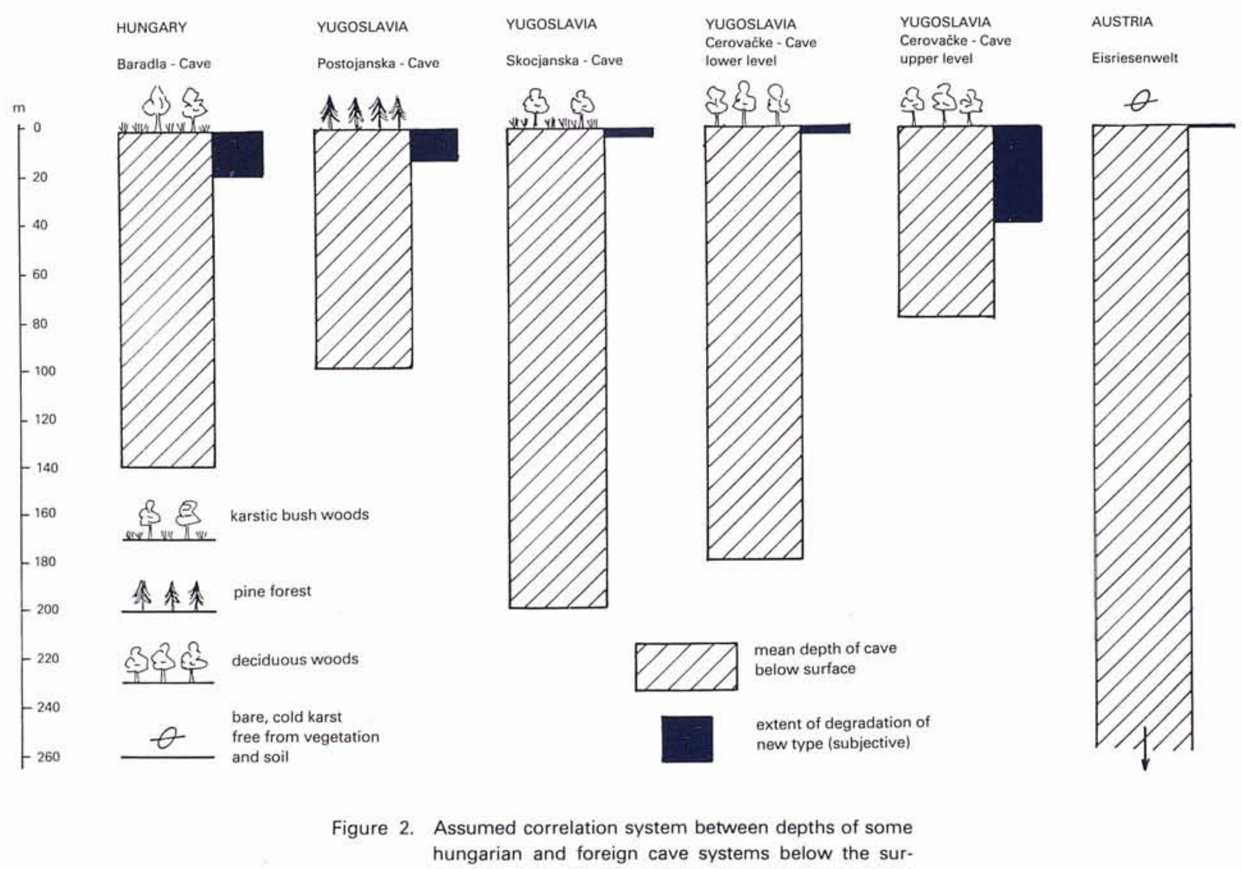

Figure 2. Assumed correlation system between depths of some hungarian and foreign cave systems below the surface, the type of surface vegetation and the degree of present dripstone degradation (original).

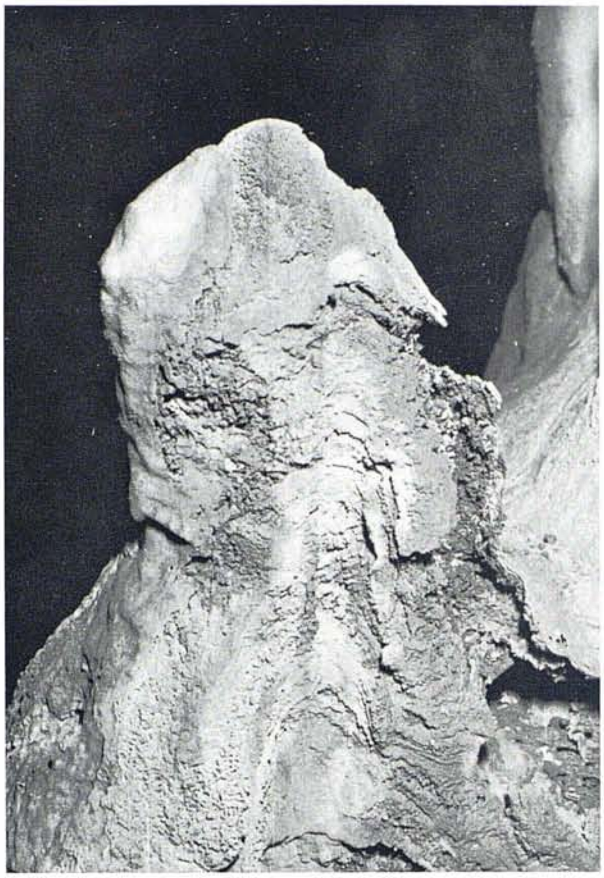

Photo 3. A stalagmite about 30 cm high in the Gombaszög Cave in Czechoslovakia. Within a few years, one side of the previously intact, smooth-surfaced stalagmite has been totally degraded by the phreatic water permeating through the wood-covered soil.

Photo 4. In recent years the dripping karst-waters have in some places become strongly aggressive towards lime. They no longer build up the stalagmites, but degrade them to their component layers. The dripstone has degraded to a loose structure, and the outer residues break away from the disintegrating figure. The photo also reveals how the rebounding karst-water spray is re-dissolving the dripstone layers of the rock walls too (Gombaszög Cave, Czechoslovakia).

it appears that sufficient data are already available for some assumptions to be made concerning the correlations. These are as follows:

1. In all cases, the re-dissolution of the dripstone is caused by the same water-dripping as that which earlier caused the build-up of the dripstone (primarily stalagmites are involved). The fact of degradation is therefore evidence that a change has occurred in the chemical or physicochemical properties of the water dripping onto the stalagmite.

2. My investigations to date indicate that, the thicker the bioactive and permeable soil layer covering the karst rock, and the deeper the roots of the macrovegetation (deciduous trees) growing in this soil, the more frequent or the more extensive the new type of dripstone re-dissolution. On the basis of the available data, it seems probable that pine woods play a somewhat different role in this correlation system from the role of deciduous woods, e.g. oak, beech, hornbeam, etc.

3. A certain degree of inverse proportionality can be documented between the frequency of occurrence of the dripstone degradation syndrome and the depth of the cave zone in question beneath the surface. The smaller the depth of a cave system beneath the surface, the more likely the occurrence of this new type of dripstone degradation in it.

The correlations referred to in points 2 and 3 are illustrated in Figs 1 and 2 on the example of some caves in Czechoslovakia, Hungary, Rumania and Austria.

I subsequently made a wide-ranging analysis of how the observed degradation syndrome is correlated with the pH of the karst soil and with the microbiological and soil-composition parameters. The trends in the chemical changes of the karst-waters entering the caves were documented.

It turned out that, compared to the water analysis data from 1929, which were used as reference basis, there had been an increase of 400-600 % in the sulphate content of the karst-water dripping in at the same points of the caves; smaller increases were also observed in the nitrate and chloride contents. In those caves and on those dripstones where the dripstone re-dissolution was particularly extensive, the sulphate content of the karst-water was higher than average.

My researches therefore suggested the result that the recent dripstone degradation may be induced *either by the recent strong increase in the sulphate concentration of the karst-waters, or indirectly by one or other of the factors responsible for the increase in the sulphate content.*

With the help of my colleague Ilona Bárány-Kevei, I was similarly able to document how the trends in the composition of the karst soils and in their microbiological conditions are correlated with the atmospheric acid sedimentation. On this basis it appears to be proved that the modifications in the chemical characteristics of the karst-water are connected with the trends in the physicochemical changes in the karst soil and with the present distortions in the ecological conditions of the soil micro-organisms. The recent dripstone degradation syndrome therefore provides *an overall indication of the effects of acid rain or sediments in the complex concatenation of correlations in the deeper karst levels* (see Tables 1-4 and Figs 3-5).

water - sampling site	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
date of examination	10.02. 1960.	21.08. 1960.	05.03. 1982.	20.11. 1957.	05.03. 1982.	22.11. 1957.	19.08. 1960.	06.03. 1982.	22.09. 1979.	22.09. 1979.	26.11. 1929.	23.07. 1969.	08.07. 1981.	07.03. 1982.
pH	7.1	7.3	6.6	7.2	7.0	7.2	7.1	7.0	6.9	6.9	7.5	7.2	7.0	6.9
Ca^{++} mg/l	103.0	124.0	86.0	92.0	83.0	101.0	122.0	99.0	92.2	98.6	54.2	106.0	111.0	83.8
Mg^{++} mg/l	1.0	2.2	1.4	4.5	2.2	1.9	1.9	3.7	12.2	11.3	3.2	2.1	3.1	3.3
HCO_3^- mg/l	298.0	370.0	281.0	322.0	267.0	288.0	380.0	235.0	238.0	226.0	174.0	303.0	310.0	266.0
SO_4^{--} mg/l	14.0	9.2	47.0	8.5	33.4	12.2	17.0	27.7	307.0	250.0	16.1	8.9	24.1	29.9
Cl^- mg/l	3.0	3.6	8.2	4.1	6.8	2.3	2.1	16.1	11.0	11.0	3.6	5.0	14.3	6.5
NO_3^- mg/l	16.2	14.8	43.2	13.7	40.9	12.2	14.2	9.7	5.9	2.2	1.0	4.2	20.3	23.5

1, 2, 3 = Baradla - Cave, Lace Well (Jakucs)
6, 7, 8 = Béke - Cave, Amphora (Jakucs)
10 = Létrási - vizes - Cave, Point 7 (Lénárt)
12, 13 = Postojanska - Cave, Calvary (Jakucs)
4, 5 = Baradla - Cave, Chinese Pagoda (Jakucs)
9 = Létrási - vizes - Cave, Point 4. (Lénárt)
11 = Baradla - Cave, Dessewffy Well (Maucha)
14 = Domica - Cave, Hall of Indian Pagodas (Jakucs)

Table 1. Comparative chemical analyses of various cave dripwaters at different and identical times

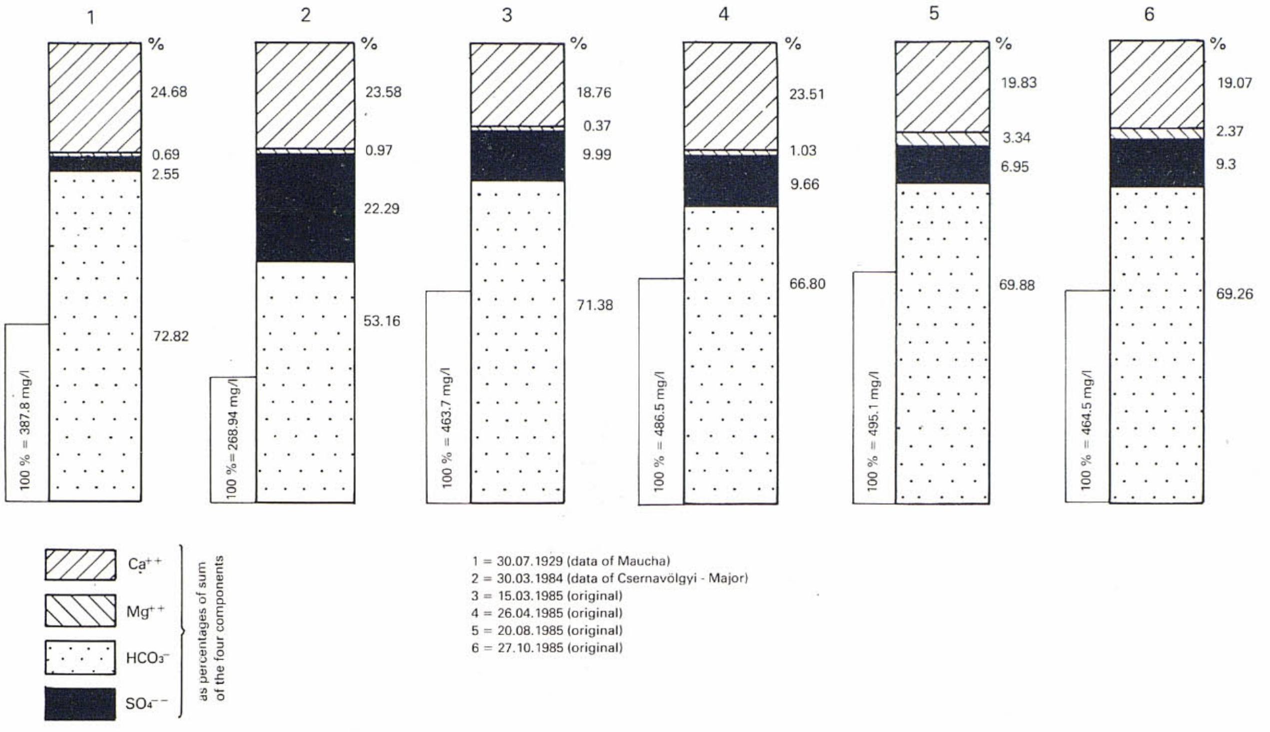

Figure 3. Water of «királykút» dripstone basin (Baradla - Cave at Aggtelek)

mg/l	30.07.1929. (Maucha) REFERENCE	30.03.1984. (Csernavölgyi-Major)	15.03.1985. (Jakucs-Franczia)	21.03.1985. (Jakab-Major)	26.04.1985. (Jakucs-Franczia)	20.08.1985. (Jakucs-Franczia)	27.10.1985. Jakucs-Franczia)
Ca^{++}	93.4	63.4	87.0	64.3	114.4	98.2	88.6
Mg^{++}	2.7	2.6	1.7	12.7	0.5	3.3	2.4
HCO_3^-	282.4	143.0	331.0	267.3	325.0	246.0	321.7
SO_4^{--}	9.9	59.9	44.0	46.9	47.0	34.4	43.2
NO_3^-	12.3	– ?	20.2	– ?	11.4	17.9	8.2
Cl^-	2.7	25.4	7.1	1.8	14.4	21.0	5.8

Table 2. Analytical data on ions expressing the trends to change in the water composition of the "Királykút" dripstone basin in the Baradla cave

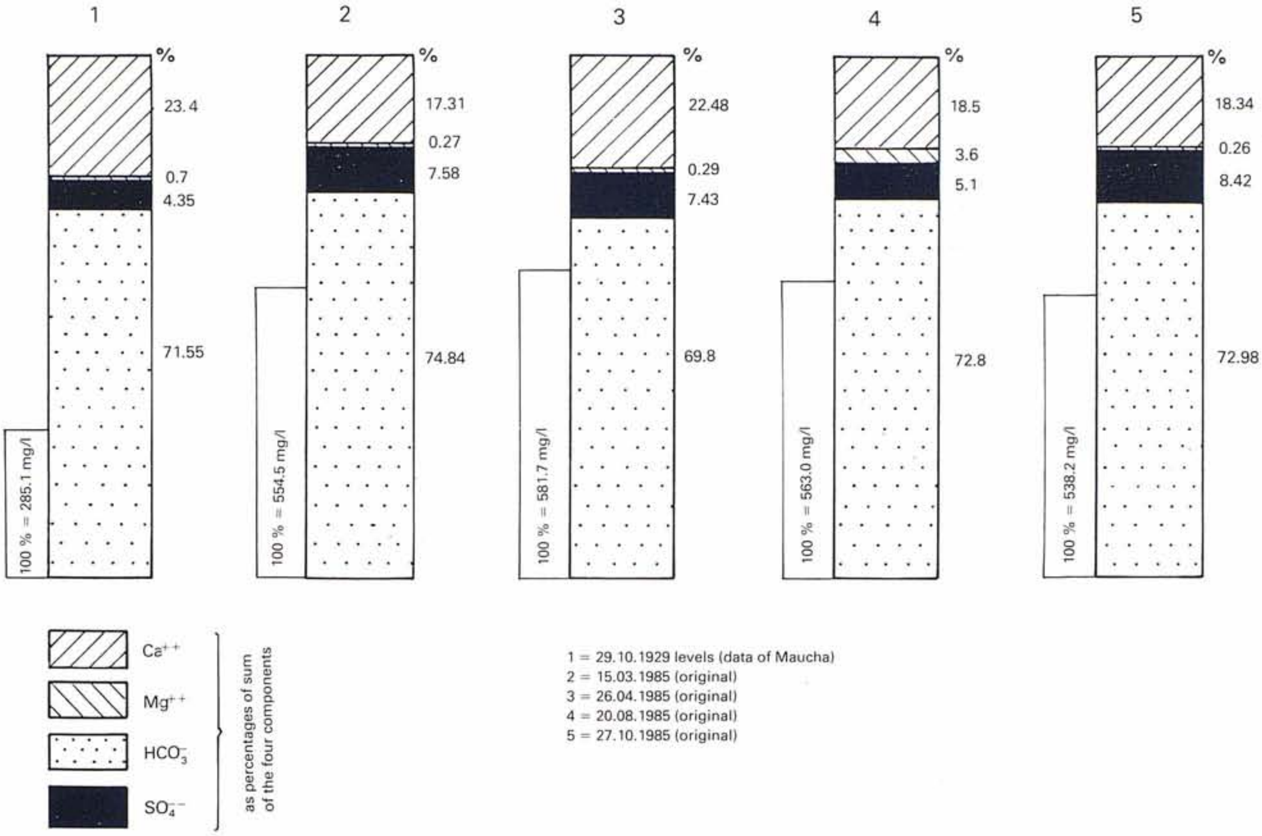

Figure 4. Water of «kéregetö - koldus» stalagmite (Baradla - Cave at Aggtelek)

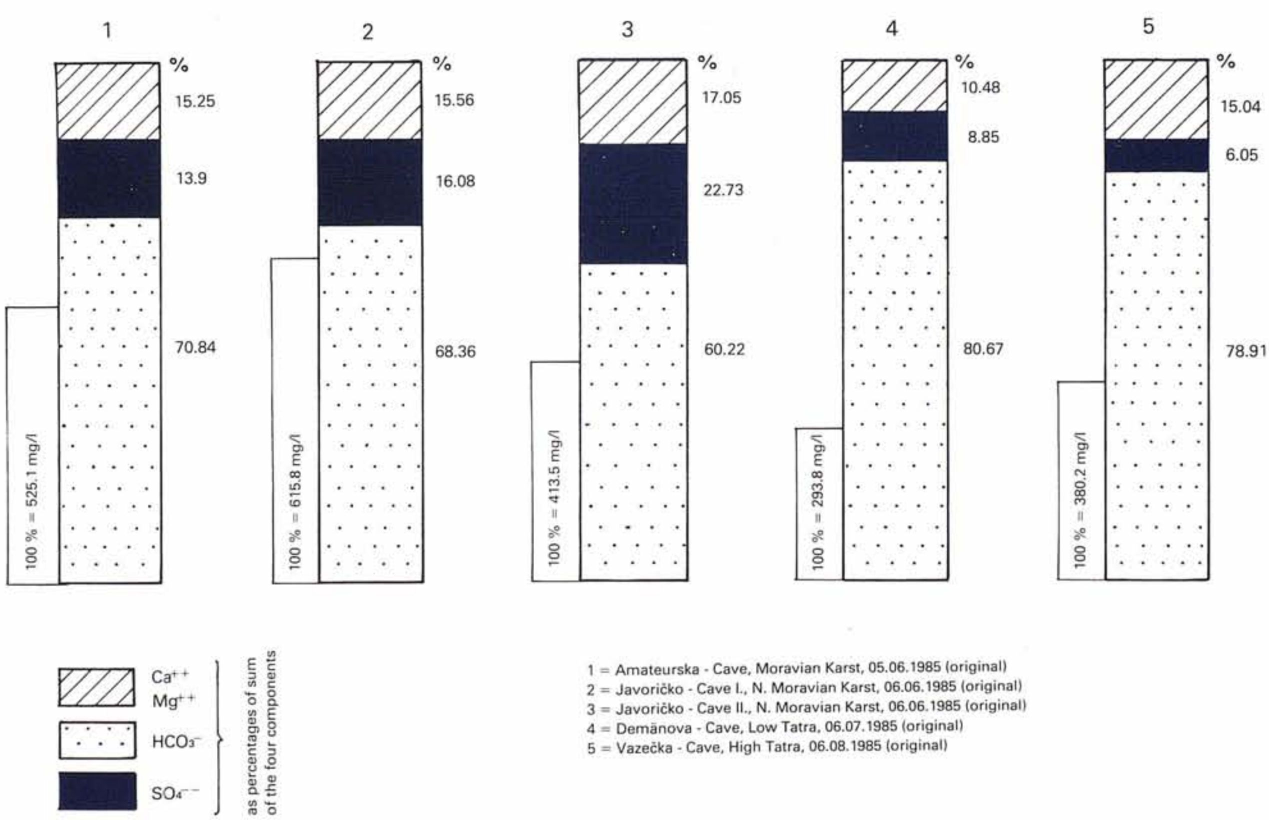

Figure 5. Waters of degrading stalagmites (Czechoslovak caves)

mg/l	29.10.1929. (Maucha) REFERENCE	15.03.1985. (Jakucs-Franczia)	26.04.1985. (Jakucs-Franczia)	20.08.1985. (Jakucs-Franczia)	27.10.1985. (Jakucs)
Ca^{++}	66.7	96.0	130.8	104.2	98.7
Mg^{++}	2.0	1.5	1.7	20.2 (?)	1.4
HCO_3^-	204.0	415.0	406.0	410.0	392.8
SO_4^{--}	12.4	42.0	43.2	28.6	45.3
NO_3^-	8.5	14.2	1.8	17.5	8.2
Cl^-	1.5	7.8	6.8	9.3	4.5

Table 3. *Analytical data on ions expressing the trends to change in the water composition of the "Kéregetö-koldus" stalagmite in the Baradla cave*

mg/l	AMATEURSKA-CAVE 05.06.1985.	JAVORIČKO-CAVE I. 06.06.1985.	JAVORIČKO-CAVE II. 06.06.1985.	DEMÄNOVA-CAVE 07.06.1985.	VAZEČKA-CAVE 08.06.1985
$Ca^{++} + Mg^{++}$	80.1	95.8	70.5	30.8	57.2
HCO_3^-	372.0	421.0	249.0	237.0	300.0
SO_4^{--}	73.0	99.0	94.0	26.0	23.0
NO_3^-	1.77	11.0	15.0	6.03	1.8
Cl^-	10.65	8.88	8.88	3.55	5.33

Table 4. *Analytical data on karst waters collected from dripstone formations attacked by recent corrosion in some czechoslovak caves*

SOIL EROSION FROM HILLTRIBE OPIUM SWIDDENS IN THE GOLDEN TRIANGLE, AND THE USE OF KARREN AS AN EROSION YARDSTICK

by Kevin KIERNAN *

Resum

El tipus de cultiu itinerant realitzat per les tribus de les muntanyes així com la cremada regular dels boscos en les àrees productores d'opi del Triangle d'Or, són responsables de seriosos danys en els recursos del sòl. L'estudi de les formes exhumades de lapiaz, que presumiblement s'han desenvolupades sota la superfície en lloc de fer-ho en condicions subaèries, es presenta com a prometedor mitjà per documentar l'erosió del sòl; no obstant això hi ha molts de problemes que romanen sense resoldre, el que fa que encara no es puguin aconseguir resultats segurs.

Abstract

Shifting cultivation by hilltribes and regular burning of the forests in opium-producing areas of the Golden Triangle is responsible for serious damage to the soil resources. The study of exposed karren forms that are assumed to have developed under subsurface rather than subaerial conditions has some promise as a means of documenting soil erosion, although serious problems remain to be resolved before reliable results can be achieved.

Introduction

While the social costs of drug addiction and associated criminal activity are well known, the environmental costs of the illicit drug trade gain far less publicity. A large proportion of the world's illicit heroin supply originates in the opium swiddens of subsistance hilltribe farmers near the common borders of Burma, Thailand and Laos, an area popularly known as the Golden Triangle. The heroin is refined in mobile laboratories under the control of private armies. Shifting cultivation has led to severe environmental deterioration in this region, including serious soil erosion from swiddens (Hurni, 1982; Dunkley, 1985). Coupled with pressures from the western world to stem the flow of heroin this has stimulated efforts by the Thai government to promote sedentary cultivation of alternative crops.

Nonetheless, opium production continues, particularly in remote and insecure parts of the region that lie beyond the control of Thai government forces. Many of these localities are underlain by Permian limestones that have given rise in the wet tropical climate to deep terra rossa soils. This note records an opportunistic reconnaissance of the erosion of these soils in one such remote centre of opium production. It also explores the potential usefulness of certain karren forms as surrogate measures of soil erosion.

Physical Environment

The Red Lahu hilltribe communities of Pha Puek and Pha Daang lie close to the Burmese border in the limestone mountains of far north-western Thailand (figure 1). The area is located at about 19° 14'N at an elevation of 960-1020 m. asl. It is drained by the Huai Pong Saen Pik, a minor tributary of the Salween River. The climate is of Koeppen Agw type and is characterised by a cool-dry season from December to February, a hot-dry sea-

* Department of Geography, University of Tasmania.

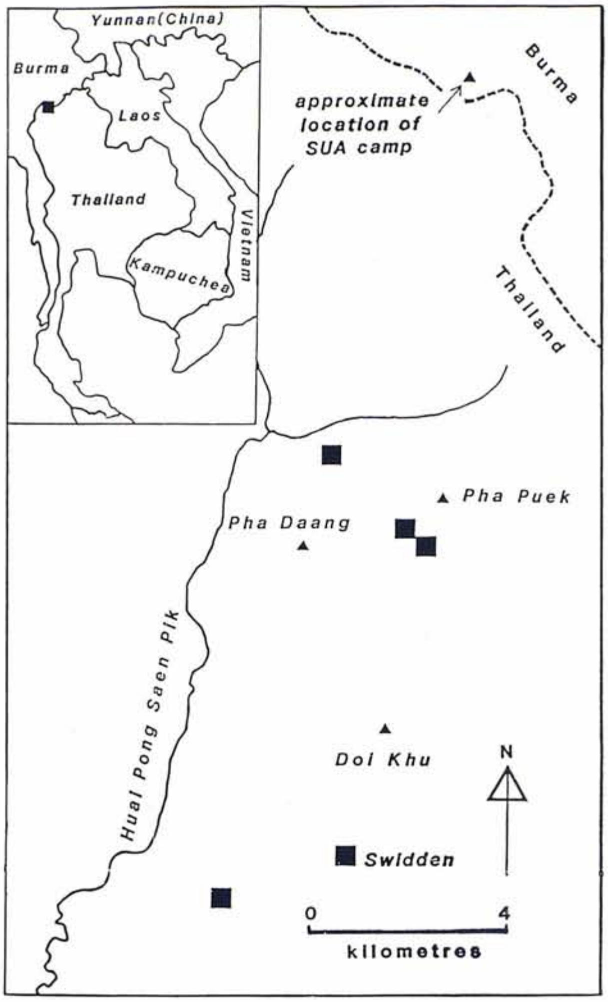

Figure 1. Location of the Pha Puek-Pha Daang area.

son from March to June; and a hot-wet season from July to November. Rainfall data are not available but about 30 km. south-east of the study area at Huai Thung Choa, downwind of the study area, it may considerably exceed 2000 mm. pa. Some 90 % of the annual total falls between May and November (Hurni and Nuntapong, 1983). The mountains are aligned north-south and orographic effects are probably considerable.

Origin and character of the Agricultural System

The production of opium is important to the economies of both Pha Puek and Pha Daang. These opium fields probably lie within the catchment of the notorious Burmese warlord Khun Sa, as his Shan United Army (SUA) maintains a base camp only a few kilometres to the north. Opium forms an important cash crop of low bulk that can be easily transported from remote areas and may be cultivated on marginal lands. Although primitive agriculturalists may have been present in these mountains since the close of the Pleistocene (Gorman, 1966) the advent of increasing population pressures, opium production and the environmental problems associated with its cultivation, are comparatively recent. Opium was probably introduced to China by Arab traders in the seventh century, but imports mushroomed from 1829-1839 when an average of 1841 tonnes of Indian opium was taken to China each year by Britain to pay for silks and tea. Attempts by China to halt this influx led to the Opium War of 1839-1842 between the two. With China's defeat this drug traffic increased further and by the 1880s reached 65,000 tonnes each year. With addiction now widespread, China began to encourage opium production by hilltribes in the South-West in an effort to reduce the drain of money from the country.

When China was subsequently divided between rival warlords opium taxes came to provide a means of financing private armies such as the Kuomintang (KMT). The need to pay these taxes forced the hilltribes to increase production. By the 1920s groups such as the Lahu were escaping southwestwards into the Golden Triangle. Following the communist takeover in China the nacionalist KMT, with support from the USA and Taiwan, made three attempts to recapture Yunnan. When they failed they were abandonned by these allies, and were left almost totally reliant upon opium for funding. This compounded the pervasiveness of the industry. In addition, anti-government forces in the Shan State of Burma, particularly the SUA, are also dependant on opium taxes and heroin refining for finance. Western concern to see the maintenance of an anti-communist buffer on Thailand's northern frontier has further complicated eradication of the illicit heroin industry. However, proposals by some Shan groups to sell all their output to the west for medicinal purposes in exchange for political recognition have been rejected and much of the world's medicinal supply is grown in economically more

Figure 2. Erosion gully 3-4 m deep cut through colluvial deposits south-west of Doi Khu.

advantaged parts of the world, such as Tasmania, were alternative crops are viable.

The opium poppies are cultivated on steep swiddens cut from the forest and burnt prior to planting. Under very favourable situations swiddens may be used for opium production for up to ten years (McKinnon, 1983) but more usually they are cultivated for less than five years. The fallow period never spans less than ten years and may have to last decades. Corn is often first planted as a food staple and cover crop for the young poppies. These flower in January and the opium is later removed by incision of the seed head. The stubble is commonly burnt at the end of the dry season which leaves the ground bare with the onset of the monsoon. Work by Hurni and Nuntapong (1983) suggest that these early rains of late May-Early June may be the most intense of the year.

Figure 3. Advanced soil erosion in a swidden 5-8 years old, south of Pha Puek. Soil has been stripped from steep slopes and deposited in the adjacent sinkhole. Karren forms of subsurface origin are common on many exposed outcrops.

Evidence of soil erosion

The heavily sediment-laden rivers that flow from these mountains each wet season attest to the extent of soil erosion. This sediment derives not only from swiddens but also from forest areas repeatedly razed by humanly ignited wildfire each dry season. Erosion gullies 4 m or more in depth have cut through colluvial accumulations near the base of mountain ridges (figure 2). Earlier damage by erosion consequent upon forest burning complicates the assessment of erosion from swiddens that may subsequently be cut. Erosion may also have been initiated during early logging operations by British and French interests that destroyed the teak forests in the area, large parts of which are now cloaked in secondary forest with widespread thickets of bamboo. Areas that have been subject to swiddening appear more seriously eroded than the floors of the burnt forests. Extensive slopes of bared limestone outcrops and thick accumulations of sediment on the floors of sinkholes and caves give the impression that sheet erosion is rapid and continuing (figure 3).

Measuring the soil erosion

Solutional karren fluting on exposed limestone surfaces provides one possible means of estimating the extent of soil loss. Because the rounded morphology of karren that develops beneath a soil or litter cover (eg. rundkarren and solution pipes) contrasts with the sharper crested forms that develop subaerially (eg. rillenkarren and rinnenkarren) the extent to which rounded forms are exposed might provide a measure of the depth of soil lost (Jennings, 1971). However caution is required because some rounded forms may develop beneath a moss, lichen or liverwort cover (Bogli, 1980).

Estimates of cover loss from two swiddens near Pha Puek, based on this approach, are presented in table 1 (n=20 in all cases). These indicate loss of up to 80 cm. of soil and litter, although the proportions of each cannot be differentiated. It is highly unlikely that this loss is attributable solely to swiddening as karren forms also indicate considerable loss elsewhere from steep forested areas subject to regular burning, and there is every reason to anticipate that the area near Pha Puek was burned repeatedly prior to clearing. Reconnaissance of erosion from the forest floor in an area only now being converted to swidden several kilometres south of Pha Puek on the southern slopes of Doi Khu also revealed similar maximum losses in localised areas although the average figure was considerably less (19.6 cm) than at Pha Puek. If it is assumed that a similar average depth may have been stripped at Pha Puek prior to forest clearing, only 20-25 cm of the cover loss there may be attributable to erosion from the swiddens. However, the karren method of estimating cover loss may significantly over-estimate overall erosion due to preferential lowering of the ground surface close to outcrops by runoff from them.

	site	a	b
	aspect	ESE	S
	slope (%)	75	40
cover loss:	range (cm)	2-80	0-80
	mean (cm)	44.4	40.9

Table 1. Estimates of cover loss, Pha Puek.

Any estimation of the rate at which erosion proceeds demands some measure of the time period over which the cover has been lost. Rounded karren forms should undergo progressive sharpening once exposed to subaerial processes. Where exposed outcrops occur in deforested areas this probably occurs fairly rapidly under a monsoonal regime. Precise rates are unknown, but some guide to the order of magnitude may be offerred by Indonesian data (Balazs, 1968) that indicates an overall limestone surface denudation rate of 83 mm. 1000 yrs. Even though flutes represent sites where rock solution occurs more rapidly than the average it seems unlikely from this figure that sharpening would become evident in less than 10-15 years. This means it is unlikely to occur during the lifetime of any swidden. Sharpening will probably be considerably delayed where a forest canopy intercepts much of the rainfall. In addition, because solution processes that give rise to karren proceed most rapidly under warm conditions (Bogli, 1960) the shading of outcrops from the sun by a forest canopy may compound the delay.

Two main problems therefore exist. Firstly, the exposure of rounded karren in this area seems to offer a useful guide to the total depth of rhizosphere lost, but provides no means by which to fix precisely the proportion represented by soil. Secondly, no time control is available. However, local information suggested that the swiddens were cleared 5-8 years ago. If it is assumed that the soil surface has been lowered by 22 cm during this time, a surface lowering rate of between 2.8 and 4.4 cm.year is implied. If this were all soil, which is likely to be substantially the case given annual burning, it would ammount to a loss of between 280 and 440 tonnes. ha.yr.

In a brief attempt to verify this rate, soil loss from a swidden north of Pha Daang was estimated using basal burnlines on stumps left standing in the swidden (figure 4). If the difference in elevation

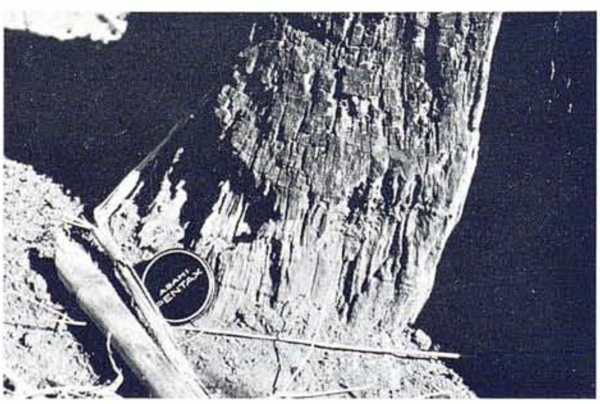

Figure 4. A basal burnline on a stump remaining in a swidden north of Pha Daang. The soil surface has been lowered by several centimetres since the swidden was burnt at the end of the previous dry season.

between the base of the burnt wood and the present ground surface is assumed to define the amount of cover lost, burning is assumed to have penetrated to the base of the litter layer, and fresh and well defined burnlines are assumed to date from the preceeding dry season, then the rate of erosion of the soil may be estimated (table 2).

	aspect	NNE
	slope (%)	60-70
cover loss:	range (cm)	1-10
	mean (cm)	3.5

Table 2. Soil loss estimates, Pha Daang, May 1985 - May 1986.

This suggests a mean surface lowering rate of 3.5 cm.year which would imply that soil loss amounts to 350 tonnes.ha.yr which is consistent with the data from Pha Puek. Once again, this figure may well be too high since runoff from the stumps themselves may erode the adjacent ground surface to a greater extent than is typical for most of the swidden. Howing close to the stumps may also be a factor (cf. Hurni, 1983). Nonetheless, erosion at broadly this rate would achieve the surface lowering suggested at Pha Phuek in 5.7-7.1 years, which is consistent with the reported age of the swiddens.

Given that these rates are founded on only a very limited date base gathered on the run, and involve untested assumptions, the coincident nature of the results may be merely fortuitous, and certainly they do not represent a realistic vindication of the use of karren as erosion measures. However, these results do suggest there may be promise in the approach.

Conclusion

The principal problems in the use of karren to measure soil erosion include the impracticability of determining the relative proportions of soil, litter, and perhaps moss and lichen within the lost cover; the lack of any presently available time control on the subaerial modification of exposed subsurface karren; and the probability of disproportionately great erosion close to the outcrops themselves. Some of the more extreme subsurface karren exposures recorded may be the result of rounded forms having developed well above the ground surface beneath moss or lichen prior to the advent of regular anthropogenic forest fires. The circumstances of the visit and the very limited amount of time that was available to gather data while moving quickly through the area also meant that only a small number of measurements could be made.

The correspondence between the burnline and karren data suggests that any disproportionate lowering due to runoff from the outcrops and stumps themselves may have approximately balanced out. The suggestion that the determined rates may be excessive is perhaps supported by erosion data from granite soils at Huai Thung Choa where Hurni (1983) has documented an average soil loss of 120 tonnes.ha.yr. Although it might be anticipated that the granite soils would be even more highly erodible than the limestone soils, the rates calculated for the Pha Puek-Pha Daang area are approximately three times those applicable to the granite swiddens, and exceed even the maximum figure of 300 tones.ha.yr obtained by Hurni. It seems improbable that rainfall differences alone could account for this, nor even the fact that the Lisu people at Huai Thung Choa appear to go to greater lengths to minimise soil erosion than do the Red Lahu people in the limestone mountains (Hurni, 1983).

Despite these difficulties it is clear that swidden agriculture, abetted by rampant forest incendiarism, is exerting profound effects upon the limestone soils: destruction of the humus layer; volatilisation of many potential new nutrient inputs; erosional loss of the remaining ash fraction that contains a high proportion of the surviving nutrients; modification of the vegetation cover; and serious progressive reduction of the mineral capital of the soils. Although forest burning causes serious erosion, that caused by swidden agriculture appears to be about 3-4 orders of magnitude greater if the forest floor erosion at Doi Khu is assumed to have occurred over about 40 years and is at all representative.

But however serious their effects, these gentle hilltribe people in their remote mountain communities are merely responding to historical and economic realities that confront them but which were not of their own making. Those who would change the situation must be sensitive to this. The occasional official burning of hilltribe opium crops in response to political pressures from the west may be more likely to create resentment and hardship than changed crop preferences or wiser land management. And, despite the commendable efforts to the Thai government to develop sedentary agro-forestry alternatives to shifting cultivation of opium, remoteness, political instability, and the lack of similar initiatives north of the border remain a stumbling block. With perhaps 30 % of the population of the southern Shan States economically dependant upon the illicit heroin industry, it is likely that unless equitable political and economic solutions can be found to regional problems, physical devastation of the mountains of the Golden Triangle and social devastation in the cities of the western world will continue to go hand in hand for some time to come.

Acknowledgements

I am grateful to John Dunkley for kindling my interest in the karsts of northern Thailand and to John Spies without whose logistical efforts this reconnaissance would not have been possible. This paper has benefitted from earlier comments by Steve Harris, Greg Middleton and Albert Goede to whom my thanks are also extended.

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ADAPTATION OF THE KARST LAND FOR THE AGRARIAN USE IN THE MEDITERRANEAN. PROBLEMS OF RESEARCH AND OF CONSERVATION (A SURVEY)

by Ivan GAMS *

Resum

En aquest article es revisen els següents mètodes de recerca:

1. Anàlisi de la part superior dels afloraments rocosos. En esser tallats a nivell del sòl, la terra s'emprava com a prat. Quan els tallaven més amunt, la terra s'emprava com a terreny de pastura o com a prat. En el darrer cas, emperò, si la superfície rocosa és llisa, el nivell del sòl ha estat rebaixat per l'erosió; aquest tipus de superfície només es pot formar en contacte amb el sòl. La superfície d'una calcària compacta, exposada a la corrosió causada per les precipitacions i per la meteorització mecànica per damunt del sòl, és cantelluda, clivellada i aspre.

2. Anàlisi de les pedres acumulades per l'home a parets, marges, a la vora inferior de les terrasses a camps rostos, o enterrades sota el sòl en aquestes terrasses o sota els prats. La mesura de llur volum i pes, efectuada en algunes illes iugoslaves, ha mostrat que centenars de quilograms de pedres, en casos excepcionals més d'un tona, han estat excavats i trencats per cada metre quadrat de terra «netejada».

3. Les formes com cocons *(Kamenitza),* xaragalls de dissolució *(Rundkarren),* tubs de dissolució, solcs de dissolució *(Korrosionskehle),* i especialment els forats de parets llises *(Kavernosen Karren),* si són trobats a la superfície indiquen una erosió soterrada.

4. Els fragments de pedra amb caires vius deixats en el sòl després de «netejar» la superfície rocosa en alguns camps representa més del 10 % del pes del sòl. Això indica l'extensió de la «netejada», fins i tot quan les pedres majors s'han retirat de la superfície.

Els ocasionals anàlisis professionals realitzats a algunes zones càrstiques de la Mediterrània, han mostrat que les zones habilitades per ús agrícola en èpoques antigues eren més grans del que sabiem per la bibliografia. L'època de la netejada no és segura i abarca des de l'època fenícia (Malta) als temps més recents.

A molts de països les modernes tècniques agrícoles destrueixen les antigues formes de preparació de la terra per al conreu amb aixada i càvec. L'article insisteix en la necessitat de l'estudi dels valors ecològics i històrics d'aquests antics testimonis de l'esforç dels nostres avantpassats pel proveïment de menjar per llurs vides, i de la conservació d'aquesta herència natural i cultural.

Abstract

The following methods of research are reviewed:

1. Analyses of the outcropping tops of stones. When cut off at the level of the soil, the land was used as meadows. When the tops are cut off in higher position, the land was used as a pasture ground or as a meadow. In the latter case, however, the soil level has been lowered by erosion if the stone surface is smooth. This can develope only in contact with the soil. The surface of solid limestone, exposed to corrosion caused by the precipitations and by the mechanical weathering above the soil, is sharply fissured and rough.

2. Analyses of the stones accumulated by man into walls, side walls at the lower edge of the slope field terraces, or buried under the soil in such terraces or under the meadow. Measurements of their volume and weight, made on some Yugoslav islands, have shown that several hundred of kilograms, in exceptional case even more than one ton of stones have been dug out and cut off for one m² of the «cleared» land.

3. Subsoil forms, such as *kamenitza,* solution runnel *(Rundkarren),* solution pipe, solution notche *(Korrosionskehle),* and especially the rocky holes with smooth walls *(Kavernosen Karren)* are, when on surface, an indicator of the soil erosion too.

* Prof., Department of Geography, University of Ljubljana, Aškerčeva 12, Yugoslavia.

4. The stone fragments with sharp edges left in the soil after the «clearing» of the stony surface represent in some field more than 10 % of the soil weight. They indicate the extent of the «clearing» even when the bigger stones are removed from the surface.

The occassional professional analyses, made so fare in some Mediterranean karst areas, have shown much larger adapted areas for agrarian use in ancient times than this is known in the literature. The time of clearing is uncertain and reaches from the Phoenician (Malta) to the recent time.

In many countries the modern agricultural techniques, destroy the old forms of land adaptation for the cultivation by hoe and spade. The article stresses the need for the study of the ecological and historical value of these old evidences of the ancient endevour of our ancestors to provide food for their life and for the conservation of this natural and cultural heritage.

Forms of adaptation and research problems described here are not limited to the Mediterranean karst countries only. The results reported here are limited to this area because the author is more acquainted with it.

First a brief review of the research methods.

1. Cutting off the tops of the stones sticking out from the land surface.

Surface of the stone cut off is more rough than the natural one and this difference is noticeable even after many hundred years. In the northwestern part of the Dinaric Karst in Yugoslavia and on the Adriatic islands, where a larger part of the results reported here is derived from, the stones cut off appear mostly on the pastures. This kind of cutting presumably occurred in the transition time from goat and sheep grazing to cattle grazing. The stones cut off appear also in the forests that have occupied the abandoned pastures.

The stone tops cut off are usually higher than the soil surface around them. But originally they have been mostly cut off on the level of the ground nearby. The present difference in the height can be considered as an effect of later soil erosion. But this method is useful first of all when the stones cut off appear in a larger area.

2. Smooth stone surface formed in contact with soil and rough one formed in the open air.

The surface of limestone, formed by corrosion of the precipitated water and (or) by the mechanical weathering, is sharp and rough. On both sides of the top ridge of some stones *Reggenkarren* occur. Contrary to that the surface of the compact limestone below the soil cover is smooth. It is smooth even in case the pebbles are thin and narrow. This difference has become more obvious, especially when the soil around the same stone sticking out from the surface has been recently removed in the lower level. The fresh surface that has recently been unearthed is lighter because the old one is darker due to the lichen and microorganisms. The calcite inlayers are more resistant to the corrosion and less to mechanical weathering. Therefore under the soil the salients, sticking out from the stone surface, are formed, and in the open air the fissures appear in them.

There are some exceptions in the mentioned rule. The surface of the homogeneous limestone becomes smooth also under the snow cover if it lasts until summer (in the alpine belt). In the dense deciduous forest the dead leaves and from them derived humus cover the larger massive stones

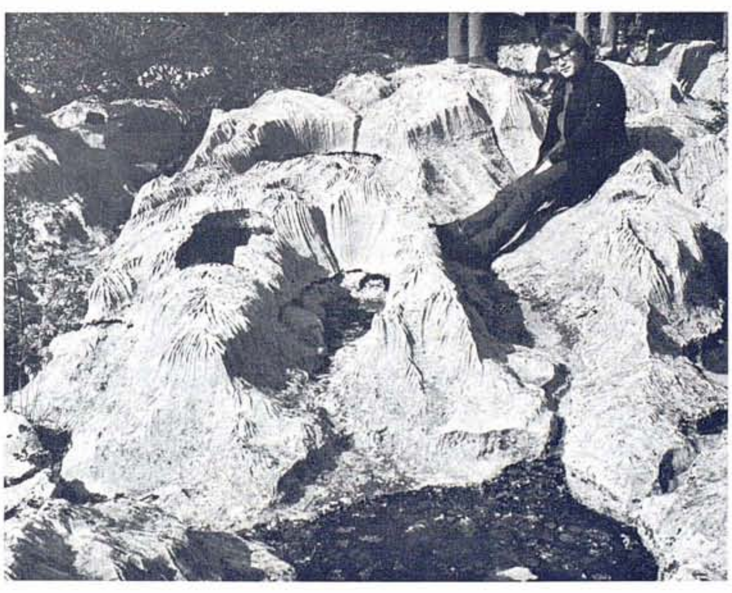


Photo 1.

The big Karren prove with their smooth stone surface their subsoil formation. The top *Regenkarren* (solution flutes) generated later after the soil was washed away due to the agrarian land use (Trieste Karst near to the village Briščiki).
Photo by I. Gams.

sticking out from the ground and form the smooth stone top surface high above the ground.

3. Smoothness of the surface of the stone has been diminishing in hundreds of years, but the proper origin of the initial surface still can be recognized after a long time. It is often accompanied by special stony forms as solution pans from which on the surface *kamenitzas* can be developed, as well as covered solution runnels *(Rundkarren),* solution pipes, solution notches *(Korrosionskehlen),* covered *bogaz,* filled funnel-like doline, filled pothole (Gams 1971, 1976, Jennings 1985). The most important of them is the hole *(Kavernosen Karren)* with smooth walls which can penetrate the whole stone mass.

When estimating the soil erosion rate by means of the two mentioned methods one has to take into account that the sunshine after the deforestation reaches the ground and accelerates the photochemical weathering of the top humus soil horizon. This and leaching (eluviation) downward after the decay of the roots cause the lowering of the soil level, too.

4. Analyses of the anthropogenic stone accumulations on the karst surface.

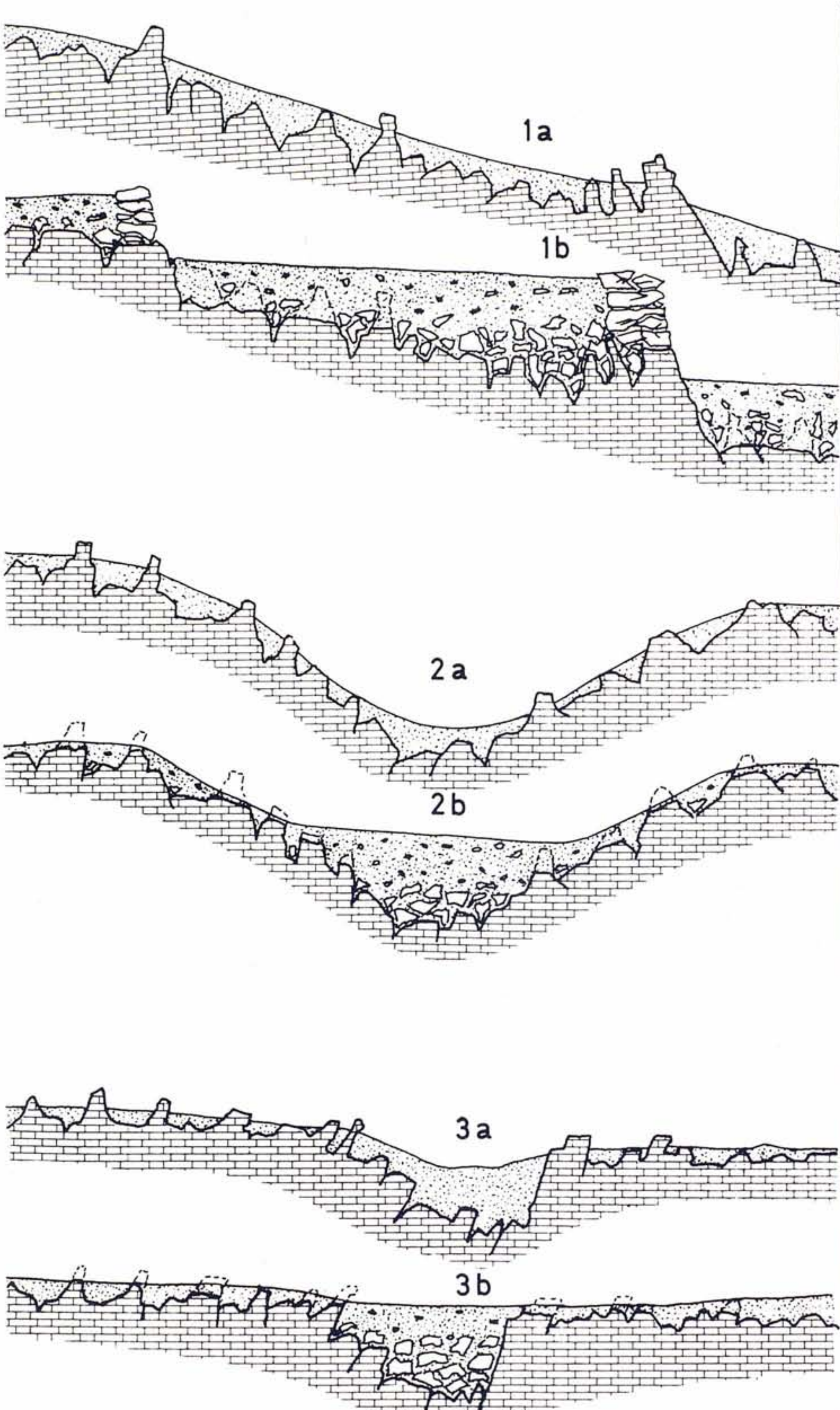
The stone accumulations typical of the proper Mediterranean karst are a by-product of the clearing of the land for different, mostly for agrarian land use. The karst is characterized by the thin interrupted soil cover with stones sticking out from the surface and by deep soil pockets in the fissures. In the natural circumstances such a karst surface is suitable only for pastures of sheeps and goats. Cutting off the stones on the surface makes possible to cut down grass with scythe. For tillage it was necessary the stones to be removed 15-25 cm below the arable land surface.

Forms of the accumulated stones are different and typical of regions. Stones can form irregular heaps or elongated rows. Systematically so called dry walls or karst walls are built. If the pebbles are compounded of one serie, the width of wall is the same as the length of pebble. Larger are the walls with two series of pebbles. Some of them have the inner part between two series filled up by minor particles. The accumulations are seldom in form of quadrangular tower of pyramidal elevations. In the past centuries the stone accumulation has been in some places removed or concentrated in big formations to get more cultivated land. The stones cut off have also been used for buildings, roads, lime-kiln, they have also been thrown in the potholes, chasms etc. A part of them had been buried under the soil what was proved by bore-holes and excavations (Gams 1973, 1974, 1977). The buried pebbles have been found: a) In the lower belt of the so called cultural terraces. When constructing them on the inclined surface the rubble has been

Photo 2. Side-walls and cultural terraces in the Adriatic island Lošinj, near to the town Mali Lošinj where in some plots more than 1.000 kg/m² of cut off and accumulated stones have been found.
Photo by I. Gams.

put on the rocky base along the lower edge of the terrace and with the rest of pebbles the vertical side-walls has been built. The new arable land in the terraces has essentially less inclined surface. b) At the clearing of the karst surface the rocky trenches with thick soil have been unearthed. After the pebbles had been deposited there the rocky surface was covered evenly with soil. c) The stones cut off on the doline slopes have been thrown in the trenches excavated in the bottom. Then all the available soil stripped off from the slopes was spread in the bottom to get a larger field (see sketch). d) The fragments of broken stones derived from clearing were left in the soil. Their weight takes 10 or more percent of the soil weight. These fragments prove the clearing in case all accumulated stones were removed from the surface.

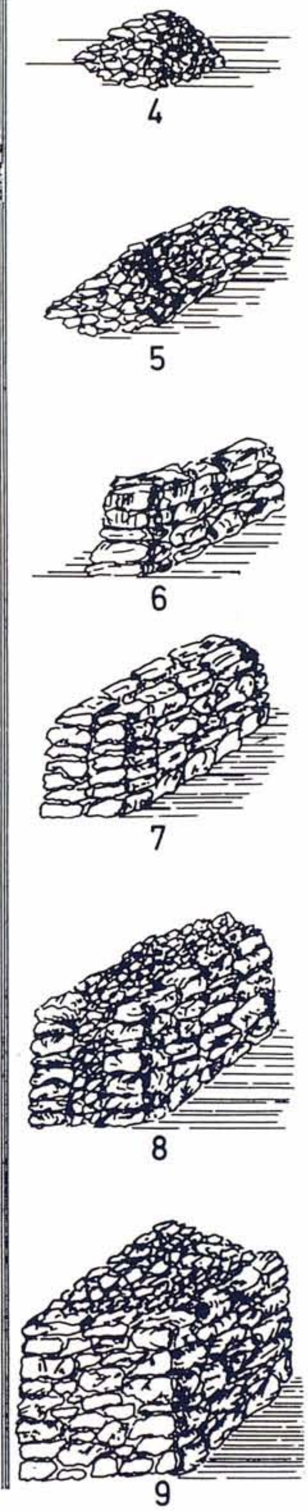
5. Instead of cutting the stone there it was possible to make the soil thick enough with transportation it from near places. Near to these plots the unearthed stones are today usually the highest. Deep trenches and dolines have also provided the soil for transportation. It is proved by their unnatural forms. The soil was seldom stripped off from the whole nearby slopes and thus made infertile (example NW of St. Julians on Malta). The difference in soil structure in the doline bottom and around it is also an indicator for transportation (Lovrenčak, 1977).



Some forms of the alteration of karst surface due to cultivation:

a - natural surface, b - alterated and cultivated surface.

1 - Field terraces on slope in semicovered karst. 2 - Alteration of the more funnel-shaped doline into the more bowl-like doline to get a larger acre on its bottom. 3 - Alteration of the semicovered karst into the covered karst in a meadow.



Forms of accumulated gravel (pebbles) collected at the process of cultivation:

4 - Heap of stones. 5 - Heap of stones arranged in a series. 6 - Wall built in one series. 7 - Wall built in two series. 8 - Wall built in two series with inner filling. 9 - Quadrangular tower (from: Gams, 1974).

Photo 3.

Form of accumulated stones used for temporary dwelling of peasant on the field near Stari grad where some side-walls still indicate the Greek field parcelling from the 2th century b.Ch.
Photo by I. Gams.

6. Historical development of the adaptation of karst surface.

The knowledge of it in single countries and in the whole Mediterranean world is deficient, the historical sources scarce and human memory lost. For example: The Polyglot guide-book entitled «Malta» reports that the Phoeniciens (there from 14th-18th century b.ch.) «brought the fertile soil to Malta, covered the nacked rocky surface with it and so acres, vineyards and cotton plants were introduced» (p. 8). The preliminary research showed that in this limestone country the soil had in reality been derived from the local clearing of stony surface. It was easy to be cleared due to the light and soft limestone. Importation of the soil could contribute only a negligible share to it. The guide-book has probably right in sense that the Phoenicians brought the culture of adaptation of karst surface already. East of the small town Stari grad on the Yugoslav island Hvar the Greek parcelling of the field (4th-2nd cent, b.Ch.) still can be seen in the form of walls. The regular Greek parcelling in «stadies» and «plethrones» was possible only in a plain area without blocks sticking out from the ground. Today this field is dotted with stones. Since the Phoenician and Greek epoches the adaptation has been continued till the present time. The new agricultural techniques brought also new adaptations and consequently the changes in cultivation of land using hoe, spade, later plough, and recently tractor. A deeper clearing of stones was necessary when the olive-trees replaced the fig-trees and later vineyards. Therefore the stones had to be cut off down to the depths of 80-100 cm. Every country has his own historical development. The walls in Pennins (England) were mainly built in the transition from feudal to private land tenure - it was in the 17th and 18th century (Raistrick, 1969).

The amount of work for adaptation of the karst land for agricultural use can be elucidated by measuring the weight of excavated stones. The measured volume of all the stones accumulated on the surface can be diverted (specific weight 2,7-2,8, value diminished by factor about 0,2 due to empty voids between the stones) into weight. This kind of measurements showed mainly less than one hundred kg/m^2 of land from where the stones had been taken away. On the Yugoslav islands in the Adriatic sea this value rises to many hundreds kg/m^2 and in some exceptional cases (Lošinj, - Gams 1974, 216) more than 1000 kg/m^2. Invisible stones under the soil and those in the soil were neglected. After deforestation the decay of tree roots has lowered the soil level for some centimetres. In case of one thousand kilos of excavated stones the soil level has been equivalently to their volume lowered for 21,6 cm. Both factors have contributed to the general soil «erosion».

The study of alteration of karst surface is important for many reasons. It is useful for pedology since the natural soil horizons have been completely destroyed and mixed. It can be of great help to the archeological excavations in establishing the natural surface. The alterations have entirely changed the ecological conditions. The resilient rubble in the soil has a better heat conductivity than the soil particles. The altered soil is therefore warmer in summer. If the pebbles are lying below the soil it is more arid and colder rain provokes a smaller reduction of the soil temperature. The inwalled plots have a reduced wind speed and therefore a higher daily maximal air temperatures. The walls hinder the gliding of near-to-surface cool air layer on the slope. The karst depressions with the walls are therefore warmer in winter. The walls hinder the soil erosion and also spreading of forest and grass fires. But in the same time the soil of cultivated land without any grass on the surface is more liable to soil wash and vertical leaching. Peasants often say the stones «grow».

Beside the ecological advances of cultivated land also some difficulties are to be found there. The walls hinder the traffic and cultivation of land by means of all kinds of machines. They also hinder the creation of larger fields to be possessed by one farmer only. For this and the other reasons the agrarian use of the altered karst land is on the decrease in modern time. The intensive use is more and more limited to the vicinity of the settlements and to less inwalled and less inclined plots, that are mostly on the bottom of the depressions and in the valleys. But the ancient agricultural land is being rapidly destroyed there by the traffic, roads, railways, and by the other non-agrarian activities. The inwalled plots seems to be incompatible with the modern agrarian techniques. But with the decay of nearly one thousand years old cultural karst land the cultural heritage would be most affected. Thus an evidence of the year-long endeavours of our ancestors for their life and food should be lost. At least some samples should be conserved for our future generations. From this point of view we have to register the dying forms of cultivation, the remnants of human knowledge, and the effects of alterations before the agricultural land of new settlements is utilized and new techniques with tractor and harvester used.

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HUMAN IMPACT ON LIMESTONE PAVEMENT

by Dr. H.S. GOLDIE *

Resum

Els paviments calcaris de les Illes Britàniques forneixen interessants exemples de l'activitat humana com a agent de canvi geomorfològic. Aquest article contempla la història de la influència humana en els paviments calcaris, especialment a l'Anglaterra nord-occidental, examina danys recents, i discuteix les accions realitzades per protegir aquestes formes paisatgístiques tan belles com fascinants. Han estat diverses les activitats que han afectat els paviments, i la importància de les activitats individuals ha canviat amb el temps. Darrerament la pressió s'ha incrementat i els organismes conservacionistes s'han interessat pel problema per tal de protegir els paviments de nous estralls. Durant els darrers 30 anys, molts pocs paviments calcaris de les Illes Britàniques han deixat d'esser afectats per agressions o alteracions, i alguns han patit molt seriosament.

Summary

The limestone pavements of the British Isles provide an interesting example of human activity as an agent of geomorphological change. This paper looks at the history of human influences on limestone pavements, especially in northwestern England, examines recent damage, and discusses the actions being taken to protect these fascinating and beautiful landforms. The activities which have affected the pavements have been varied, and the importance of any individual activity has changed over time. In recent decades the pressures have increased and conservation bodies have become concerned with the problem in order to protect pavement sites from further damage. Very few pavement sites in the British Isles have been unaffected by damage or alteration in the past 30 years, and some have suffered very severely.

Introduction

The effects of man as a geomorphological agent have been discussed in the literature at various times, for example Thomas (1956), Brown (1972). To elucidate these effects it is necessary to examine both field evidence and historical documentation of economic processes, as has been illustrated by Prince (1962).

In the case of limestone pavements field observation shows that the blocks or «clints» which compose them have in places been removed by man and used in various ways. Previous literature has briefly mentioned areas where this has occurred, and types of evidence for the damage and its dating (Sweeting, 1972; Goldie, 1973, 1976, 1981, 1986; Ward and Evans, 1976). In the present research the author has looked particularly at field evidence, and at material made available by the Nature Conservancy Council, which is active in trying to protect limestone outcrops. This work comes at a time when there is an increasing need to conserve valuable landscape features, in the face of increasing environmental pressure. Other karst landforms, for example caves, have also been vulnerable to damage (Black, 1969; Stanton, 1982).

The evidence establishes that limestone pavements in the British Isles have been profoundly altered by human activities. Merely to observe the pavement outcrops and to conclude that their features are entirely natural could encourage erroneus ideas about their development. Analytical problems arise in situations where proof of human interference is not available, but where the field situation suggests damage. Older damage is more difficult to recognize in the field than recent. Further problems arise when trying to establish what effect in-

* Dept. of Geography, University of Durham.
South Road, Durham, U.K.

direct activities have had on pavements. Direct effects have been so profound and extensive in some areas as to justify the legal protection of limestone pavements in Great Britain under the Wildlife and Countryside Act, 1981. No such protection exists in the Republic of Ireland, although clint removal is also very extensive there.

Man's influence on limestone pavement, particularly in Britain and Ireland, stems from several factors, including its proximity to settlements and communications, the value of the pavement areas to upland agriculture, and the value of limestone itself as a marketable commodity. Economic activities have directly or indirectly affected limestone pavement features and distribution for a long time. Areas where pavements are found have been grazed and cultivated since pre-historic times and these activities have affected vegetation and soil cover, thereby indirectly influencing pavement distribution. Other activities have directly affected pavement outcrops. These include limestone removal for roads, walls and buildings and their decoration; its burning for lime; its removal to improve pasture, and to supply garden rockery stone.

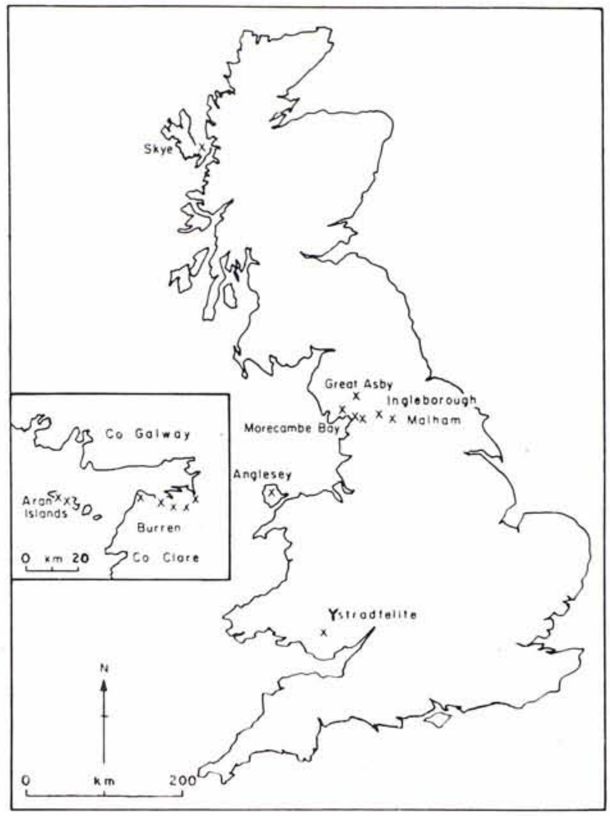

Figure 1. Location map of places cited in the text.
x = main pavement area examined.

Sources and methods

Varied sources and methods have been used to obtain evidence for the effect on pavements of these activities. Field evidence has been the most important, especially as it shows exactly how the ground surface has been altered. But other sources are interesting and some supply information for sites lacking field evidence, whilst others give figures of quantities of stone involved. Local contacts, literature sources, examination and comparison of different map series, examination of aerial photographs, Inclosure Acts, estate records, local newspapers and Nature Conservancy Council files have all been used, in addition to field evidence, to compile a picture of what has happened to these landforms. The location map (fig. 1) indicates the main areas of pavements examined.

Local contacts have not been informative because there is great reticence in N.W. England over this question of pavement damage. The problem is over a clash in attitudes to the land which arises between different interests in a National Park, Site of Special Scientific Interest or other partly protected area of natural beauty. This is particularly so in the Yorkshire Dales National Park, where many important pavement sites are found and where they have been much damaged.

The Chartulary of Fountains Abbey, which in Mediaeval times owned much of the land containing pavement in Craven, Yorkshire, offered no specific information on limestone use, but the evidence it gave of the economic activities up to 1539 supports the idea of grazing pressure on soil and vegetation which might lead to soil erosion and exposure of pavement outcrops.

Archaelogical literature confirmed some of the field evidence for clint use in building old structures, and confirmed general settlement pressure in pavement areas. Field examination of some sites in this literature shows that pavement was cleared and used in construction, for example the prehistoric standing stone circle at Knipe Scar near Bampton, Cumbria (Noble, 1907).

Maps might reveal evidence of recent changes in the pavement extent. The 1890's edition of the six inches to one mile Ordnance Survey maps of Craven was therefore compared with the most recent available. Unfortunately, this source was not fruitful, due to inaccurate mapping and differences in the representation of pavement; indeed there are differences in the cartographic representation within editions. Consequently, changes which appear to have occurred may not have, but merely reflect changes in cartographic method or accuracy. Six inch Ordnance Survey maps where also used to ascertain pressure on limestone from usage in walling, lime kilns, sheepfolds and quarries.

The Inclosure Awards of the late 18th and early 19th centuries for Craven show that pavement was used in walling. The Malham Inclosure Award Map depicts limestone pavement outcrops with walls crossing them (Goldie, 1976). Walling pressure was greatest in the dales rather the moors, but in both areas pavement was used where it provided the most available stone. Calculation of quantities involved is difficult, as is assessment of the exact effect on the pavement. Grassy areas on either side of walls which cross pavement indicate removal, for example in Wharfedale above Chapel House Wood, and on Gauber Pasture on Ingleborough. Measuring wall length per kilometre square on the six inch maps indicates the scale and variation in pressure (Goldie, 1986). Densities as high as 8 km of wall per km² are found in Wharfedale and Ribblesdale. The majority of the walls involved are of limestone.

The Ingleborough Estate Cash Books document the amount of stone used on the estate for walling and lime in the early 19th century. Wall construction peaked in 1842, 1855 and the early 1870's. Most of the stone involved was limestone, though some was grit. Use of limestone for lime showed a very large peak around 1842.

Air photographs show examples of direct pressure on pavement from old settlements. One photograph in Raven Scar, Yorkshire (UH 93, Committee for Aerial Photography, Cambridge) shows how a space in pavement has been cleared for sheepfold construction; another of Scales Moor, Yorkshire (UH 83, Cambridge) shows a further example of a sheep shelter using pavement. Photographs of old hut circles, settlements, small enclosures and field systems from the Iron Age, near pavement, indicate the possible pressure on outcrops at this period, for example on Cowside Flask, Malham Moor (BAQ 47, Cambridge).

Local newspapers in N.W. England, (Craven Herald and Westmorland Gazette) confirm the occurrence of removal and have reported on Public Inquiries into the problems. Information has also come from the Files and records of the Nature Conservancy Council (NCC) and discussions with

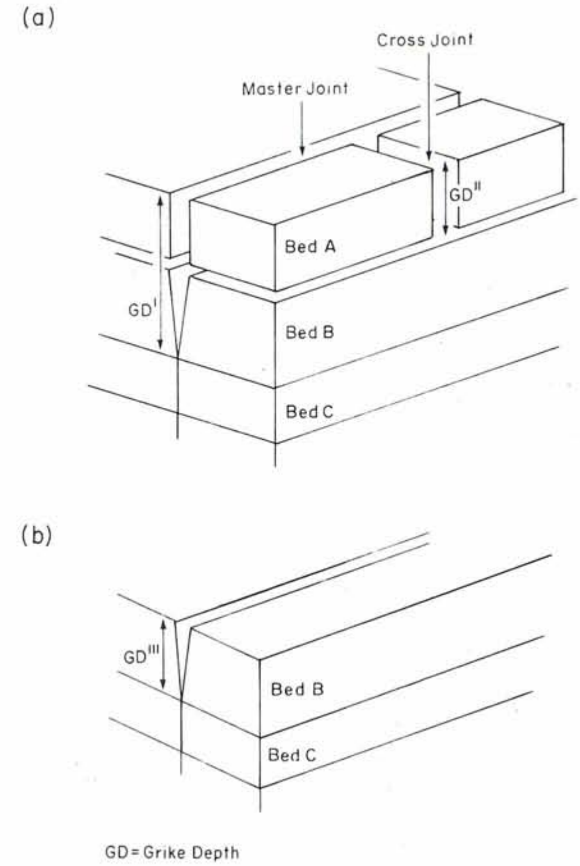

Figure 2. Diagram showing effect of clint removal on grike depht.

NCC officers have provided evidence. A comprehensive botanical survey of limestone pavements by Ward and Evans (1976) included assessments of pavement damage and is an important source of information for the NCC in its pavement protection work. There is approximately 2,150 ha. of limestone pavement in Britain and this survey detected damage to 97 per cent of the sites and regarded only 13 per cent of pavement sites as being 95 per cent or more intact. (Ward and Evans 1976; Frankland, 1980). The report estimated that about half of the total pavement had been damaged.

Field evidence of damage includes contractors' equipment, hydraulic shovels, heavy lorries and other equipment which have been seen by observers on damaged pavements (photo 1). Sweeting recorded an example on Graythorne Plain, Cumbria (Sweeting, 1972). Equipment has been seen on the same area more recently, and at Andrew Scar. Further features of damage have a geomorphological expression, such as access tracks onto pavement, and machinery and explosive marks in the rock. Track construction often involves filling in grikes with rubble, as at Gaitbarrows, Cumbria.

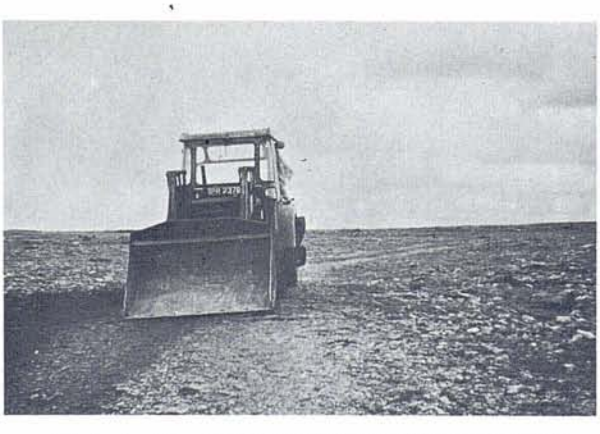

Photo 1. Heavy equipment on Gaythorne Plain, Cumbria.

Geomorphological characteristics of limestone pavement damage

Geomorphological changes due to clint removal include obvious changes in rock level to the extent of the bed thickness removed and concomitant changes in pavement morphometry. After damage clints are in general longer and wider than before, and grikes shallower (figs. 2 & 3). The rock surface beneath clints is rougher than usual on pavement surfaces which have been scoured by glaciers and affected by solution, probably under a soil and vegetation cover, for a lengthy period (photo 2). Removal also produces much small debris, which can be seen on damaged surfaces, filling remnants of small solution features, with larger material blocking the grikes. Clints can be found wedged in grikes, or left in heaps. Observation of this depends on the stage of removal when the site is examined but at Hampsfield Fell (photo 3), removal was stopped by legal action so clint heaps remain on the site. There is also a lack of lichen growth on freshly damaged pavements. Study of this phenomenon could produce useful evidence for dating damage areas where no other precise information is available, similarly to the way lichen studies have been used to date exposure due to soil erosion (Trudgill, Crabtree and Walker, 1979).

Damaged limestone pavement looks very different generally and in detail from undamaged pavement. The geomorphological effects at a freshly damaged site are clear, but problems arise when trying to interpret field evidence in areas of old damage with its effects obscured by the passage of time.

Photo 2. Gauber Pasture, Ingleborough, with damaged pavement (foreground) and intact pavement (background).

Destinations of clints removed from limestone pavements

One of the clearest types of evidence for clint removal comes from seeing them at their destinations. Though some uses totally destroy the limestone, for instance lime making, the use of clints for construction and decoration of buildings and gardens can clearly be seen. Not all limestone blocks used in limestone areas for constructions such as walls, roads and buildings will be clints, some will be loose surface stones, or from quarries. But there are many occasions when the state of a pavement, and its proximity to settlement strongly suggests that its clints have been used in construction. This is confirmed when the characteristic runnel markings of clints are seen on building stones. Some buildings use trimmed clints in their construction, others contain whole clint blocks. Ob-

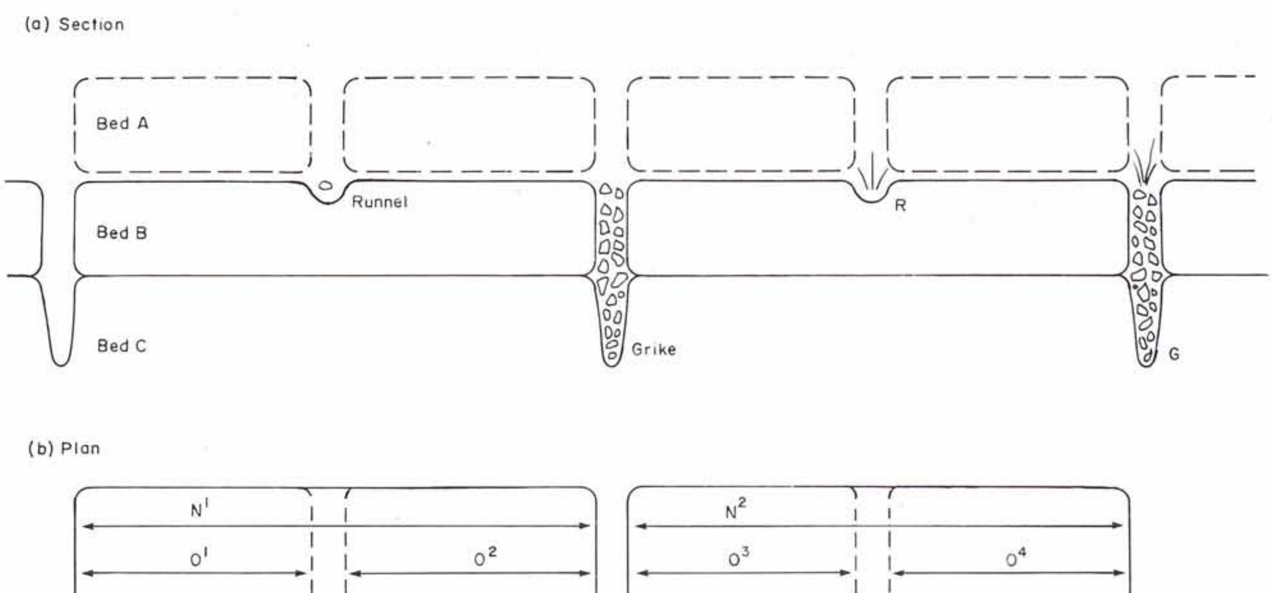

Figure 3. Diagram showing effect of clint removal on clint size.

Photo 3. Hampsfield Fell, damaged pavement, debris in background.

Photo 5. Poulnabrone Dolmen, Burren, Eire.

vious instances of the latter are ancient structures such as the remains of hut walls in Oxenber Wood, Yorkshire and at the 4th century A.D. village at Din Lligwy, Anglesey. At Din Lligwy there is a clearing of c.o.2ha for the village between two wooded areas of limestone pavement (Craster, 1953). The hut walls' bases are clints in situ, and other blocks and gateposts are displaced clints (photo 4).

Other ancient structures constructed of clints include Plas Lligwy burial chamber, Anglesey; the dolmens of Burren, Eire, for example Poulnabrone Dolmen (photo 5); and other smaller burial chambers in Burren.

There is also evidence of indirect effects on pavement distribution. Raistrick and Holmes (1962) drew attention to the Iron Age field boundaries on Malham Moor, which indicate settlement pressure on the environment as the fields would have originally had soil in them, where now they are bare rock. Drew (1983) discusses the evidence for deforestation and soil erosion in Burren in the late Bronze Age, which supports the idea that limestone pavement has been increased in extent by indirect human effects. It also confirms that the rock was used to build structures in this period.

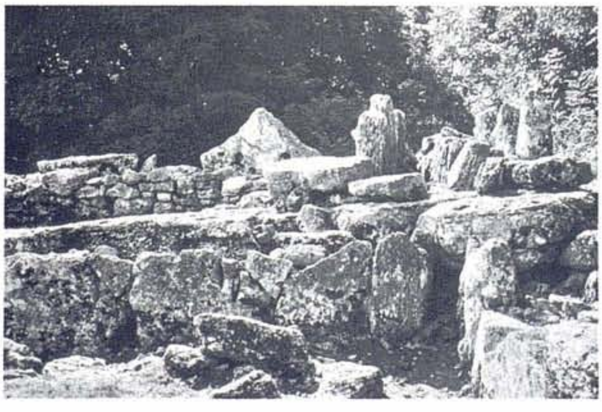

Photo 4. Din Lligwy, Anglesey.

A frequent modern use of broken pieces of well-runnelled clints is for decoration on garden walls. This is a common feature of villages and towns in N.W. England, for example Horton-in-Ribblesdale, Tebay, Bowness-on-Windermere, and Kendal (photo 6). It is systematic along whole streets and in some cases is added to by using large clints (C. 1.5m by 0.5m) for gate posts. In one suburban road in Kendal 42 such clint posts have been counted (photo 7), and neighbouring roads have the same feature. This housing development is early 20th century and the gate posts were probably put in when the houses were built. At a minimum these posts account for the damage of 30 m^2 of pavement, excluding allowance for grike widths. The clints would have been selected carefully for this use as their size and shape was important, so a much larger pavement area would have been damage to obtain them. Other examples of the decorative use of clints includes toppings for gateposts, and doorways, and as a shield to municipal waste bins.

On Arainn, Eire, clints are used to make water-troughs found in many of the very numerous small fields. These troughs and their catchment slopes are constructed from limestone pieces cemented together. General clint clearance is common in Burren, Co. Clare, Eire, and appears to have increased in frequency recently. Pavement is cleared by bulldozer, any soil left grasses over quickly, and the area becomes good grazing. However, the Irish have not developed a taste for decorating their gardens with water-worn limestone, hence the clints bulldozed aside are abandoned around the field edge. In Ireland clints have also been used for construction and many damaged pavement sites near settlements testify to this, for example near Ballyvaughan and Kinvarra. In England abandoning clints is fairly rare as they have horticultural value. Nevertheless at Little Urswick, Cumbria, clints were seen cleared, heaped up with vegeta-

Photo 6. Decorative clints, Kendal, Cumbria.

tion, and burned by a farmer to increase pasture.

Finally, the use which has caused most of the damage to pavements in the last twenty or thirty years, paticularly in Cumbria and Yorkshire has been of 'water-worn' limestone for garden rockeries. 'Water-worn' limestone means the solution runnelled clints. These attractive features have been much sought after in the horticultural trade. The efforts of the NCC and other bodies have prevented this in some areas, for example, the Yorkshire Dales, but the figures quoted earlier indicate that possibly over 1000 ha. of pavement may have been damaged by removal. Accurate figures are hard to obtain as removal was a casual industry, but table I quotes figures from the Public Inquiry in 1962 on removal from Scales Moor, showing that much water-worn limestone had been removed from the pavements around Ingleborough.

British Rail estimated that between 1947 and 1955 a maximum of 300 tons p.a. of rockery limestone was forwarded from Ribblehead, Horton and Settle stations. This is a small amount, consisting of odd loads picked up by farmers to enhance their livelihood. However, removal was more commercial on Gauber Pasture and on Scales Moor. According to the Dalesman (Oct. 1956), 8,000 to 14,000 tons of clints were removed from the area each year, by rail and lorry, clearly for several years. Accessibility almost certainly influenced the extensive removal from Scales Moor.

District	*Approx. period*	*Approx. quantity removed*
Gauber Pasture	1910 - 56	20,000 - 25,000 tons.
Ingman Lodge Hall & High & Low Pasture	1927 - 35	7,000 - 8,000 tons.
Ashes Shaw Pasture	1945 - 50	4,000 - 5,000 tons.
Philpin Sleights	1954 - 58	3,000 tons.

(source Ward and Evans 1976 vol. VI)

Table I. Estimates of quantities of clints removed from limestone pavement, presented to the Scales Moor Public Inquiry 1962.

Rockeries made from clints are fairly common in N. England (photo 8). Sometimes the blocks are well-runnelled, especially in older, larger gardens. In the early days of clint removal for rockeries it was done carefully, by crowbar, and for a specialized market. Such activity, though causing damage did not produce the devastation seen more recently. The modern mechanised methods, sometimes even using explosives, damage the clints and break up the runnel patterns, the very feature which attracts people to this particular rockery stone.

There are well-known gardens which contain water-worn limestone rockeries; some are open to the public, or are featured in magazines, thus encouraging demand (Minney, 1983). One well-known example is Sizergh Castle, Cumbria, a National Trust property. It contains a large clint rock garden with a stream. It was built at the turn of the century, before present concern about pavement damage,

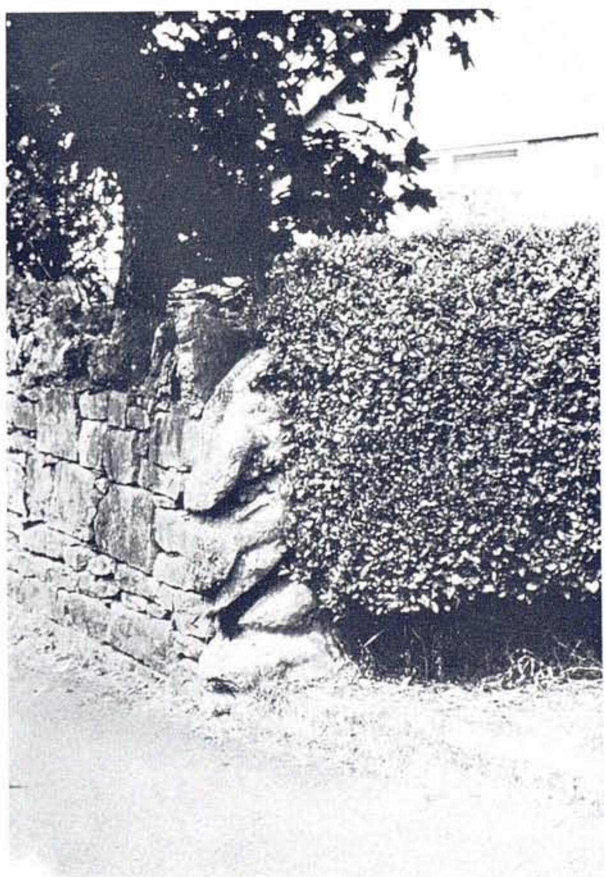

Photo 7. Cornerpost, Kendal.

indeed it would not have been built by the castle's present owners. Limestone pavement rockeries were displayed at the 1863 and 1911 exhibitions at Crystal Palace, and at the 1951 Festival of Britain. The limestone at Crystal Palace was obtained from Gauber Pasture, Ingleborough. Such rockeries were destroyed at the end of the exhibitions! The use has continued recently, for example at the 1981 Chelsea Flower Show (NCC NE 6/5/7/2). In the nineteenth century runnelled limestone from the Ingleton area was even exported to South America for garden rockeries on coffee plantations (Anon, 1956).

Even local authorities are known to purchase water-worn limestone and blocks can be found in such strange places as a York traffic island, and the garden of a York museum. Private examples include the landscaped garden of a London hotel, clint rockeries on the Calthorpe estate in Birmingham, similar rockeries in Leeds, Grassington (photo 8) and other towns and a rockery which decorates a factory at Netherton near Dudley, W. Midlands. This illustrates the wide range of destinations of clints.

A further threat to limestone pavements is incidental to commercial limestone quarrying. In Britain an estimated 26 per cent of the aggregates used are crushed limestone (NCC file S601/5/1). Large limestone quarries even in national parks, such as that at Horton-in-Ribblesdale in the Yorkshire Dales, testify to this their economic importance. Some quarries are in limestone hillsides surmounted by pavements, which will be chewed into as the quarry expands. Table II lists those identified by the NCC as threatening limestone pavement, some of which have already removed large amounts of pavement. For example Holmepark quarry, Cumbria, has destroyed pavement which had unique geomorphological features. The quarry now surrounds a pavement site (Clawthorpe Fell) which has been protected from further inroads under a National Nature Reserve agreement with the owners, but which could be threatened again. Some pavements affected by quarrying are good and important for their botanical and geomorphological features, for example Kilnsey in Wharfedale and Blindcrake Clints, Cumbria. At other quarries, such as at Strath Suardal on Skye, the pavement has not yet been damaged but could be, if not protected, due to proximity.

Photo 8. Garden rockery, Grassington, Yorkshire.

Name	*Location*
Maeshafn	Clwyd
Haverbrack Bank	Cumbria
Middlebarrow	Cumbria
Holmepark	Cumbria
Blindcrake Clints	Cumbria
Crosby Ravensworth	Cumbria
Gaythorne Plain	Cumbria
Ribblehead	Yorkshire
Horton-in-Ribblesdale	Yorkshire
Skythorns	Yorkshire
Strath Suardal	Skye

(Source: NCC file S601/5/ pt 3)

Table II. Location of limestone quarries adjacent to limestone pavement outcrops.

Problems in interpreting the field evidence

Virtually no pavement site in the British Isles visited by the author appears to be completely free of damage. However, there are cases were field evidence is ambiguous, especially if the limestone is well-fractured and the clints therefore small and easily displaced by natural processes and grazing animals. There are areas where the pavement's natural state is very disturbed and where it is virtually impossible to assess damage if no independent evidence exists. So the assessment of damage by Ward and Evans (1976) may be an overestimate for some areas. When there is independent material, such as walls and cairns made of limestone on fractured pavements, for example at Ystradfellte in South Wales (photo 9) this is evidence of human involvement, though not proof that all the apparent 'damage' is artificial. The field evidence is more convincing on pavements with clints too large for animals to dislodge, and where natural processes are possibly the main cause of dislodgement, aided by human interference. For example on the west-facing scar of Hampsfield Fell clints of approximately 1m to 3m in dimensions have been displaced downslope, and frost action, joint opening aided by pressure release, and gravity could all be involved. If blocks are obviously missing from such

Photo 9. Clints near Ystradfellte, S. Wales.

a site then human removal is likely to be involved, but this would need careful field checking. Documentary evidence (NCC files) shows that human interference has affected much of this area, and so the displacement here is probably due to a combination of human and natural processes.

Problems can arise in interpreting older damage, for instance at Gauber Pasture, Ingleborough. The apparently older damage here fits the known usage of clints from this area in the nineteenth and early twentieth centuries. There is lichen regrowth on lowered clints, and solution features are reforming. Further evidence are the clints used in old walls and sheep shelters. In the western part of Gauber Pasture extensive damage appears to be fairly recent compared with further east (photo 2). Removal in the whole area was facilitated by proximity to roads and a railway-station. In other areas though, similar evidence may lack independent corroboration of human influence.

Case studies

1. Hampsfield Fell

Extensive limestone pavement occurs on Hampsfield Fell, north-west of Grange-over-Sands. The area is popular with walkers, and has excellent views towards the Lake District. The pavement has been severely damaged, mainly on the eastern side, and is now subject to the first limestone pavement protection order under the provisions of the 1981 Wildlife and Countryside Act. The pavement is good, though not unique, and it displays varied massive and undamaged pavement and many runnel features.

Damage has occurred over many years but increased in 1968 when it became the concern of protection bodies. Efforts were made to safeguard the site and enforcement procedures were imposed which limited damage to the removal of 10 to 20 tons of limestone pavement blocks per week (NCC fill (c) SD 38/2 part 3). Operations in the 1970s involved the removal of blocks as large as 200 kg, c. 0.5m by 1m, by a single operator. Attempts to increase the scope of the removal were unsuccessful. In 1982 a Public Inquiry confirmed a ban on limestone removal and this was upheld by the Environment Secretary. Thus there should be no further stripping of clints here.

Clints removal has left very clear geomorphological effects. On the fell top there is a small area of damaged pavement and a pile of rubble, in addition to good intact pavement on the damaged part there is grass growing where the grikes of the top clints would have been or where deep runnels cut through the top bed and begun to etche into the bed below. One possible effect of removal is to leave larger clints beneath and this is illustrated by measurements (Table III and Fig. 3).

	'Before'	*'After'*
Clint 1	1.50 0.90 1.15 1.55 2.40	7.5 N.B. 'Before' clints marked on this larger clint beneath by 4 areas of gravel and grass across its width
Clint 2	1.05 1.95	3 N.B. 1 gravel and grass mark
Clint 3	1.30 1.20	2.5 N.B. 1 gravel and grass mark

Table III. Clint sizes 'before' and 'after' damage, measured on Hampsfield Fell, Cumbria (in metres).

Figure 4a illustrates what was found in the field, and Figure 4b illustrates the possible interpretations. Measurements were made of undamaged pavement at Hampsfield Fell on the same stratum and very close to the damage site. The clints at the undamaged sites are well and deeply runnelled, suggesting that the clints at the damaged site could have been similar. If so the clints removed would have been arranged in the possible options of A, B or C (fig. 4b) rather than D.

2. Great Asby Scar

Limestone pavement removal near Great Asby Scar, Cumbria, took place «on an organised basis for many years» (NCC file 81-AS2). The operation was small-scale, but over a period of years the damage was widespread. Nothing remains of the original pavement surface in some areas, for example Gaythorne Plain (photo 1), and elsewhere pavement is partially damaged. NCC files on the Asby pavements show that planning permission for sur-

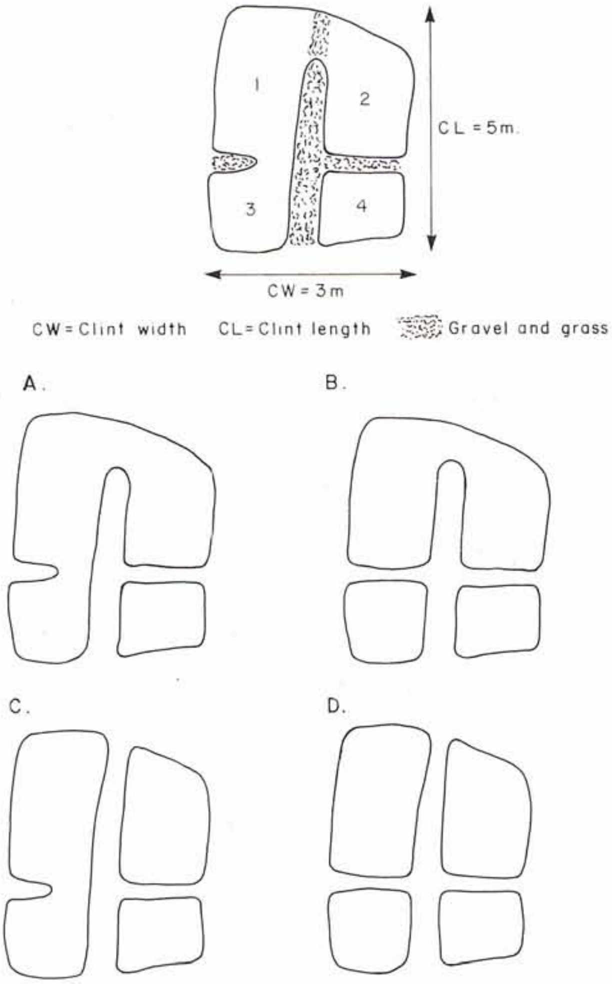

Figure 4. Possible interpretations of damage at Hampsfield Fell.

face limestone removal was refused. However, in spite of this, removal occurred, action was therefore taken in 1970 and 1971 to prevent it. It was difficult to control the removal of loose rock, however, as a legal problem concerning ownership of the loose rock complicated matters.

In the early 1970's the area was described as possessing a number on fine pavements with well-

Photo 10. Lowered clint surface, Gaitbarrows, Cumbria.

Photo 11. Limestone pavement near Carron, Burren, being built on in 1980.

developed clint and grike structures and an abundance of lime-loving plants. Simultaneously though, tractor-mounted power shovels were seen on these pavements, removing clints (photo 1). The surface is now typical damaged pavement: rough, lacking surface solution features and with much small limestone gravel. Gaythorne Plain is probably the most extensively damaged pavement in N.W. England.

The NCC pressed for the cessation of removal, and purchased some of the land for a Nature Reserve at Asby Scar.

3. Gaitbarrows

Ratcliffe (1977) refers to this pavement in Cumbria as being the most important single example of limestone pavement in Britain. Its botanical importance is very great; it is top of Ward and Evan's floristic assessment of pavement sites in Great Britain. It is also very interesting geomorphologically, showing a wide range of surface solution features. As an example of the problems involved in trying to protect valuable scientific sites from clint removal its history is sobering. Concern began in the 1960's when damage became obvious (removal had occurred as early as 1912). Being private, wooded land, it was extremely difficult for NCC officers to gather information about illegal clint removal, and they were acutely conscious of the potential dangers of the legislation process. The site was eventually made into a National Nature Reserve in 1977. Despite removal of about 50 % of the original pavement Gaitbarrows is still extremely important scientifically, with about 5 ha. of intact pavement. The effects of clint removal are clear (photo 10), with lowered clints, rubble strewn surfaces and access tracks across pavement with grikes infilled with rubble. Heavy machinery and explosives were used at Gaitbarrows and an important lesson learnt here was that even thicklybedded and large clints are not safe from such modern extraction methods.

4. Eire

In Burren, Eire, many pavement sites observed show evidence of damage. At various places, e.g. in the north near Blackhead, there are lowered surfaces near intact pavement; and at other sites, e.g., Burrenwee, pavement is smashed and messy. Near both of these particular sites there are walls and buildings made of limestone. Elsewhere there are bulldozed sites, e.g. near Kinvarra; sites cleared and manured for agricultural improvement, e.g. near Corcomroe Abbey; and pavements broken by tracks cut through them, e.g. above Aillwee cave. At Corcomroe Abbey damaged pavement shows grikes averaging 0.68m deep, whilst on intact parts they average 1.0m deep. In the Carron depression grikes on damaged pavements average 0.28m deep, in undamaged 0.6m. Stone-working for tombstones was observed here, nearby a limestone pavement was being built on in 1980 and 1983 (photo 11), and all over N. and E. Burren there are field boundaries made from clints.

Limestone pavements on the main island of the Aran Islands, Arainn, also display damage. This is not surprising as the extensive bare limestone makes life extremely hard for farmers, who literally make soil by scraping the meagre soil from the pavement, and adding sand and sea-weed to it. Many fields have been cleared of limestone, the rock being used to build the numerous walls. Arainn shows some interesting types of damage, including clearance of clints to construct several stone forts of Iron Age period (Robinson, 1980). These involve huge amounts of the rock in their walls, for example, Dun Dubhcathaire and Dun Aonghasa (photo 12). In addition to this, jagged clint blocks were used to form defensive lines or 'chevaux de frises' beyond the walls. Pavements near these forts

Photo 12. Dun Aonghasa stone fort, Arainn, Eire.

Photo 13. Displaced clints near Dun Dubhcathaire stone fort, Arainn.

show the expected effects of damage (photo 13). Lastly, near Mainistir, an area of several hectares of pavement was seen being destroyed for gravel, with the crushing machinery on site.

Conclusion

This paper has drawn attention to the effects of human activities on limestone pavements. It has shown that these activities have been extensive and damaging to these landforms. There are areas where the effects have been the understandable result of a landscape having an overabundance of surface limestone, for instance on Arainn and in Burren. Here human effects have largely been the consequence of farmers' attempts to increase their grazing areas. But clints from limestone pavements have also been deliberately used in structures of many kinds both in Britain and Ireland. In many parts of Britain large areas of clints have been exploited for their horticultural value and for other decorative purposes. This has caused extensive and serious damage, sufficient to require legal protection for limestone pavements.

The evidence for these effects has been varied, including historical sources as well as field evidence. There are circumstances where it is necessary to look beyond field evidence to other material to elucidate what has happened in the field. The combination of evidence from a variety of sources is essential if a full picture of the effects of man on these landforms is to be obtained.

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USE AND REGULATION OF KARST POLJES IN YUGOSLAVIA

by Peter HABIČ *

Abstract

The traditional use of karst poljes in different parts of Dinaric karst is presented from the efforts for water regime change in order to dry up the poljes as well as to retain periodically or permanently the water for agricultural, touristical, energetical and complex hydro-economy use. The attempts for protection of karst poljes natural properties within the frame of regional karst park are mentioned.

Extrait

On y présente l'emploie traditionelle des poljés karstiques dans les différentes parties du karst Dinarique et tous les efforts de changer le régime hydrique, ainsi dans la direction du desséchement comme dans celle de la retenue permanente ou périodique de l'eau pour l'exploitation agriculturelle, touristique, énérgetique et pour l'economie hydraulique complète. On y mentionne les efforts pour la protection permanente des caractéristiques naturelles des poljés karstiques dans le cadre du parc karstique régional.

Big karst depressions with flat, alluvial bottom and sinking streams which are in the geographical literature the most frequently defined as karst poljes (Cvijić, 1895; Šerko, 1947; Melik, 1959; Roglić, 1964; Gams, 1978), according to Šerko there are more than 200 of them in Yugoslavia, are the only bigger, fertile and inhabited oases in the middle of the Dinaric karst. Man exploits them from the beginning of settling by different ways, adapts to their natural properties, more or less successful he tries to change them according to his own wishes and needs. In the last decades in Yugoslavia quite a big progress was attained.

1. Traditional use of karst poljes

According to morphogenetical and hydrographical criteria the karstologists divided karst poljes into several types (Lehmann, 1959; Gams, 1973). Regarding their economic geographical properties, it means the situation, size, water conditions and climate and regarding the manner of economic use the dinaric kast poljes can be divided into following groups:

1.1. Permanently flooded lake poljes on low above the sea level altitudes without an important agricultural surface and urban function, convenient for natural reserve, tourist exploitation and natural reservoir of water; such are Vrana on island Cres, Vransko jezero near Šibenik, Bačinska jezera near Neretva, Skadarsko jezero, etc.

1.2. Submediterranean, periodically, partly or completely flooded karst poljes with fertile agricultural surface, which can be intensively cultivated in the dry half of the year when the water flows off. Their use depends on size and lasting of flood. Mediterranean climate with favourable temperatures accelerates the agrarian production, but summer aridity diminishes it. Permanent settlements and communication system are situated on the border of the flooded surface, agricultural land lies in the flood area too. Such poljes are: Imotsko, Popovo, Rastok, Jezero, etc.

* Inštitut za raziskovanje krasa ZRC SAZU.
YU-66230 POSTOJNA, Titov trg 2.

1.3. Dry karst poljes in submediterranean belt are regarding the size smaller but more fertile; the lack of water diminishes their economic value (Dugo polje, Dicmo, Ljubinje).

1.4. Temporary flooded poljes in the mountainous continental part of Dinaric karst are regarding the climatic and productive conditions more suitable for cattle-breeding, either exclusively as grassland and pasture ground or supplementary agricultural surfaces for mainly cattle-breeding oriented farms. The way of economic use is in great extent influenced by lasting and annual variability of floods, but the agriculture is limited too by the altitude and lower temperatures connected to climatic inversion. Beside cattle-breeding on the poljes the woods are important on the poljes borders encouraging the woodworking industry.

1.5. Dry karst poljes in higher continental part of Dinaric karst in between the wood belt are suitable exclusively for grassland and cattle-breeding (Glamočko polje, Babno polje). The wood on littoral mediterranean side is extremely degraded or even completely extinguished because of exaggerated exploitation, as for example in Montenegro (Cetinje, Grahovo, Njeguši).

Beside the agricultural function the poljes are important because of their situation among higher karst ridges for their communication significance. Across them the old roads had been leading from the interior towards the coast and back, modern circulation communications, more roads than railway, are there too. At cross-roads on poljes smaller urban centres developed, being the industry centres and causing new problems regarding protection and management of karst.

On some poljes of tectonic origin with Neogene lacustrine sediments there are stocks of brown coal and lignite which are more and more important as energetic sources (Gacko polje). Superficial waters on dinaric poljes with common underground connections and possibilities for construction of greater accumulations on the different altitudes present the main energetic potential of Dinaric karst (Trebišnjica system, Cetina).

2. The purpose of intervention into the karst water regime

By social economic development and building industry progress as well as by research results the human interventions on karst poljes increased, specially regarding their water regime by drying them up, partly by irrigation and mostly by exploitation of available energetic potential. According to exploitation the interventions into karst poljes can be divided to:

2.1. Arrangement of water conditions for the need of agriculture and cattle-breeding production by either drying up or irrigation with local use of water energy at springs and ponors.

2.2. Arrangement exclusively for energetic use by construction of accumulation basins and artificial outflow tunnels and energetic plants.

2.3. Arrangement for several purposes of water economy use, agricultural, energetic and touristical ones and by limited coordination of ecological and landscape problems.

2.4. Preservation and conservation of natural unchanged properties in a form of reserves, touristic curiosities or protected catchment areas of water sources.

3. Problems of karst poljes regulations

Forms, ways and problems of regulation and use of karst poljes are connected with:

3.1. knowledge degree of karst phenomena and karst processes investigation rate on the surface and in the underground of narrow and wider background,

3.2. technical mastery degree of karst phenomena and their progress and ecological lawfulness,

3.3. the expanse of interventions,

3.4. accordance and coordination of interventions to purpose,

3.5. expected and secondary effects,

3.6. cost of interventions and other fees,

3.7. valorization of natural properties in present and in future, not yet known, economic and social demands.

According to tasks and needs the research methods and technical interventions as well as the organisational management demands have been considerably ameliorated (Herak, 1972; Mikulec & Trumić, 1976; Milanović, 1978).

4. Improved research methods

On the research area the efforts were directed to:

4.1. Inventarisation and classification and cartographic documentation of the karst phenomena in the poljes region as well as in their wider background. From this point of view were important geological, geographical and speleological investigations beside the geodetic surveys.

4.2. Finding of water quantities, regime, precipitation budget, inflow and outflow - for all these tasks the improved hydrometeorological service has taken care.

4.3. Finding of underground water connections on outflow side by corresponding springs and definition of catchment area on inflow side. The water tracing methods were introduced and improved (different tracers were used), somewhere in big quantities. Water tracing methods were improved by international collaboration of different institutions (Ist - 5 th SUWT).

4.4. Study of cavernosity and permeability and distribution of different hydrogeological units, complete, partial and hanging barriers, influencing to distribution and direction of karst underground waters flow. From this point of view the geological investigations by detailed mapping and boring, geomechanical and geophysical measurements and analyses contributed the most.

4.5. At first bigger technical interventions the planners had not taken enough care for natural and ecological investigations. They followed later, when the problems of preservation of endemic subterranean animal specimens have emerged, when the changed microclimatic conditions and troubles of human adaptation to new conditions in life, empty settlements, interrupted roads, disturbed agrarian production and agricultural use and other different results and changes in karst ecosystem have occurred.

5. Ways and effects of technical interventions

While planning and realizing the regulation projects some new methods have been introduced just because of specific karst circumstances.

5.1. By previous cleaning and opening of ponors no essential ameliorations of poljes water regime have been achieved; on one side a man wanted to avoid the floods while on the other he surpasses the lack of water in dry summer months by difficulties (wells, rain-water, reservoirs). The majority of outflow tunnels, constructed on lower lying karst poljes (Jezero, Bokanjačko blato, Imotsko polje, etc.) were not conceived on the real water conditions, the planners did not consider enough the entire underground water system. Thus the drought was increased but the floods were not eliminated (Bonacci, 1985).

5.2. The attempts of simple water retention on poljes by closing up the swallow holes and by controlled water outflow into existent natural conduits did not give the expected results either. The floods increased, threatened the agricultural surface and settlements on the border, the drying up started a little later but has finished more quickly (Cerkniško jezero, Habič, 1974).

5.3. First serious attempts for permanent retention of water on the karst poljes have been furthermore conceived on superficial tightning and isolation of the known swallow-holes. In the alluvium inside the artificial accumulations have occurred new one (Nikšić).

5.4. The ill success forced the technicians to conceive new methods for deep tightning of water courses in karst. Practical realizations of deep injections in borders and under the superficial dams have been sometimes accompanied by surprises when big caverns have been hit by boreholes (Lika, Buško blato) but these problems have been promptly successfully solved. Supplementary investigations and tightnings have namely risen the costs of the objects, but with rare exceptions, the foreseen effects have been achieved (Mikulec & Trumić, 1976).

6. The meaning of karst landscape regulation

In the sphere of management and complex landscape arranging an important progress has been achieved. Exclusively energetic use of karst waters for which the only fertile and for life suitable surfaces in the middle of the karst have been sacrified, soon proved to be too much biassed (Mikulec & Trumić, 1976). Agressive drainage of water through the shortest artificial way from the mountains to the sea, in spite of useful energetic objects, unabled the exploitation of precious karst waters for other purposes, water supply, irrigation, ecological balance, sport and tourist activities etc. The plans for several purposes use of karst waters and for available agricultural surfaces have been done, which had diminished the energetic profit in behalf of other users of water and space. On the other hand such way had increased the costs of building and indirectly the price of energy. Regarding the fees only big, connected systems are acceptable (for example Trebišnjica). At particular smaller poljes the costs of intervention were too high and the effects too small. It is important specially when considering unfavourable ecological consequences of unilateral and exaggerated intervention into natural karst system. More reasonable natural conservation and preservation measures were proved, accelerating accordant agricultural, touristical, urban and other economic uses of karst poljes. Classical karst poljes of Notranjsko, as are Cerknica and Planina poljes should be, together with their environment and several caves, among them the world famous Postojnska jama, included into natural karst park.

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TENDENCIES TO CHANGE IN THE COMPOSITIONS OF THE KARSTIC SOIL AND THE VEGETATION IN THE DOLINES IN THE HUNGARIAN BÜKK MOUNTAIN

by Ilona BÁRÁNY-KEVEI *

Résumé

Au cours des dernières décennies les conditions oecologiques des territoires carstiques ont subi des changements, par suite de l'intervention humaine.

Les changements des indicateurs les plus sensibles de l'environnement, ceux de la végétation et du sol, signalent les changements de la valeur oecologique.

En ce qui concerne les sols, notre évaluation a porté sur le teneur en humus, la réaction et la compacité du sol, le teneur en micro-éléments, et les cations et les anions hydrosolubles. Au cours de l'analyse, pour montrer les tendances des changements, nous avons comparé les données de trois ans (1978, 1984 et 1985).

Le teneur en substance organique du sol est élevé, en raison de la minéralisation lente. Les valeurs du phosphore sont moins importantes dans la subsurface que dans les couches situées plus bas. La réaction chimique est généralement indifférente ou légérement acide. La corrélation entre la quantité des anions et des cations hydrosolubles a été très étroite en 1978. En 1985 ce rapport est moins marquant.

Les valeurs de la réaction du sol, d'après l'indication d'espèce de plante étaient plus basses en 1985 que dans les années précédentes. La valeur des indices de l'economie thermique a diminué, tandis que celle des indices de l'hydro-économie a augmenté.

Zusammenfassung

In den letzten Jahrzehnten haben in den ökologischen Verhältnissen der Karstlandshaften durch den Einfluss des Menschen Änderungen stattgefunden. Die Wandlungen in der Zusammensetzung des Bodens un der Vegetation die die sensibelsten Indikatoren unserer natürlichen Unwelt sind, weisen auf die vor sich gegangenen Änderungen des ökologischen Wertes hin.

In Bezug auf die Böden hat unsere Bewertung die Angaben des Humusgehalts, der Bodenreaktion, der Bindigkeit, des Mikroelementsgehalts und die im Wasser Löslichen Anionen und Kationen erfasst.

Zur Darstellung der Tendenzen in den Veränderungen haben wir die Angaben von drei Jahren (1978, 1984, 1985) veglichen.

Der Humusgehalt der Böden war hoch infolge der langsamen Mineralisierung der organischen Stoffe. Die pH-Werte waren in den der Oberfläche nahen Schichten kleiner als in den tieferen Schichten. Die Reaktion war im allgenseinen neutral und schwachsauer. Zwischen der im Wasser löslichen Anionen- und Kationen-menge bestand im Jahre 1978 eine feste Korrelationsbeziehung. Im Jahre 1985 wurde diese Beziehung zwischen den Anionen und Kationen lockerer.

Nach der Indikation der Vegetation waren die Werte der Bodenreaktion kleiner im Jahre 1985 als in den vorangegangen Jahren. Die Verzeichniszahle des Wärmehaushalts haben sich vermindert, die Werte des Wasserhaushalts haben dagegen engenommen.

One of the most important tasks of environment management today is the study of ecological factors with a view to maintain the balance of ecosystems. This goes hand in hand with the development of the evaluation methods of ecological resources. Detailed ecological studies are carried on these days to find out, for example, about the causes of damages to the vegetation, primarily to forests. The deterioration of vegetation indicates the changes in the environmental factors that in the long run lead to the upsetting of the ecological balance. Forest damages are usually attributed to, and can also be proved to be the result of, the harmful effect of acidic precipitation. Researchers,

* University of Szeged. Hungary.

however, seldom conduct detailed analysis of the processes that occur as the consequence of acidic precipitation, but also within the ecological system of the soil itself. W.D. Blümel (1986) points out four sources of soil acidification. The first he mentions is the natural atmospheric H deposition, a result of volcanic activity, nitrogen circulation, etc... He also regards as important anthropogenic atmospheric H deposition, the result of burning processes during industrial production, etc... The third source is particularly important for us, and that is the result of processes within the ecosystem of the soil, such as soil breathing, cation intake, and the H eduction of plants, and humus producing processes. The fourth, but not the least significant source of acidity according to him is the acidifying effect of the nutriment intake during the agricultural utilization of the soil.

Acidification occurs, if less forcefully (due to the stronger buffer effect of the soils on calcic rockbed), in karstic soils as well. In the soil this process goes hand in hand with the increase of H ions and cation-acids (Al^{3+}, Fe^{3+}, and Mn^{2+}) on the sorption carrier. This process, in the long run, leads to the structural deterioration of karstic soils and an increased danger of erosion. At the same time, the intensity of the karstic corrosion also changes, which may cause changes in the superficial and sub-superficial processes.

Photo 1. One of the examined dolines of the Hungarian Bükk Mountain. Typical solution doline. Deep: 18 m. Diameter: 50 m.

The phenomena outlined above have been triggered off on a larger scale in the last decades, by human activity. The present paper attempts to show the changes in the ecological value of karstic areas by examining in detail the soil and the vegetation as the most important ecological indicators.

Those karstic areas are adequate for microarea ecological studies that have been formed as the result of the interaction of external and internal environmental factors, but still represent autonomous dynamic units. The dolines of karstic areas satisfy these requirements since in respect of the microclimate determining the microarea ecofactors, they are considered as third-rate microclimate areas with independent heat ecologies.

Of the ecological components, the soil and the vegetation were minutely examined, but the peculiarities and change trends of the soil microclimate and of the biogenic processes in the soil will also be referred to, when necessary.

Tendencies to change in karstic soils

The properties of karstic soils are influenced by the fact that these soils are thick in karstic valleys and sink holes, while they form thinner or thicker layers on slope surfaces, depending on the angle of the slope.

On the surfaces with relatively little relief energy, the processes of redeposition go on vertically, while on sloping surfaces these processes are vertical and horizontal, depending on the inclination. On the slopes the processes of leaching and redeposition intensify, the aggresivity of the solvent water increases, which adds up in the depressions.

In the dolines of the Hungarian Bükk mountain clay soils, usually indicative of the dynamics of brown forest soils are the rule, with dark, often black, rendzina soils on the rock-extrusions and the northern exposures. Owing to the horizontally layered soil profile, the little soil depths, and horizontal (sloping) redepositional processes, in addition to elluvial and illuvial processes, good soil could not form here.

As regards its physical qualities, this soil consists of less classified sediment in terms of the finer soil components (warp, clay), and better classified sediment in respect of the larger components. This indicates that the soils are immature and unconsolidated, made up of solution residue to a larger, and of loess-like sediment to a smaller extent. The unconsolidated state allows a smaller degree of protection from erosional damages. Fine silt sand (0,1 mm - 0,02 mm ∅) makes up 50-60 per cent of the soil, with a great proportion of larger sand in it.

The organic matter content of the soils is generally high, but this is not utilised by the vegetation as a consequence of the slow mineralization of organic matter. Differences were detected in the humus contents of the northern and southern exposure slopes. On the northern exposure slopes the decomposition of organic matter is slowed down by a lower temperature and a higher soil humidity, while it is sped up by higher temperature and lower soil humidity on the south exposure slopes.

The soil pH, an important ecological indicator of the range of plant species, changes in direct proportion with the number of bacteria in the soil, and in an inverse ration with the humus content.

The pH was lower in the layers close to the surface than in the deeper levels; it was generally neutral or weakly acidic. The impermeability was high, which resulted in a good retention of water (Table 1 and 2).

An examination of the water-soluble anions and cations showed that the soil is well supplied with Ca^{2+}, K^{+}, and N ions, the quantity of Mg^{2+} ions being medium. Of the anions, the levels of HCO_3^- were high, but the Cl^- and SO_4^{2-} ion content was also significant.

It was observed that the Ca^{2+} and HCO_3^- contents were higher in the higher parts of the dolines than in the lower parts. This is the result of the ad-

Photo 2. The characteristic association of Hungarian karst dolines is the Nardo-Festucetosum ovinae, Nardetum strictae, association type of sub-alpine pastures.

Denotation of soil samples	Depth	pH (KCl)	Total salt %	$CaCO_3$ %	K_A	Tot. humus %	Zn	Cu	ppm Mn	Na	Mg	NO_3 NO_2	P_2O_2	K_2O	SO_2 SO_4
N_3	5 cm	6,08	0,02	0,1	71	5,04	4,9	3,1	273,8	36	144	9,3	15	128	12,8
N_3	30 cm	5,96	0,02	0,0	77	3,49	1,2	3,7	170,5	32	46	3,4	6	60	8,4
N_6	5 cm	5,51	0,02	0,0	68	5,02	4,9	2,7	297,2	31	133	9,2	14	133	13,7
N_6	30 cm	4,90	0,02	0,0	53	2,95	1,2	1,5	153,8	70	60	2,8	3	60	22,0
N_9	5 cm	5,30	0,02	0,0	66	4,99	4,4	1,7	208,3	37	209	5,1	13	238	16,2
N_9	30 cm	4,80	0,02	0,0	52	2,79	4,1	2,0	120,9	45	106	2,4	4	103	9,2
S_3	5 cm	5,80	0,06	3,6	62	6,24	14,4	2,6	143,4	45	212	28,5	270	317	37,4
S_3	30 cm	6,81	0,03	8,8	54	5,99	16,8	5,1	95,6	60	134	23,0	221	181	15,0
S_6	5 cm	6,84	0,02	2,9	81	6,12	16,3	5,7	143,4	42	196	19,6	122	270	27,8
S_6	30 cm	6,97	0,05	5,8	71	5,98	17,0	6,6	95,6	99	168	21,6	86	194	39,7
S_9	5 cm	6,78	0,04	3,3	75	6,20	18,1	6,2	224,5	39	196	25,8	89	216	19,3
S_9	30 cm	6,98	0,05	4,0	74	5,98	16,7	5,8	197,5	52	156	22,3	75	220	18,4
S_{12}	5 cm	6,73	0,04	2,0	80	6,37	17,4	5,5	197,7	47	302	32,8	69	279	28,4
S_{12}	30 cm	6,84	0,06	1,9	71	5,99	14,5	5,0	192,3	41	166	27,3	66	204	11,7
F_1	5 cm	5,18	0,02	0,0	81	5,47	14,9	3,7	296,3	42	288	37,3	97	607	20,7
F_2	30 cm	5,24	0,02	0,0	68	5,49	8,7	2,1	221,6	51	264	9,3	242	288	17,3

K_A = Qualifying numbers according to Arany S.
N_3, N_6 etc. = northern slope at the levels of 3, 6 etc. metres.
S_3, S_6 etc. = southern slope at the levels of 3, 6 etc. metres.
F_1 and F_2 = the bottom of the doline.

Table 1. Data of Basical Researches of Soil on the Northern (N) and Southern (S) Slopes and at the Bottom of Doline (Bükk Mountain, Hungary 1985)

Denotation of soil samples	Depth	pH (KCl)	Total salt %	$CaCO_3$ %	K_A	Tot. humus %	Zn	Cu	ppm Mn	Na	Mg	NO_3 NO_2	P_2O_2	K_2O	SO_2 SO_4
E_3	5 cm	5,54	0,02	0,0	73	5,08	6,2	3,1	303,6	54	198	11,8	16	187	16,6
E_3	30 cm	5,41	0,02	0,0	52	2,46	1,0	1,4	138,5	25	62	3,4	3	64	7,3
E_6	5 cm	5,55	0,02	0,0	66	5,16	11,0	7,3	361,8	29	199	11,4	13	151	10,1
E_6	30 cm	6,16	0,02	0,0	62	5,19	6,2	7,1	358,2	47	83	6,8	11	131	9,1
E_9	5 cm	6,25	0,03	0,5	81	5,69	16,4	8,1	360,9	31	189	23,9	33	177	21,3
E_9	30 cm	6,56	0,02	0,9	71	5,45	12,9	7,2	341,1	21	125	13,2	24	159	17,5
E_{12}	5 cm	6,39	0,03	0,5	74	6,07	17,4	6,2	356,6	54	218	31,3	51	227	32,2
E_{12}	30 cm	6,75	0,02	2,2	80	5,82	13,0	5,1	221,0	37	139	19,3	40	160	17,7
W_3	5 cm	5,66	0,02	0,0	70	5,07	9,5	3,4	347,9	25	230	18,3	15	159	15,9
W_3	30 cm	5,55	0,02	0,0	52	3,44	3,2	2,2	286,9	18	124	3,3	7	74	7,7
W_6	5 cm	6,32	0,02	0,5	68	5,24	15,6	8,2	369,6	27	200	9,9	19	261	13,3
W_6	30 cm	6,90	0,03	1,5	56	4,86	9,3	7,5	346,5	41	93	4,0	12	180	12,6
W_9	5 cm	6,85	0,03	3,6	66	5,29	15,9	8,0	291,7	36	180	23,1	33	439	26,6
W_9	30 cm	6,94	0,05	5,1	63	5,20	12,9	7,2	225,7	72	121	8,1	24	243	42,2
W_{12}	5 cm	6,99	0,03	5,5	78	5,53	15,5	6,5	221,4	46	197	27,4	45	357	22,6
W_{12}	30 cm	7,04	0,03	5,8	79	5,25	13,2	5,2	107,3	58	134	10,4	35	250	15,0

K_A = Qualifying numbers according to Arany S.
E_3, E_6 etc. = eastern slope at the levels of 3, 6 etc. metres.
W_3, W_6 etc. = western slope at the levels of 3, 6 etc. metres.

Table 2. Data of Basical Researches of Soil on the East (E) and West (W) Slopes of Doline (Bükk Mountain, Hungary 1985)

ded up effects at deeper levels of the water filtering in. The K^+ and Na^+, as the most frequently moving ions, remain at the bottom of the dolines in smaller quantities, naturally, which results in the acidification of the soil, while the Fe^{3+} and Fe^{2+} ions are abundant in the deeper parts, this also being an acidifying factor.

In the case of water-soluble anions and cations, we have compared the data for 1979 and 1984 from 38 places.

Of the cations, the amount of K^+ ions decreased in most places, but in several instances the quantity of Mg^{2+} ions also decreased. The amount of Na^+ ions increased, on the other hand, which impairs the physical and chemical properties of the soil. The increase of Ca^{2+} ions can be the result of the solution of $CaCO_3$ in the presence of SO_4^{2-} ions ($CaSO_4 \cdot 2H_2O$ being the result), and a simultaneous increase of Ca^{2+} ions. An increase of the SO_4^{2-} anions suggests the effects of acidic precipitation. At most places, however, the amount of HCO_3^- and Cl^- ions decreased.

The changes of the correlation between anions and cations were also examined in three years (1978, 1984, and 1985) (Table 3).

With the exception of Mg^{2+}, in 1978 there was a close correlation ($R = 0,5$ or more) between the amounts of the cations and the anions. It may be food for thought that this correlation could no longer be detected everywhere in 1984 and 1985. This was particularly true for the northern and western slopes (i.e. the southern and eastern exposures) of the dolines in 1984, where close correlation could be detected only in 2 or 3 places. In 1985 the correlation between the amounts of anions and cations was stronger on the northern slope (southern exposure). At the same places on the other slopes the correlation was loose between the Cl^- and SO_4^{2-} ions and the total cation content. The cause of the weakening of the correlation may have been the change in the soil composition as a consequence of the acidic precipitation, but this proposal needs further proving.

No earlier data concerning of microelements (Zn, Mn, Mg) being available for comparisons, the examination of these remains a task of the years to come.

Besides, and taken as a function of, the soils, we also examined the changes in the composition of the vegetation. Naturally, a few years are not sufficient for an examination like that, but still, with a knowledge of the tendencies of soil changes, the modifications in the indications of plant species, together with soil processes can indicate the changes to be expected in ecological values.

The characteristic association of Hungarian karstic dolines is the Nardo-Festucetosum ovinae, Nardetum strictae, which is the association of subalpine pastures.

We have compared the data from 1979 and 1985, with special regard to the species composition, domination, and plant ecological indication. In the examination of plant ecological indication we used indicators for heat balance (T), water balance

	HCO_3 1978	HCO_3 1984	HCO_3 1985	Cl 1978	Cl 1984	Cl 1985	SO_4 1978	SO_4 1984	SO_4 1985	
Ca	0,83	0,47	0,58	0,61	0,35	−0,66	0,73	0,17	0,83	NORTHERN SLOPE
Mg	0,31	0,37	0,78	0,16	0,35	−0,87	0,41	0,06	0,62	
K	0,53	−0,11	0,70	0,55	0,49	−0,70	0,58	0,64	0,72	
Na	0,72	−0,48	0,84	0,67	0,42	−0,60	0,73	0,89	0,48	
Ca	0,91	0,47	0,70	0,71	0,74	−0,28	0,60	0,75	0,29	SOUTHERN SLOPE
Mg	0,38	0,86	0,71	0,77	0,01	−0,41	0,83	0,31	−0,43	
K	0.94	0,91	0,28	0,71	0,11	0,37	0,94	0,22	−0,90	
Na	0,07	0,27	−0,47	0,74	0,71	0,88	0,81	0,75	−0,55	
Ca	0,94	—	0,99	0,46	0,54	—	0,22	0,75	0,31	EASTERN SLOPE
Mg	0,53	−0,56	0,84	0,63	−0,50	−0,20	0,56	−0,05	0,38	
K	0,81	0,29	0,72	0,46	0,49	0,47	0,20	—	−0,19	
Na	0,09	−0,85	0,92	0,68	0,10	0,01	0,73	0,88	0,46	
Ca	0,05	0,41	0,30	0,33	−0,35	−0,66	0,91	−0,07	−0,23	WESTERN SLOPE
Mg	0,15	−0,07	0,20	0,35	0,82	0,12	0,50	0,67	−0,57	
K	0,13	0,17	0,49	0,50	0,16	−0,16	0,85	0,40	−0,32	
Na	—	−0,14	0,63	0,18	0,96	−0,13	0,03	0,85	−0,31	

Table 3. Correlation coefficients between in water soluble anions and cations

(W), soil reaction (R), and nitrogen demand (N) (ZÓLYOMI, B. 1966), then ecological average numbers were calculated:

$$Tá = \frac{x_i \cdot y_i}{i \cdot n}, \text{ where}$$

Tá = the number of the average heat balance value for the found species,

x_i = the given ecological value,

y_i = the species number of the given ecological value,

n =the number of the found species.

The average value of the heat balance numbers calculated according to the relationship above is higher (5,5) than it was in 1985 (5,17), which means that in addition to the species characteristic of temperate zone deciduous forest climate, a few of the species of the submediterranean forest and the warm steppe climate could still be found in 1979, mostly on the northern and western slopes. The water balance indicator numbers ranged between 3,67 and 3,77 in 1979, and between 3,62 and 4,89 in 1985. In the latter year several species favouring higher moisture contents could be found in the dolines.

The average values of the soil reaction indicators range between 2 and 3, indicative of weakly acidic and nearly neutral soil reaction. This average

Photo 3. Afforested doline in the Hungarian Bükk Mountain. The age of the pine saplings are the same. The growing of pines is slowly in deeper part of doline because of the cold-airlake (Kaltluftsee).

value, however, on one hand, hides the presence of lime-favouring plant species, occurring with great frequency while, on the other, several plant species are neutral as regards the soil reaction. These two extreme values impair the chances of assessing the real situation. In both years the species that favour lime could be found in the greatest numbers in the dolines. During the seven years in question the average number indicating the value of soil reaction decreased a little, indicating, it is inferred, a shift of the soil pH in the acidic direction. The soil reaction average values of the occurring plant species indicate the tendencies of the soil change detailed earlier. Today the karstic sink holes contain more plant species, compared with 1979, which favour a neutral or weakly acidic soil pH.

The indicator number of the nitrogen demand (N) ranges between 0 and 3 in the area. Its value was 2-3 or 1-2 most of the time, which means medium nitrogen requirements.

On the basis of earlier data we also examined the association of a dolines planted with pine saplings, and it was possible to analyse the differences and similarities in the association compositions of an open, grass-grown, and an afforested dolines.

The planted dolines contained associations richer in species than the open dolines. The difference in composition is the consequence of the presence of the forest, which is closely related to soil ecological conditions.

We can sum up with the conclusion that even minor anthropogenic interventions (e.g. periodical mowing or pasturing) on the karstic surfaces with their restricted ecological features may lead to changes in the soil and the natural vegetation, and these changes, if coupled with the increasing effects of acidic precipitation, may have appreciable effects on the nature (character) of the processes of karstic corrosion proceeding through the soil.

All this should focus our attention on the future importance of microarea ecological research.

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KARST IN SOUTHERN AFRICA

by Margaret E. MARKER * and Frances M. GAMBLE **

Resumen

En el presente trabajo se revisa la distribución de las rocas karstificables en África meridional, distinguiendo entre dos clases predominantes: las calizas dolomíticas proterozoicas de textura esparítica, propias de las mesetas interiores, y las calizas arenosas terciarias de la costa, cuya textura es micrítica. La densidad de formas kársticas superficiales es variable y comparativamente baja en relación con otras regiones. Las cuevas corresponden a un origen freático-somero y pueden contener abundantes espeleotemas. Se han podido detectar dos fases principales de crecimiento, aunque la precipitación moderna es menos intensa. El más importante periodo de karstificación puede ser atribuido a tiempos considerablemente remotos.

Los impactos ambientales sobre el karst de África meridional abarcan desde cambios en la hidrogeología debido a la extracción de agua con fines económicos, pasando por el drenaje de minas y las modificaciones en la cubierta superficial, hasta efectos directos resultantes de actividades mineras, en especial para la obtención de oro, de guano de murciélago y primitivamente de espeleotemas. Algunas rocas madres son empleadas en minería para su aprovechamiento en la fabricación de acero. Hasta ahora los problemas causados por la contaminación son de escasa importancia. Las cuevas situadas cerca de los principales centros de población sufren impactos de utilización que a menudo pasan inadvertidos. Las consecuencias de nuevas instalaciones militares, junto a Bredasdorp están siendo objeto de seguimiento. En África meridional se cuenta con las bases necesarias para la realización de programas efectivos de gestión ambiental.

Abstract

The paper reviews the distribution of karst rocks in southern Africa and distinguishes between two dominant types: the sparitic Proterozoic dolomitic limestones of the interior plateaux and the Tertiary micritic sandy limestones of the coast. The density of surface karst forms is variable and low by comparison with overseas regions. Caves are shallow phreatic in origin and may contain massive speleothem development. Two major phases of growth are recognised. Modern precipitation is minor. The major karst forming period is believed to be of considerable antiquity.

The impacts on southern African karst range from changes to the geohydrology due to economic extraction, mine dewatering and changes to the surface cover, to direct effects of mining particularly for gold, for bat guano and formerly for speleothems. Some host rock is directly mined for use in steel making. Pollution is so far of minor importance. Caves near major population centres suffer user impact which is often inadvertent. The consequences of a new military installation near Bredasdorp are being monitored. In southern Africa the basis exists for effective management programmes.

Potential karst host rocks cover 50.000 km² in Southern Africa [1]. This is 1.9 % of the total area. There are two extensive karst host rock types (Table 1): the Proterozoic dolomitic limestones of the interior plateaux and, secondly, the Tertiary Coastal Limestones [2]. The dolomitic limestones are resistant, sparitic, well-jointed and highly lithified ancient rocks. Chemically they are not true dolomites, being $CaMg(CO_3)_2$ rather than $CaCO_3.MgCO_3$, and they do not weather to dolomitic gruss. Beds with low magnesium ratios, almost pure limestones, occur in the middle sequence (Button, 1971). Although deposited in separate, shallow tidal basins, the Transvaal Sequence containing the Chuniespoort

* Fort Hare University
P. Bag X 1314
Alice 5700. Rep. of the Ciskei
** P.O. Box 51218
Raedene. Johannesburg 2124. Rep. of South Africa

[1] Defined as the Republic of South Africa as of 1960, Namibia, Botswana, Lesotho and Swaziland.

[2] The informal term Coastal Limestone was coined by Siesser (1972) to include the Langebaan Formation, the Alexandria Formation, the Bredasdorp Formation and the Uloa Formation.

Formation and the less extensive Duitschland Formation of the Malmani Subgroup are similar lithologically to the Campbell Rand Group of the Griqualand West Sequence of the Northern Cape Province (Brink, 1979). Both Sequences exhibit considerable stromatolite and algal dome development resulting from deposition in a tidal lagoonal environment (Eriksson, 1977).

In contrast, the coastal limestones are soft, variably pure, weakly jointed and dominantly micritic, sandy limestones. These Coastal Limestones outcrop discontinuously on land around the coast of southern Africa from Saldanha Bay to Zululand, but on the Continental Shelf are more continuous (Siesser, 1972; Fig. 1). In addition there are also areas of Palaeozoic Damara marble and associated limestones in Namibia and western Botswana. Palaeozoic Cango Limestones outcrop within the Cape Fold Belt and Tertiary calcretic, impure limestones have limited occurrence along the inner margin of the Namib desert. There is a basic division between ancient, hard carbonate rocks above the Great Escarpment and the younger, softer micritic limestones below. The only exceptions are the Damara marble outcrops within the Namib desert and the Cango Limestone outcrop.

Surface karst forms have a low density overall and strongly karstified areas are very localised. Inland above the Great Escarpment the karst landforms are of considerable antiquity, apparently being initiated contemporaneously with the evolution of the mid-Cenozoic African planation surface. The almost ubiquitous presence of insoluble terra rossa type residues limits surface karst expression and causes infilling of hollows and blocking of major cave systems.

Virtually all major caves are shallow phreatic in origin, drought restricting the presence of point input and therefore vadose development. Speleothems are massive in some caves, indicating two major periods of deposition interrupted by resolution. Recent deposition is on a small scale only.

Below the Great Escarpment the karst of the Coastal Limestones is associated with a suite of Cenozoic marine benches from 250 m altitude to below present sea level (Marker, 1985). The highest density and largest amplitude surface karst forms are associated with the 240 m and 200 m benches (Marker and Sweeting, 1983; Russell, 1985), also suggesting a mid-Tertiary period of maximum development. Caves are rare with the exception of the Bredasdorp area, where they tend to be prefe-

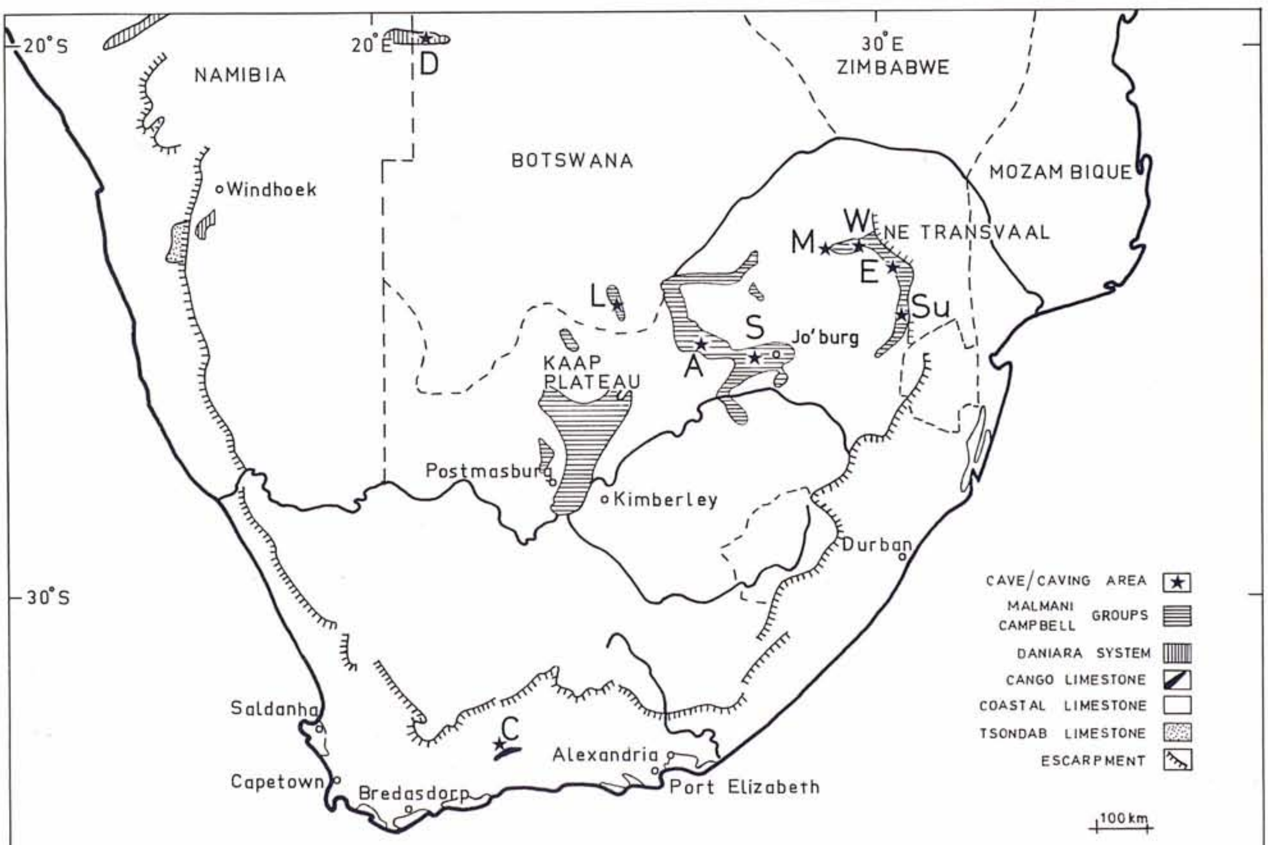

Figure 1: Karst areas of southern Africa
(A = Apocalypse, C = Cango, D = Drotsky's Caves,
E = Echo, L = Lobatse Caves, M = Makapansgat,
S = Sterkfontein, Su = Sudwala, W = Wolkberg).

CLASSIFICATION	LOCALITY	ROCK FORMATION	AREA (km^2)	ANNUAL RAINFALL (mm)	TOTAL AREA (km^2)
SPARITES	NE Transvaal	Transvaal Sequence	3025	550-1200	
	Marble Hall	Malmani and Duitschland Groups	450	600	
	Central and N Transvaal	(dolomitic limestones)	10450	450 - 600	
	S Transvaal		350	650	
	Botswana		1000	200 - 400	
	Kaap Plateau	Griqualand West Sequence	17500	350	
	Postmasburg-Sishen	Campbell Group	900	300	
	Prieska	(dolomitic limestones)	300	300	
	Botswana	Damara System	115	450	
	Namibia	(marble and limestone)	7775	200 - 400	
	Cango	Cango Limestone	175	350	
					42040
MICRITES	W Cape	Coastal Limestone	525	400	
	S Cape	Longebaan Fm	2575	500 - 700	
	E Cape	Bredasdorp Fm	2300	500 - 700	
	Zululand	Alexandria Fm	1850	1000	
	Namibia	Tsondab Limestone	450	250	
					7700
					49740

Table 1: Karst areas of Southern Africa

rentially located beneath the 60 m and 30 m benches. The cohesive strength of the Coastal Limestones in most areas restricts cave development. Nevertheless the existence of major springs with distinct chemical characteristics suggests that the existence of major conduits is far more general than the existence of enterable caves.

The best-known karst areas are the central and south-western Witwatersrand, in the vicinity of Sterkfontein and Carletonville respectively (Brink, 1979; Gamble, 1981; Moon, 1973), the north-eastern Transvaal (Marker, 1985), and the Alexandria and Bredasdorp areas on the Coastal Limestones (Marker, 1981; Marker and Sweeting, 1983; Russell, 1985). Elsewhere isolated sites have been investigated as in the Namib (Sweeting and Lancaster, 1984; Marker, 1982), but much more detailed work is required.

Impacts on Southern African Caves

Southern African caves are particularly distinctive and vulnerable because of the resistant nature of the host rocks, especially the dolomites, and the semi-arid characteristics of the areas in which most of them have formed through phreatic processes. Resultant cave dimensions are small, cave entrances are usually single, cave temperatures are comparatively high and cave systems are generally dry.

A number of caves intersect the water table with a resultant occurrence of underground pools or lakes such as that in Sterkfontein. Running water is known in only 1 % of the dolomite and limestone caves. This means that weathering and erosion processes are usually very slow and that the food chain is very limited in the majority of caves (Gamble, in press).

The major threats to the cave ecosystem are associated with urban and peri-urban sprawl and with major development projects such as the construction of roads. They are manifiest in both surface and subsurface disturbances, and most commonly include extraction, construction, pollution especially of air and water, research and recreation impacts (Fig. 2).

EXTRACTION affects both the host rock and its secondary contents such as water.

— Dolomite and limestone are used as flux or as a source of manganese for the metallurgical industries, posing ever-increasing threats to the karst areas, including the caves.

— At approximately the turn of the century speleothems were extracted during small-scale mining operations in order to produce slaked lime for the building industry. At present extraction of speleothems is confined mainly to limited removal for research purposes, or to more extensive removal as part of the casual vandal and souvenir trade.
— Since the late nineteenth century deposits of bat guano in local caves have been excavated by farmers as a source of fertilizer.
— In semi-arid to arid areas, where surface water supplies are limited, increasing reliance is placed on ground water. Lowering of the water table results from pumping to facilitate sub-water table mining, and the provision of water for surface activities such as irrigation, and industrial and domestic developments. Sub-water table mining is extensive near Carletonville. In 1970 the town of Bank had to be abandoned because of the hazards resulting from sinkhole development consequent upon the dewatering of the dolomite for gold mining on the West Rand. At present a borehole project of the Department of Water Affairs threatens extensive karst areas in the central Witwatersrand as a result of major water extraction schemes to alleviate the current drought.
The impact of increasing peri-urban sprawl, particularly in the areas close to Johannesburg, is already evident in the number of long-term boreholes which have dried out as a result of the increasing demand for water on the smallholdings in the area.

CONSTRUCTION and the provision of services are associated with all development activities in karst areas. The specific disturbances associated with these alterations are several and complex, manifest mainly in the alteration of surface water-flow patterns and the consequent dehydration of karst and cave areas. In all instances there is encroachment of artificial surfaces in the form of roads, buildings, parking lots, agricultural lands and some levelling of the area by infilling. All such activities decrease percolation and increase surface runoff.
Increased loading by surface structures may also have some impact, particularly where instability of

PARTY	ESTABLISHED AREA OF CONCERN
NATIONAL LEGISLATION AND CONTROLS	
Dept. of Water Affairs, Forestry and Environmental Conservation	Permits to enter forest and water reserves
National Parks	Act protecting geological forms
National Monuments	Act proctecting individual sites e.g. Sterkfontein Cave
Mines and Minerals	Act pertaining to damage through mining
Dept. of Defence	Permits to enter military areas
Homeland Governments	Permits to enter homelands
PROVINCIAL LEGISLATION AND CONTROLS	
Peri-urban Board	Deterrent notices at caves
Provincial Nature Conservation	Legislation and Ranger control
SPELEOLOGICAL ORGANISATIONS	Conservation - cleaning; gating; advice
PRIVATE PROPERTY OWNERS	Subjective control - mainly acces, e.g. Sudwala Cave and show caves
UNIVERSITY SCIENTISTS	Restricted access to sites, e.g. Makapan Cave
ENVIRONMENTAL ORGANISATIONS	Conservation areas, e.g. Wildlife Society of Southern Africa
PUBLIC PARTICIPATION	
Gem and Mineral Clubs	Speleothem supplies
Gemstone Retailers	

Table 2: Parties to whom cave management is of concern in southern Africa (*after:* Gamble, 1981b).

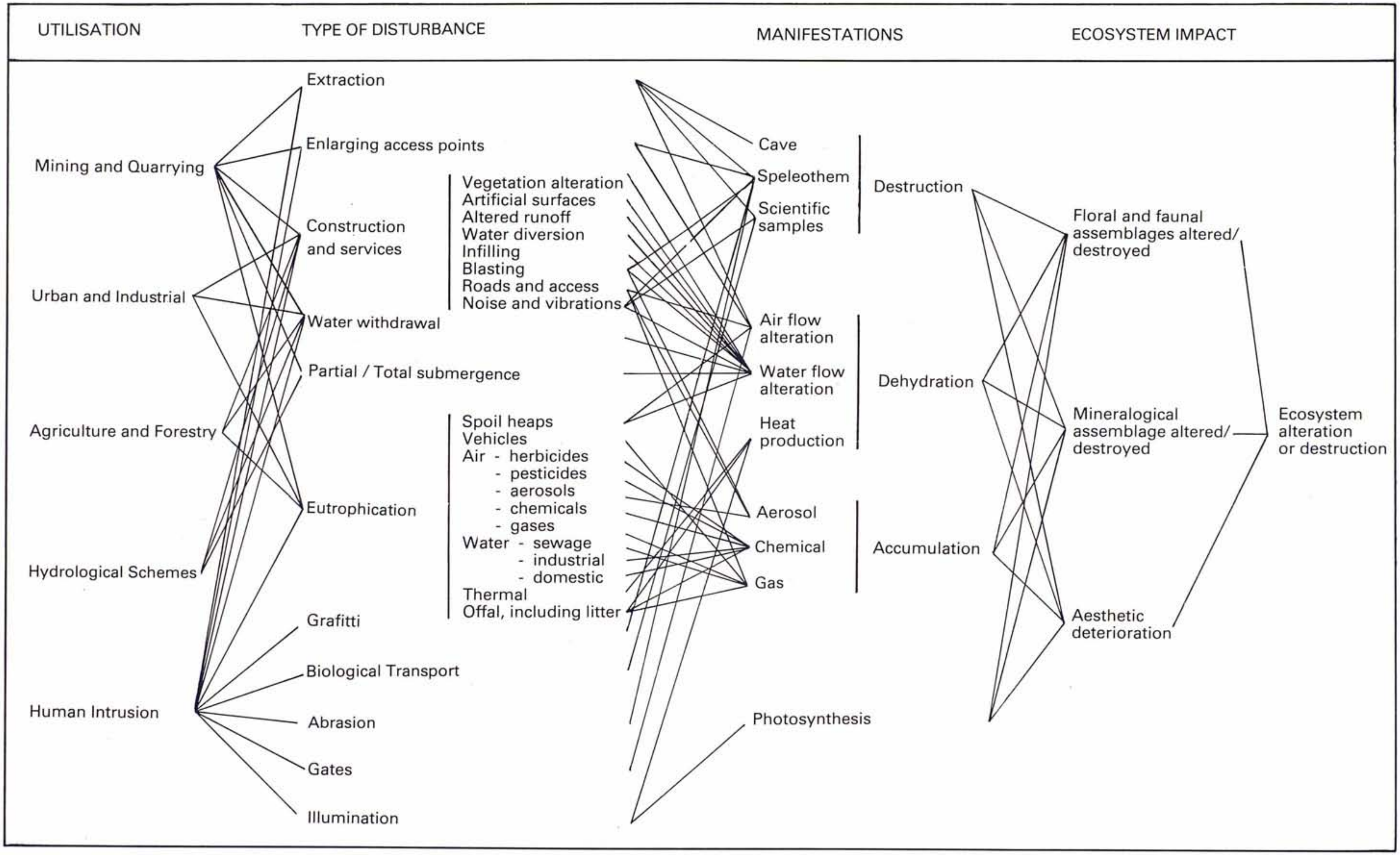

Figure 2: Summary of the disturbances and their impacts on a karst cave ecosystem.
These disturbances are regarded as possible, their occurrence and magnitude being dependent upon the cave itself and the nature of the disturbance.

GEOGRAPHICAL	PHYSICAL	SOCIAL	MANAGEMENT PROGRAMME
Remoteness Rough Terrain Climate Vegetation Homelands Small, inaccesible caves Paucity of caves in South Africa	Cave destruction Cave Hazards Carrying Capacity of cave	Education Haste and thoughtlessness Cultural Diversity Dispersion, Diversity and non-involvement of general population Few speleologists Increased leisure and mobility Industrialisation Construction Economics	Trained manpower Expertise Economics Politics Effective legislation

Table 3: Problems of karst cave management in southern Africa (*after:* Gamble, 1981b).

underlying rock occurs. Vibrations, mainly as a result of blasting, noise and heavy vehicle movement may result in increased joint dimension and in damage particularly to cave systems.
The current development on the De Hoop Nature Reserve at Bredasdorp has been a source of national concern because of the anticipated possible impacts on the karst and cave area.

POLLUTION is derived in varying ways and to varying degrees from all activities in a karst area. It is usually inadvertent, in association with atmospheric, hydrological and solid waste pollution, resulting in the accumulation of gases, aerosols and chemicals. Atmospheric pollution is probably the least obvious, while water pollution is the most ubiquitous. In many areas remote from urban and industrial areas karst regions are subject to solid waste disposal in caves and sinkholes, the consequences of which may be long-term and dramatic.

RESEARCH AND RECREATION of necessity impact karst areas and especially the caves as there is increasing pressure on wilderness areas. Damage to caves is most often in the form of compaction and abrasion, and is usually inadvertent. However, the impacts are usually more direct on a cave system and are very often irreversible. Tourists, scientists, cavers and casual visitors to caves all affect the cave ecosystem to varying degrees.

Awareness of caves which require conservation in their own right and for the protection of visitors is recent. Over time efforts at cave conservation in South Africa have taken several forms (Table 2), such as legislative controls, the construction of gates at cave entrances, the restriction of access by landowners, and educational programmes undertaken by concerned scientists and speleologists. The most important of the controls operating to protect the Southern African caves are cultural hesitation; the natural protection afforded by cave location and configuration; landowner control over access and legislative control such as the National Monuments Act, the Forestry Act and the Transvaal Nature Conservation Ordinance.

The problems associated with cave conservation are similar throughout the world, although each area has certain unique aspects (Table 3). In southern Africa the basis exists for future management programmes and several advantages exist in comparison with other parts of the world particularly in terms of time and circumstance.

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PRELIMINARY STUDY OF KARST COLLAPSE. FORECAST METHOD

by Tan JIANYI * and Chen JIAN **

Resum

L'objecte d'aquest treball és analitzar diversos mètodes de predicció d'enfonsaments càrstics. S'estableixen dos models de predicció, en diferents condicions, d'acord amb el principi d'equilibri límit.

Es contrasten ambdós models amb les dades procedents de Yulin, Guilin, Guangxi i d'altres llocs. Els resultats de l'aplicació d'aquests models mostren l'existència de concordància entre el resultat calculat pel model i la realitat. Així, els dos models es poden usar en la predicció d'abisaments càrstics i en l'estimació de l'estabilitat de la cobertura superficial del terreny.

Aquesta nota s'ocupa detalladament de la relació entre els models i els factors que influeixen en ells, en base a la situació dels coneixements actuals; també s'apunta, més generalment, el contingut dels esmentats mètodes quant a la predicció d'eventuals abisaments. Per acabar, la predicció d'enfonsaments ha estat realitzada a San Lidian, Guilin, Guangxi, usant els dos models.

Abstract

The object of this paper is to discuss forecast methods of karst collapse. According to limit equilibrium principle two collapse forecast models are established in different conditions of the level.

Two models are checked by the data in Yulin, Guilin of Guangxi and other places. The checking result show to be consistency between the calculating result by the model and reality. So the two models can be used in forecast of karst collapse and estimation of the cover stability.

The paper dealt in detail with the relationship between the model and its affecting factors in the light of actually situation and also generally point out the collapse forecast content. Finally the collapse forecast is carried out using the two models in San Lidian, Guilin, Guangxi.

Introduction

Karst collapse is the most projecting problem of environmental engineering geology in covered karst area. Collapse serious consequences have been widly paid attention to. In order to avert and reduce collapse and losses the research on different aspects of collapse has been done. The collapse genesis and type research are focal point, the collapse forecast research is the gap yet. Therefore it is necessary to do collapse forecast.

The formation of collapse is a complex process. The cover up karst cave slack and peel with the groundwater erosion, vacuum draw erosion, aero-erosion etc, to form the soil cave, the one extend continuously up until collapse with gravity.

Karst collapse result from many factors such as karst development degree, groundwater fluctuation, cover thickness and its physical mechanic property. These factor affect the formation of collapse.

Premise condition

Premise conditions of establishing model are assumed in the paper, they include:

1. Karst developed under cover and there are karst cave;
2. The collapse to be assumed cylinder;
3. There is flowing groundwater; and
4. The cover may be slacking or peel.

* Central Station of Environmental Hydrogeological Observation of Guilin, Guangxi, China.

** Institute of Karst Geology of Guilin, Guangxi, China.

Model establishment

According to different conditions of groundwater level two models of collapse forecast are established.

1. The First Model

The first model is established in the condition of confined water. In this case, there are several acting force of the cover. They are:

1) gravity of soil body

$$G = \frac{\pi r \left[(y - vt) - \left(\frac{H - vt}{l_0 + 1} \right) \right] D^2 + \pi r_1 \left(\frac{H - vt}{l_0 + 1} + M \right) D^2}{4}$$

2) internal friction force

$$F = \pi D \int_0^{\left(y - vt - \frac{H - vt}{l_0 + 1} - M\right)} \left(\frac{1 - \sin\varphi}{1 + \sin\varphi} \operatorname{tg}\varphi \; rh + 1000c \right) dh + \pi D \int_{\left(y - vt - \frac{H - vt}{l_0 + 1} - M\right)}^{(y - vt)} 1000c\, dh =$$

$$= \frac{1}{2} \pi r D \operatorname{tg}\varphi \frac{1 - \sin\varphi}{1 + \sin\varphi} \left(y - vt - \frac{H - vt}{l_0 + 1} - M\right)^2 + 1000 \pi c D (y - vt)$$

3) buoyancy

$$N = \frac{\pi D^2 r_w (H - vt - \triangle H)}{4}$$

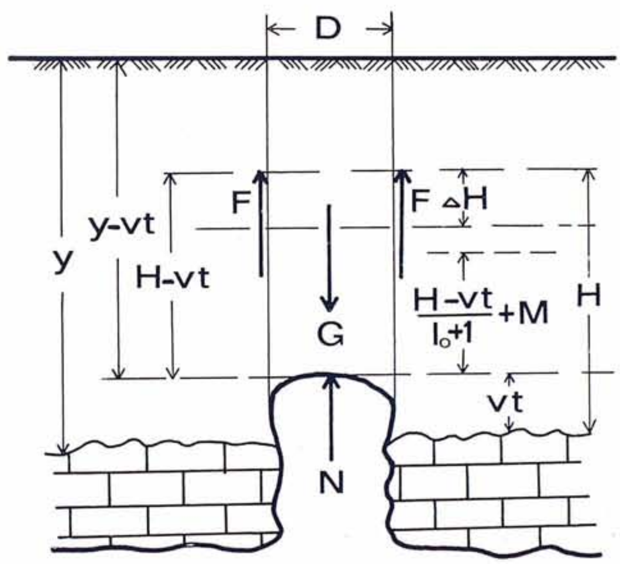

Figure 1. Sketch forced cover.

The state to be forced in cover show in Figure 1.

Thus according to acting direction of force the first collapse forecast model is:

$$K = \frac{F + N}{G} = \frac{2r \operatorname{tg}\varphi \frac{1 - \sin\varphi}{1 + \sin\varphi} \left(y - vt - \frac{H - vt}{l_0 + 1} - M\right)^2 + 4000c (y - vt) + D r_w (H - vt - \triangle H)}{D r \left(y - vt - \frac{H - vt}{l_0 + 1} - M\right) + D r_1 \left(\frac{H - vt}{l_0 + 1} + M \right)} \quad \ldots\ldots (1)$$

where,

K = equilibrium factor;
D = diameter of assuming collapse (cm);
y = covering thickness (cm);
H = groundwater level (cm);
$\triangle H$ = groundwater level amplitude (cm);
r = natural unit weight (g/cm³);
r_1 = saturation unit weight (g/cm³);
r_w = water specific gravity (g/cm³);
c = internal cohesion (Kg/cm²);
φ = internal friction angle (degree);
t = time of collapse formation (year);
I_0 = initial hydraulic gradient (I_0 assume 1.11 in the paper);
M = capillarity height (cm) (measured volume is about 100 cm); and
v = slacking or peel rate (cm/year).

2. The Second Model

The model is established in the condition that the groundwater is unconfined. In the case there are three main force in the cover. They are:

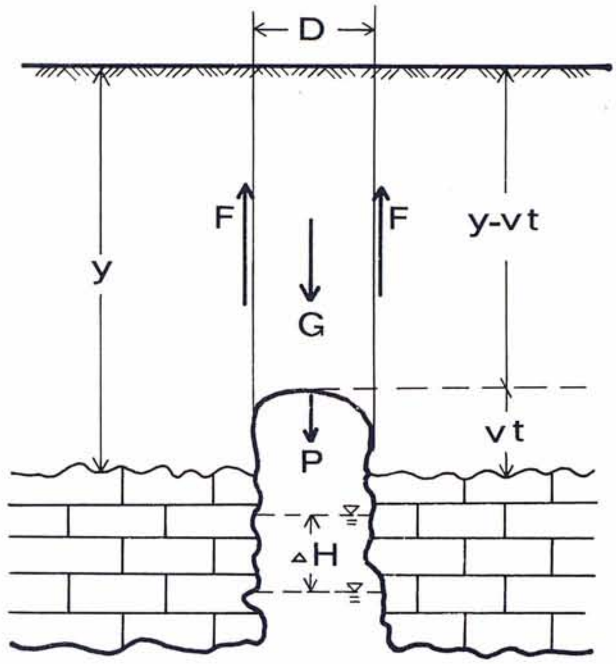

Figure 2. Sketch forced cover.

1) gravity of soil

$$G = \frac{\pi r\ D^2\ (y - vt)}{4}$$

2) internal friction force

$$F = \pi D \int_0^{(y - vt)} \left(\frac{1 - \sin\varphi}{1 + \sin\varphi}\ tg\varphi\ rh + 1000c\right) dh = \pi D \left[\frac{1}{2}\ rtg\varphi\ \frac{1 - \sin\varphi}{1 + \sin\varphi}\ (y - vt)^2 + 1000c\ (y - vt)\right]$$

3) attraction from the change of groundwater level

$$P = \frac{\pi D^2\ \triangle H\ r_w}{4}$$

The state to be forced in the cover show in Figure 2.

According to the acting direction of force the second model is established. It is:

$$K = \frac{F}{G + P} = \frac{2r\ tg\varphi\ \frac{1 - \sin\varphi}{1 + \sin\varphi}\ (y - vt)^2 + 4000c\ (y - vt)}{r\ D\ (y - vt) + r_W\ \triangle HD} \qquad (2)$$

Model analyse and discussion

Above two models are established now following to only analyse the first model.

The model (1) show that: if $K > 1$, the cover is relative stable state; $K = 1$, the one critical state; $K < 1$, the one unstable state (that is collapse).

1) The Relationship between the Equilibrium Factor (K) and Covering Thickness (y)

Assuming other variable value to be no variation experct the covering thickness (y), the K is a function of the y. To seek the derivative for the y and to identify monotone increasing or decreasing of the function show that the K is a monotone increasing, that is, the K is increasing with the y. For example, measured data are:

$\triangle H$ = 384 (cm),
H = 705 (cm),
r = 1.85 (g/cm³),
r_1 = 2.06 (g/cm³),
c = 0.13 (kg/cm²),
φ = 13 (degree),

letting t = 0, D = 447 (cm) and assuming y to be variable, the calculating result show that the larger the cover thickness, the larger the K is. If the cover is more than 11 meter, the cover is no collapse in present (Table 1).

y (cm)	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
K	0.91	0.95	0.99	1.03	1.08	1.14	1.20	1.26	1.32	1.38	1.44	1.51
y (cm)	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900	3000	
K	1.57	1.64	1.70	1.77	1.84	1.90	1.97	2.04	2.11	2.18	2.25	

Table 1. The relationship between the equilibrium factor (K) and the covering thickness (y)

According to preliminary statistics of collapse number with covering thickness in Guilin. Collapse number mainly distributed over the cover that its thickness is less than 10 meter and show that the less the thickness, the more the collapse number is (Table 2). This phenomenon is consistency with the result calculating by model.

2) The Relationship between the Equilibrium Factor (K) and Groundwater Level (H) and Amplitude

To seek derivation for the H and $\triangle H$ and to identify monotone of function show that the K is monotone decreasing, that is, the K is decreasing with the increasing of H and $\triangle H$. It also show that the larger the $\triangle H$ and H, the easier the collapse is in cover. This conclusion is consistency with reality. In face, the water is a active factor in the forming course of collapse. It not only directly affect the physical mechanic property of cover, but also exert influence on the collapse formation by its action. According to incomplete statistics 80 % of collapse number are related to draw-off. As draw-off are made with larger drawdown, the $\triangle H$ is larger and K value is less. Therefore, the cover produce easily collapse. In addition, the cover often produce collapse after heavy rain. The reason is that the level rapidly rise with the larger value of H soon after heavy rain and that the groundwater level rapidly fall with larger value of $\triangle H$ in several day.

3) The Relationship between the Equilibrium Factor (K) and the Physical Mechanic Property (c and φ)

c and φ are main index representing physical mechanic property. The model show that the K is decreasing with decrease of c and φ value. Therefore, the less the K, the easier the collapse in the cover is.

4) The Relationship between the Equilibrium Factor (K) and the Slacking and Peel Rate (v) or Time (t)

The first model show that the equilibrium factor (K) is decrease with the increase of slacking (or

covering thickness range (m)	0 - 5	5 - 10	10 - 15	> 15
collapse number	94	46	11	0
percentage (%)	62.3	30.5	7.2	0

Table 2. Statistical data of relationship between collapse number and covering thickness

peel) rate (v) and time (t). It is say the faster the slacking or peel rate, the easier the collapse in the cover is. Thus the cover can be transformed stable state into unstable with time. That is, there is a evolution in collapse formation.

Model check

Can the model use in collapse forecasting or not? How do we check the model? The most efficacious and simplist method to check the model is comparing the result calculating by the model with the reality of collapse in the cover. This paper check the model by the reality data in Yulin, Guilin and other places.

The checking result show that the area of larger equilibrium factor is no collapse at present, and the collapse is always in the area of equilibrium less than 1 (Table 3).

It also show that the result of calculating by the model is consistency with reality, and the model can be used in collapse forecast.

Collapse forecast

The main content of collapse forecast are:

1. collapse site or range;
2. collapse time; and
3. drawdown causing collapse.

Collapse site and range is important forecast content. There are three methods and techniques to determine distribution of karst cave or soil cave under the cover. They include: (1) airborne remote sensing, ground geophysics and direct ground investigation. The discussion about the methods and techniques have gone beyond the scope of this paper. Therefore, here is no more discussion.

Will the cover that is stable at present is stable or not? It must be forecast. Letting $t = 0$ and analysing cover stability is status quo estimation; letting $K = 1$ and solving t is forecast, the t is the need time that the cover transfred stable state into unstable. There are two case in forecast. The first case is that the forescast result show that the cover may be collapse using the first model, if $H \geqslant vt$. The second case is that the cover may be stable if $H = vt$. In the case, at first, the t is equal to $\frac{H}{v}$, then using the second model forecast, finally two time add together to make total time from stable to unstable.

For example, at the 9th site in Sanlidian, Guilin, the data are:

$\triangle H$ = 420 (cm)
H = 713 (cm)
r = 1.99 (g/cm^3)
r_1 = 2.06 (g/cm^3)
y = 1498 (cm)
c = 0.47 (kg/cm^2)
φ = 20.5 (degree)
l_0 = 1.11 (empiric value)
v = 0.20 (cm/year, assuming value)
D = 345 (cm, statistical value)

According to above analyse stage and putting each value into the first model, the K is 3.08 if v product t is equal to H. This result show that the cover will be stable, the time is equal to 3565 year. Then putting y being equal to 785 cm (1498-713) into the second model and letting K to be equal to 1, seek time (t), the t is 3355 years. That is the cover need about 6920 years transforming stable state into unstable (That is collapse).

For the covered karst area suppling groundwater in order to avert or reduce collapse production the limit drawdown must be controlled, this aim may be realized by controlling amplitute $\triangle H$ at critical state that the K is equal to 1.

site			$\triangle H$ (cm)	H (cm)	y (cm)	r (g/cm^3)	D (cm)	φ (^{0})	c (kg/cm^2)	K	reality
Yulin		1	280	129	379	1.94	(500)	11.4	0.15	0.57	collapse
		2	280	699	919	1.94	(500)	11.4	0.15	0.80	
		3	280	294	544	1.94	(500)	11.4	0.15	0.70	
		4	280	284	1234	1.94	(500)	11.4	0.15	0.85	
		5	280	1034	1284	1.94	(500)	11.4	0.15	0.70	
Guilin		6	600	425	850	1.91	230	21	0.04	0.88	
		7	124	360	734	1.82	423	19	0.02	0.44	
	Sanlidian	8	413	580	1706	1.96	(345)	23.4	0.43	3.52	no collapse
		9	420	713	1498	1.99	(345)	20.5	0.47	3.28	
		10	220	1770	2649	1.95	(345)	18.1	0.64	4.01	
		11	385	1034	1789	1.78	(345)	24	0.42	3.12	

Table 3. Comparing data between status quo estimation and reality. (r_1 assume all 2.06 (kg/cm^3), The data with brackets is quoting one)

Conclusions

Karst collapse result from many factors. Two models based on affecting factor such as covering thickness; physical mechanic property of soil; groundwater level fluctuation; time can be used in collapse forecast. The model analysis show that collapse is produced easily as the covering thickness (y) and the c or φ value representing the physical mechanic property of soil is less, the amplitute larger, and the cover can be transform stable state into unstable (collapse) with time.

Collapse forecast is a new topic of engineering stability evaluation. Forecast key is to define the distribution of karst or soil cave and to measure slacking or peel rate of soil etc. All of these are pending further discussion and study in practice.

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TIMBER HARVESTING ON KARST LANDS: SOME OPERATIONAL CONSIDERATIONS AND PROCEDURAL REQUIREMENTS

by Kevin KIERNAN (*)

Resum

En emprendre el desenvolupament de zones càrstiques, els tècnics en gestió forestal es troben amb la preocupació pel medi ambient i amb uns especials problemes pràctics. Durant la fase operacional cal fer uns acurats ajusts. S'ha de parar especial esment al drenatge i al disseny, localització i manteniment dels camins. És necessari prendre precaucions especials durant l'extracció de troncs i en la localització i ús de les instal·lacions de càrrega de troncs. Aquí avançam unes propostes estudiades per reduir l'impacte ambiental associat amb el procés de tala als boscos de les zones càrstiques de Tasmània. Aquestes propostes poden tenir una aplicació més ampla o adaptar-se a medis càrstics onsevulla s'emprengui l'activitat fustaire.

Abstract

The forest Manager is confronted by special environmental concerns and practical problems in seeking to develop karst areas. Carefull adjustments need to be made at the operational stage. Particular attention must be given to drainage and road design, road location and road maintenance. Special precautions need to be taken during log extraction and in the location and utilisation of log loading facilities. Specific proposals are advanced that have been designed to minimise the adverse environmental effects associated with the process of timber harvesting in Tasmanian karst forests. These may have wider potential application or may be adaptable to karst environments elsewhere where logging activity is undertaken.

Karst landscapes result from the dissolving of soluble bedrock by acidic natural waters, and are characterised by predominantly underground drainage systems; underground caverns; surface depressions (sinkholes); dry creek beds; large springs; sinking streams and other landforms. Because such landscapes commonly offer a variety of economic, scientific and recreational resources, and because these are often highly sensitive to disturbance or damage, forestry operations must be conducted with extreme care. At all times very high priority should be accorded to:

— protection of the soil and its ability to store and transmit water;
— protection of water quality and the natural drainage pattern - if streams become silted it could lead to caves being blocked or underground water supplies being damaged perhaps many kilometres distant;
— protection of the natural processes or airflow between caves and the outside world;
— protection of a zone of natural vegetation around cave entrances - cave dwelling organisms may be dependent upon this for their food supply.

Roading

(a) The principal environmental concerns in karst forest roading lie in the risk of soil erosion; blockage of underground drainage channels by sediment; drainage diversion; cave air flow diversion; increas-

(*) Department of Geography, University of Tasmania (formerly Division of Engineering and Operations, Forestry Commission, Tasmania).

ing public access to sensitive caves; overstressing thin cave roofs; diminution of water quality; and structural damage or damage to cave decoration by shock wave production during construction or by vibrations during road use (Kiernan 1984).

(b) The practical problems posed for the roading authority by karst include the presence of deep rifts in the bedrock or complexly fluted and undercut surface outcrops; ground surface instability including occasionally the possibility of collapse or washout; road subsidence due to sinkhole development (sometimes actually induced by the drainage changes caused by the road itself); and difficulties with highly irregular bedwork topography leading to unpredictable foundation depth (and strength) beneath overburden. Where sudden collapse has occurred, it tends less often to be due to bedrock failure than to the failure of overburden after fines have been flushed out of it and into hidden solution cavities in the limestone (Aley et al 1972, Kiernan 1984).

(c) The possible hydrological and water quality impacts of roads (Parizek 1971) include:

1. the beheading of aquifers in soil and shallow bedrock;
2. the development of groundwater drains where cuts extend below the local water table;
3. changes in ground and surface water divides;
4. the reduction of infiltration rates beneath the road and associated drains;
5. the reduction of streambed infiltration where sedimentation has occurred;
6. the silting of channels causing flashier runoff or flooding;
7. changes in runoff and recharge characteristics generally;
8. erosion and reduction in recharge areas and on flood plains;
9. the obstruction of groundwater flow by abutments and retaining walls;
10. changes in water chemistry where new bedrock components are exposed (e.g. more acid drainage if pyritic rocks such as pyritic shales in limestone are exposed);
11. pollution by petroleum, silt or other materials.

(d) The risk of mass slope failure is increased where road cuts are excessively steep or designed profiles exceeded; where roads cut below the local water table; where roads truncate the toe of previously stabilised transported mantles; where there is an increase in the pore water pressure of previously stable areas due to diminished transpirational uptake resulting from removal of adjacent vegetation; where roads incise steep slopes below convex breaks of slope; or where works are poorly drained (Kiernan 1974).

Road Design

With the above considerations in mind, road designers should take account of the need to:

1. await the completion of karst inventory and assessment procedures along the road route and in its general vicinity prior to the commencement of design work;
2. plan to construct roads only in fine weather and ensure that earthworks are stabilised as much as possible, particularly prior to any cessation of work for 48 hours or more or when rain is expected;
3. wherever possible, keep road width to a minimum to reduce the area of permeable mantle converted to an impermeable surface which will promote runoff rather than infiltration;
4. consider leaving roads across unmantled limestone country unsealed to slow runoff, unless siltation is a hazard;
5. balance cuts and fills to the maximum possible extent to avoid dumps of unused fill which may be washed into karst channels;
6. not construct roads across unstable sites such as active sinkhole margins or slip zones; to ensure assessment of mantle stability beforehand; to consider adopting an alternative route or leaving the particular location unharvested where necessary;
7. utilise full bench construction in critical situations;
8. bring in any extra fill needed from outside the karst area concerned or from sites where the karst is very heavily mantled by transported surface deposits;
9. ensure that roads do not enter any karst reserves apart from necessary crossings of streamside reserves where bridges are present;
10. anticipate survey and design for karst roads;
11. keep batter angles low where erosion susceptibility is high and siltation of underground karst channels is a risk; and to minimise the extent and angle of exposed soil and the duration of exposure.

Drainage Design

In order to safeguard soil and water values the following steps are recommended:

1. ensure that silt traps are provided downstream of bridgeworks or in other situations where there is a risk of karst stream siltation; and ensure there is adequate access to enable the traps to be periodically cleaned and the sediment placed in a position where there is no risk of it regaining access to the stream;
2. ensure adequate drainage and stabilisation during all stages of construction;
3. consider catch drains above cuttings to mini-

mise their erosion by surface runoff; line any steep portion, disperse water into soil or grade to culvert; the drains should be designed so as to minimise the localised entry of water into the soil profile and consequent risk of slope failure;

4. ensure table drains are of adequate capacity;
5. drain outlets to side drains, culverts, watercourses or soaks at a spacing in accordance with the criteria for high erosion risk class soils on bare karst, and according to the nature of the mantle in karst catchments;
6. provide for sediment traps to be installed on all surface watercourses (permanent or ephemeral); where streams enter nearby caves the trap should be sufficient to minimise the influx of material down to silt grade;
7. disperse runoff at bridges into vegetation rather than directly into the stream; construct bridges only when the risk of high flows is limited; properly bridge permanent, intermittent and ephemeral channels; contain the road surfacing material to the bridge; and emplace silt traps downstream during construction;
8. minimise any modifications to the catchment size or runoff characteristics of sinkholes when planning road drainage;
9. site sediment traps some distance downstream from the disturbance to maximise the length of natural channel available to absorb some of the sediment.

Road location

The following safeguards may be particularly important in karst areas:

1. to await the completion of karst inventory and assessment procedures before attempting to finalise road location;
2. to fit roads to the topography in an effort to minimise the infilling of sinkholes and generally minimise earthworks by adhering to topographic form;
3. to avoid unstable slopes, erodible soils, sinkholes, active or inactive drainage routes, draughting holes or cracks in the ground;
4. not to locate roads over the top of caves and to minimise road construction over probable underground drainage corridors along which caves probably occur;
5. to ensure that sidecast material cannot reach watercourses or sinkholes;
6. to avoid steep slopes where runoff is more difficult to control;
7. to respect all karst reserves and to maintain or establish buffering vegetation to filter runoff;
8. to minimise stream crossings and interference with natural drainage;
9. to minimise the clearing of vegetation beside roads consistent with allowing the road surface to dry satisfactorily;
10. not to leave excess ballast in a position where it may be eroded either during or subsequent to construction;
11. not to permit ballast or any form of debris to enter any cave entrance; karst reserve; significant sinkhole; active or inactive watercourse; draughting hole;
12. to stockpile soil for later revegetation wherever necessary and to revegetate construction tracks as soon as they are no longer needed;
13. to plan the location of snig tracks in conjunction with road planning, bearing in mind those considerations which are suggested in the karst logging guidelines.

Road Maintenance

(a) It is absolutely fundamental that all silt traps be regularly inspected and cleaned; access for cleaning and a safe site for debris dumping should be established beforehand.

(b) All drains should be regularly inspected and kept clear, particularly after logging ceases.

(c) Roads to be put to bed should be outsloped, drains cleared, water barred, blocked to traffic, also ripped and re-seeded if necessary; monitored.

(d) Consideration should be given to eliminating a road no longer in use if a sensitive cave exists close by and an effort to minimise excessive visitation appears warranted.

(e) Signposts referring to karst features should be installed only after detailed consideration of the implications by the karst specialists.

(f) Maintenance should be kept up on roads to be retained; some roads may need to be gated to limit misuse or excessive access to sensitive sites such as baseline karst process monitoring installations.

Logging operations

1. No forest operations should commence until the distribution and nature of the various karst resources of the area has been mapped and assessed.
2. All planning with respect to road and snig track locations and drainage should be in accordance with the provisions of the Karst Management Policy.
3. No logging operations should commence until the planning of any necessary karst reserves or other special safeguards has been finalised.

The following general guidelines should be followed:

1. No logging should occur on steep limestone slopes.
2. Logging of limestone slopes of more moderate angle should only occur during the driest months, in very small and dispersed units; logging should be curtailed with any unseasonal onset of wet weather when water runs in the table drains.
3. All karst reserves should be respected. These exist not only to protect environmental values but also to safeguard forest workers in areas prone to ground subsidence or collapse.
4. These should be no felling of trees towards any karst reserve, cave entrance or watercourse; sinkholes should also be avoided especially where they are known to contain a cave or stream.
5. No form of rubbish, debris or toxic material should be permitted to enter any sinkhole, watercourse or cave entrance; no insecticides should be allowed to settle in any natural vegetation zones outside cave entrances.
6. Where silt traps are installed they should be regularly inspected and cleaned when necessary; the silt removed from the trap should not be placed so as to be at risk of being washed back into the stream.
7. If further caves or streamsinks are discovered during logging the site should be avoided until assessment procedures have been completed.

The following specific precautions are suggested to minimise the risk of erosion and siltation during logging operations:

Log Extraction

1. Because soils are most susceptible to damage when they are wet, and because underground karst water channels are most easily silted when runoff is prevalent, forest managers should err on the side of caution in transferring logging from sensitive karst sites during winter.
2. The often sensitive soils, risk posed to drainage patterns by excessive silt in streams and the often rocky nature of karst means that particular care needs to be exercised in the selection of extraction equipment -
   a) where karst assessment procedures have identified the existence of a thick deposit of naturally transported earth and rock overlying the limestone, logging operations may proceed normally but giving full regard to the need to minimise soil erosion and stream siltation;
   b) where only thin residual limestone soils are present neither wheeled nor flexible tracked skidders should be used on limestone slopes of even moderate angle; only highline systems hauling upslope or skyline systems should be permitted on slopes steeper than about 10° and no logging at all on such slopes steeper than about 20°.
3. Snig tracks warrant particular attention because they frequently destabilise the soil, concentrate and alter the surface drainage pattern, and represent sites of soil compaction which alters the balance between water running off the soil and the water which soaks into it.
4. Planning of snig tracks should aim to reduce the length, density and gradient of snig tracks and should occur concurrently with road planning.
5. Cross drains should have been planned in advance to disperse rather than concentrate runoff, reduce water velocity and minimise sediment transport. Some of these cross drains should be activated whenever track use is interrumpted for 48 hours or more or if heavy rain seems likely.
6. Because maximum ground compaction occurs after only a few passes, snig tracks should be limited in number to reduce the affected area but carefully sited with respect to karst landforms and karst reserves.
7. Snig tracks should be outsloped and if necessary stabilised by fast growing grasses or legumes after use; sediment traps should be installed where required.
8. No snig track should enter any karst reserve or significant karst depression.
9. No watercourse should be used for snigging; no watercourse should be diverted to flush mud from a snig track, or any other form of mudflushing undertaken.
10. Snigging should be conducted in an upslope direction to minimise downslope concentration of runoff in gouged channels.
11. Inadvertent water diversions should be dispersed and the basic cause rectified.
12. Drain spacing for karst areas with thin residual soils should be in accordance with high erosion risk sites; even where soils are thick they should be managed as posing not less than a moderate erosion risk.
13. In some cases it may be desirable to reduce log size in an effort to minimise the greater erosion potential posed by handling large logs.
14. To reduce ground vibration, logs should be suspended above the ground while being moved over shallow caves.
15. All assessments of erosion risk should be made by the karst inventory assessors and based

upon the true field-verified character of the soil and parent materials, not extrapolations from bedrock geological maps.

16. Cross cutting and debarking should occur at the stump to minimise the extent of necessary landings, but bark and other debris should be prevented from entering karst reserves and sinkholes etc.
17. Where logs are used as sediment barriers it will be necessary to clean the sediment out occasionally. If this is not done water may simply overtop the log and erode back underneath it through the development of a plunge pool. By this means the trapped sediment may eventually be realised as a result of drainage passing under the log.

Landings and Loading

1. No landings should be sited close to any karst reserve or significant karst depression.
2. Landing size should be minimised and alteration of the existing topography minimised.
3. Wherever feasible the surface soil should be stockpiled and kept free of logging debris for later restoration work.
4. Winter landings should be corded and all landings should be located on well drained sites.
5. Landings in karst areas should be drained into the surrounding vegetation or silt traps whenever wet weather threatens; this should occur whenever operations on thin limestone soils are suspended for 1 week or more increasing to one month or more on thickly mantled karst catchments.
6. Within reason the original ground contour should be restored as soon as possible after logging ceases; if necessary landings should be ripped and hand replanted. Operators should bear this in mind and not unnecessarily disturb stock piled soil.
7. Tracked front end loaders exert a significant cutting action upon the soil and should only be used where karst is thickly mantled by soil and of moderate angle. They should not be used during wet conditions. Where the soil is thin or the slope steeper (greater than about 10°) loading should only be by crane.

In addition to the safeguards that are presented here and are aimed specifically at the protection of karst environments, normal sound logging practices (eg. Forestry Commission 1981) should be adopted.

Acknowledgements

This paper stems from a study which originated in 1983 with financial support from the Tasmanian Forestry Commission and Australian Heritage Commission and logistical assistance from the National Parks and Wildlife Service (Tasmania). I am grateful for assistance and useful discussions at that time with Brendan Diacono, Phil Jackson, Steve Harris, Elery Hamilton-Smith, the late Joe Jennings, Paul Wilkinson and others. I am also grateful to the Director, Australian Heritage Commission, holder of copyright on the study, for permission to include here the work done at that time.

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ON THE CHARACTERISTICS OF YUGOSLAVIAN RIVERS IN COMPARISON WITH JAPANESE RIVERS

by Kazuo MITSUI *

Abstract

This article deals with the characteristics of rivers in Yugoslavia and Japan, based on the results of the field survey and the data observed by the Hidrometeorological Institutes, F.R. of Yugoslavia.

Roughly speaking, the river systems in Yugoslavia are classified into two: the Danube (including the Sava, the Drava, etc.), a long, gentle current, and the Neretva and the Vardar, relatively short, rapid ones. In the karst region, where the two river systems mentioned above are included, many discontinued rivers are found.

Seasonal changes of run-off amount of the rivers in Yugoslavia differ very much from those of Japan, which show maximums in the typhoon season in autumn or in the baiu (rainy) season in early summer. In such rivers as the Sava and the Drava the coefficient of river regime is less than 30, and the level of water becomes higher in April through June due to melting of snow and from November to December by rainfall. The water level is the lowest in July and August.

Because of the high seepage and flowing-out characteristics in the karst regions the run-off ratios of the rivers in Yugoslavia are relatively high, ranging approximately from 60 to 90 %; as an extreme case, the Una shows a value of 112 %. The velocity of floodwaves in the case of a great flood of the Sava, a tributary of the Danube, was 0.6-0.7 m/sec for a distance of 680 km. from the river head to Beograd. A similar value, 0.7 m/sec, was obtained for the Drava. The water level changes more widely in the lower course than in the upper course of the Sava. However, the coefficient of river regime is rather small probably because the current velocity is relatively low. In contrast to this, the floodwaves of Japanese rivers generally travel more rapidly at a rate of more than 3 m/sec or even 10 m/sec on some occasions.

The water temperature of the Sava is nearly constant in February, being about 1°C both in the upper and lower courses. In August it is 12-13°C in the upper course, gradually becomes higher in the lower basin, rising up to 25°C in Beograd. It is found that there is a close relationship between the levels of underground and river waters along the course of the Sava river.

The water quality of the Yugoslavian rivers, for instance, total hardness, Ca hardness, total solid and pH contents are much higher than Japanese rivers and, on the contrary, Cl and SiO_2 contents are lower.

Resumen

Este artículo trata sobre las características de los ríos en Yugoslavia y en Japón, basándose en los resultados de estudios de campo y de la información recopilada por los Institutos Hidrometeorológicos de la Rep. Fed. de Yugoslavia.

En líneas generales, los sistemas fluviales de Yugoslavia son clasificados en dos tipos: el Danubio (incluyendo el Sava, el Drava, etc.), de larga extensión y corriente lenta, y un segundo tipo de ríos relativamente cortos y rápidos como el Neretva y el Vardar. En las regiones del Karst, donde los sistemas fluviales arriba mencionados están presentes, existen muchos ríos de carácter discontinuo.

Respecto a los cambios estacionales en la cantidad de agua circulante, los ríos yugoslavos difieren mucho si se les compara con los ríos japoneses, los cuales muestran máximos durante la temporada de tifones en otoño o durante la temporada lluviosa *(baiu)* a principios del verano. En ríos tales como el Sava y el Drava el coeficiente del régimen del río es menor de 30, y el nivel del agua sube de Abril a Junio debido al deshielo y a partir de Noviembre hasta Diciembre debido a la precipitación pluvial. El nivel del agua alcanza su punto más bajo en los meses de Julio y Agosto.

Como consecuencia de la elevada infiltración y efluencia que caracteriza a las regiones del Karst, los índices de circulación *(run-off ratios)* en los ríos de Yugoslavia son relativamente altos, cifrándose entre un 60 y un 90 % aproximadamente; como un caso extremo, el río Una muestra un

* Hosei University. Tokyo, Japan.

valor de 112 %. La velocidad de las olas de crecida durante una gran inundación del río Sava, afluente del Danubio, fue de 0,6-0,7 m/seg en una distancia de 680 kilómetros, desde la cabecera del río hasta Belgrado. Un valor similar fue obtenido durante una crecida de río Drava. Los niveles del agua cambian más ampliamente en el curso bajo del Sava que río arriba. Sin embargo, el coeficiente del régimen del río es más bien pequeño debido quizás a que la velocidad de la corriente es lenta. Al contrario de lo anterior, las olas de crecida de los ríos japoneses avanzan más deprisa, a una velocidad que supera los 3 m/seg o incluso los 10 m/seg en algunas ocasiones.

La temperatura del agua en el río Sava es casi constante en Febrero, siendo de aproximadamente 1°C tanto en el curso alto como río abajo. En el mes de Agosto es de 12-13°C en la parte de la cabecera del río, elevándose gradualmente aguas abajo hasta llegar a 25°C en Belgrado. Se comprueba que existe una fuerte correlación entre los niveles de las aguas subterráneas y de las aguas del río a lo largo del curso del Sava.

La calidad del agua en los ríos de Yugoslavia, por ejemplo la dureza total, el contenido en calcio, la cantidad total de sólidos y el pH dan valores mucho más altos que en los ríos japoneses, y por el contrario, la clorinidad y el contenido en SiO_2 son inferiores.

1. Introduction

This article deals with the characteristics of rivers in Yugoslavia, a widely developed karst region and Japan, a volcanic country, based on the results of the field survey and the data observed by the Hidrometeorological Institutes, F.R. of Yugoslavia.

Roughly speaking, the river systems in Yugoslavia are classified into two: the Danube (including the Sava, the Drava, etc.), a long, gentle current, and the Neretva and the Vardar, relatively short, rapid ones. In the karst region, where the two river systems mentioned above are included, many discontinued rivers are found (Figs. 1-6).

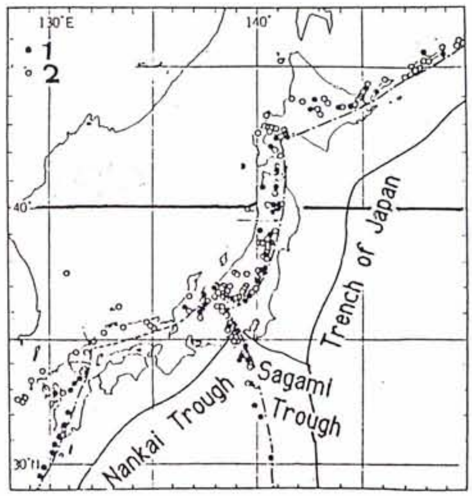

Figure 2. Distribution of Volcanic front around Japan (by Sugimura).
1: active volcano. 2: other quaternary volcano.

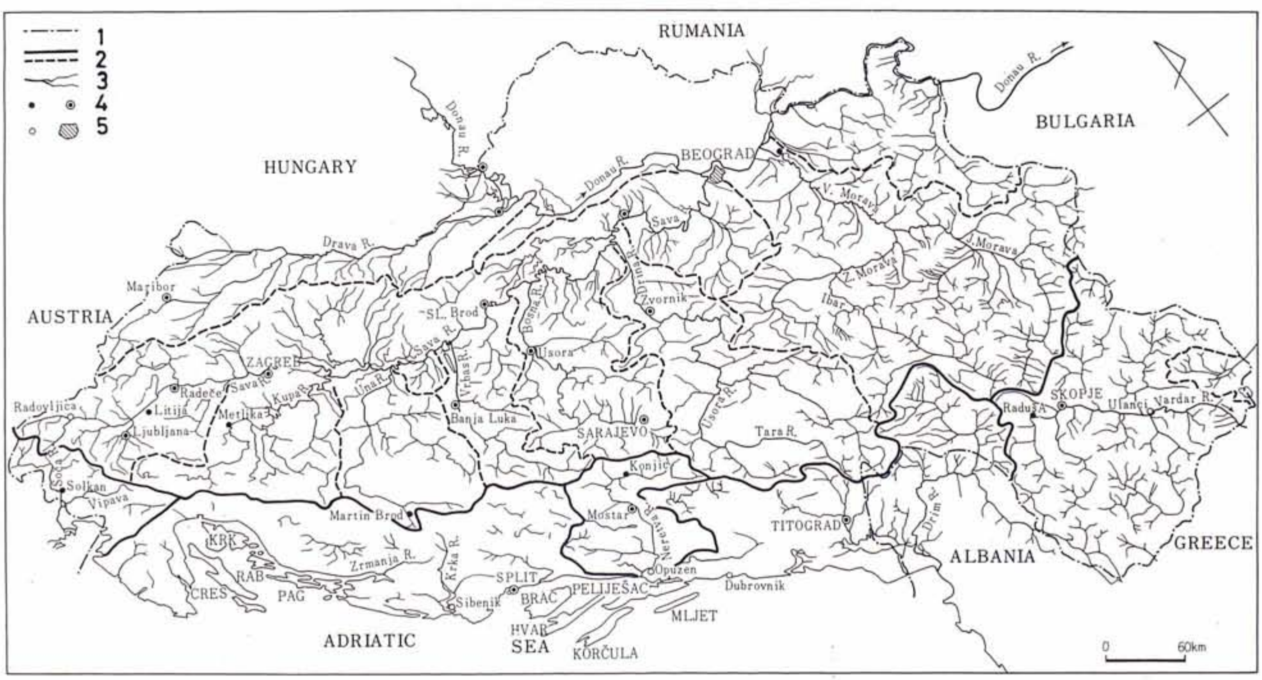

Figure 1. Distribution of the river systems in Yugoslavia.
1: frontier. 2: watershed. 3: river. 4: observation point.
5: city.

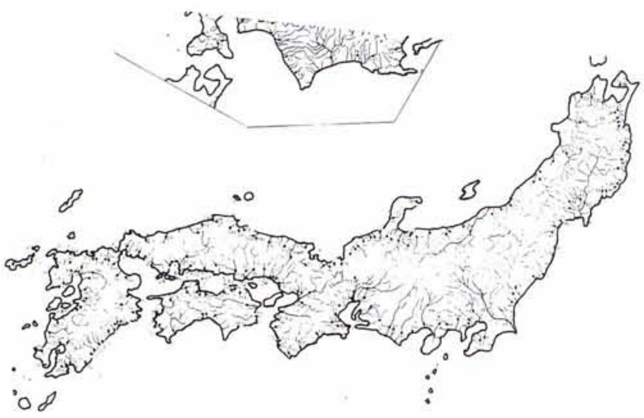

Figure 3. Distribution of analysed water quality of Japanese Rivers.
by Dr. J. Kobayashi (1960).

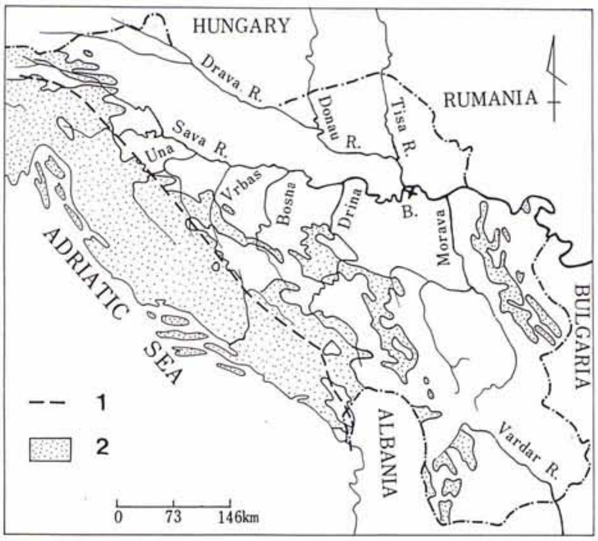

Figure 5. Distribution of limestone and Karst region, and main rivers in Yugoslavia.
1: east boundary Karst region. 2: limestone.

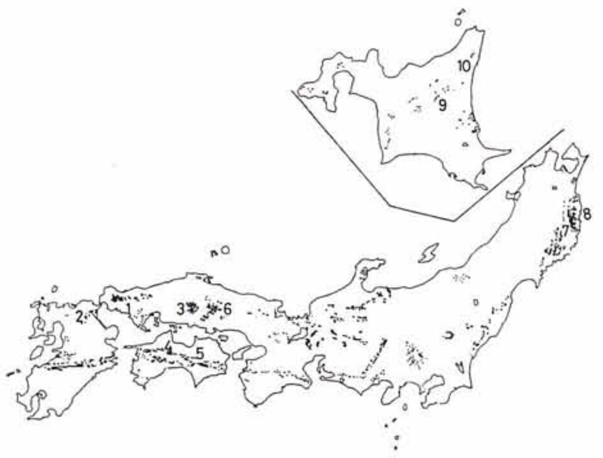

Figure 4. Distribution of limestone and main stalactitic cave in Japan.
1: Akiyoshi. 2: Hirao. 3: Taisyaku. 4: Shikoku. 5: Ryuga. 6: Atetsu. 7: Ryusen. 8: Akka. 9: Toma. 10: Nakatonbetsu.

2. Discussion

1) Run-off percentage and coefficient of river regime

Seasonal changes of run-off amount of the rivers in Yugoslavia differ very much from those of Japan, which show maximums in the typhoon season in autumn or in the baiu (rainy) season in early summer. In such rivers as the Sava and the Drava the coefficient of the river regime is less than 30, and the level of water becomes higher in April and continues until June due to melting of snow and from November to December due to rainfall. The water level is the lowest in July and August (Fig. 7).

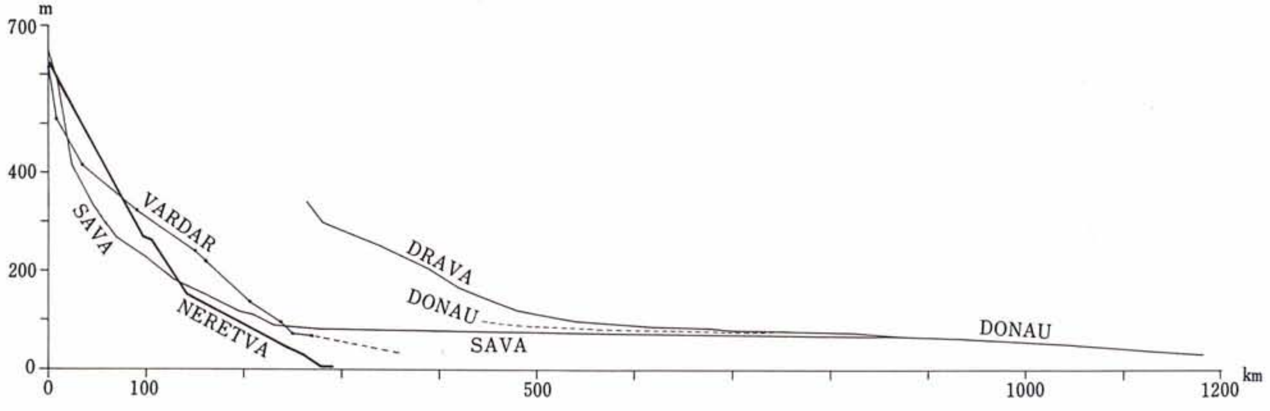

Figure 6. Longitudinal profile of main rivers in Yugoslavia.

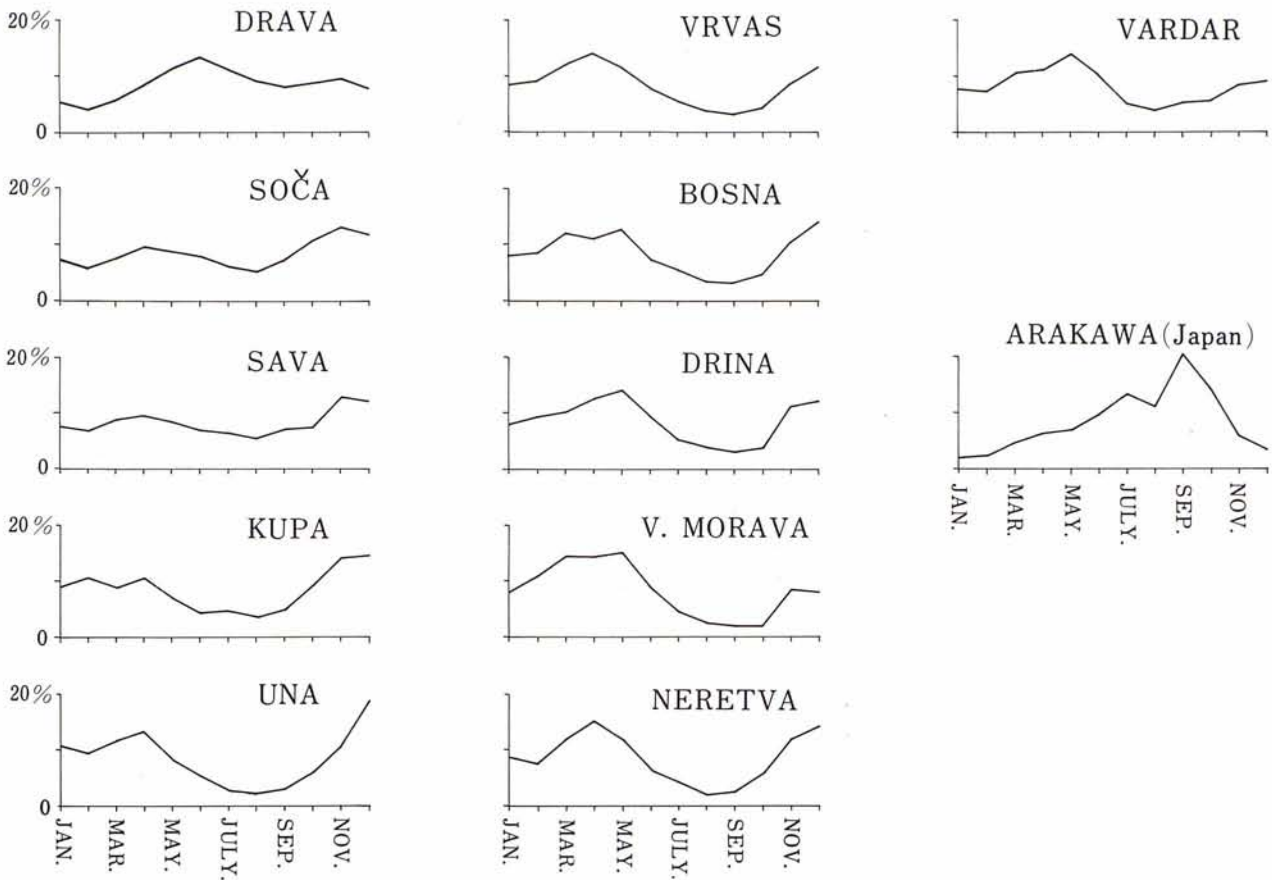

Figure 7. Seasonal change of run-off amount (average of 1956-1966) of the main rivers in Yugoslavia and R. Arakawa in Japan.

Due to the high seepage and flowing-out characteristics in the karst regions the run-off ratios of the rivers in Yugoslavia are relatively high, ranging approximately from 60 to 90 %; as an extreme case, the Una shows a value of 112 % (Table 1).

2) The velocity of floodwaves

The velocity of floodwaves in the case of the great flood of the Sava, a tributary of the Danube, was 0.6-0.7 m/sec for a distance of 680 km from the river head to Beograd. A similar value, 0.7 m/sec, was obtained for the Drava. The water level changes more widely in the lower course than in the upper course of the Sava. However, the coefficient of the river regime is rather small probably because the current velocity is relatively low. In contrast to this, the floodwaves of Japanese rivers generally travel more rapidly at a rate of more than 3 m/sec or even 10 m/sec on some occasions.

3) The water temperature

The water temperature of the Sava is nearly constant in February, being about 1°C both in the upper and lower courses. In August it is 12-13°C in the upper course, gradually becoming higher in the lower basin, rising up to 25°C in Beograd. It has been discovered that there is a close relationship between the levels undergound and river waters along the course of the Sava river (Fig. 8).

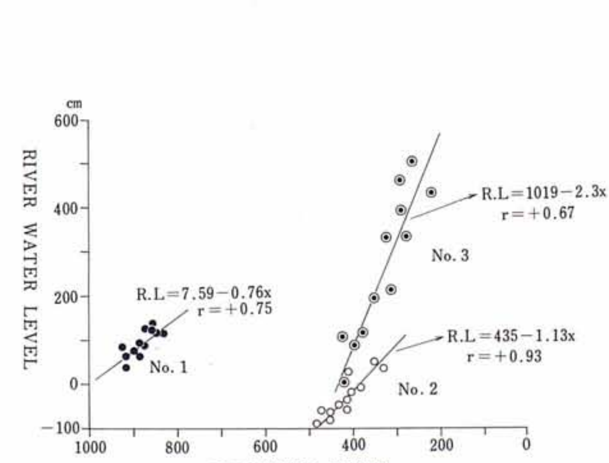

Figure 8. Relationship between groundwater level and river water in Sava river basin.

4) The water quality

The water quality of the yugoslavian rivers, for example, total hardness, Ca hardness, total solid and pH contents are much higher than Japanese rivers but contrary to this, Cl and SiO_2 contents are lower.

5) The characteristics of the Inland-water in Slovenia

1. Almost all parts of Slovenia are on the Dinaric Karst with mountains, hills and plateaus of limestone which belongs to the Pre-Cretaceous period. It's typical topography includes doline, uvala, ponor, karren and stalactitic caves. For this reason, river water often flows into the ground and then springs out and sometimes flow into the caves again.

2. The river systems can be roughly classified into two the Vipava and Soča River systems in the western part and the Ljubljana and Sava systems in the eastern part of the country. The river systems in the former part tend to continue to run on the ground surface for long distances. On the other hand, those in the latter part seem to have been developed by the Reka, Pivka and Unica Rivers, which run into caves several times and it is difficult to determine, where the end of the river is (Fig. 9).

3. In comparing the quality of the water systems of the Vipava and Soča Rivers with that of Ljubljana and Sava Rivers, we find that the regional difference of the total hardness and total solid are higher in the latter systems. However, both of them have common characteristics of the rivers running in the Karst region: that is, their total hardness, Ca hardness, total solid and pH contents are much higher than Japanese rivers and, on the contrary, Cl and SiO_2 contents are lower (Table 2).

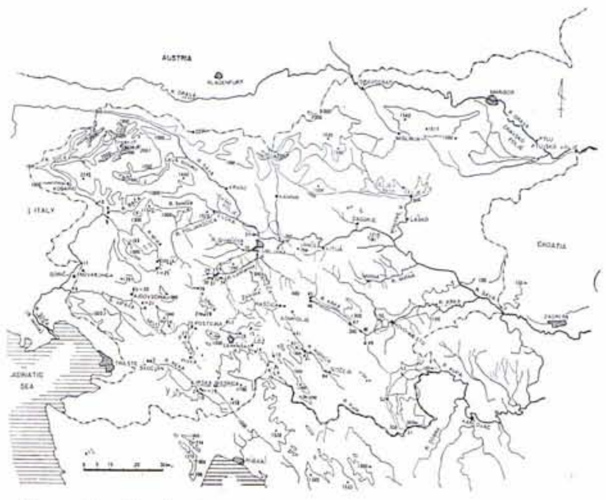

Figure 9. Distribution of the river systems and observated points in Slovenia.

4. It seems that the flow of surface water as well as cave water is closely related to rainfall, this relation to the systems is not yet clear.

5. Changes in the quality of water, particularly the hardness, are related to the run off amount and tempeature, but this does not mean that an increase in water flow by rainfall may cause a lowering in the concentration of the components of water. In the case of the cave water the relationship is more complicated by the varying depths of the ground surface to the water, and types of vegetation land over the caves.

6. As mentioned by Prof. Ivan Gams, the limestone in this area has a corrosion intensity of more than 50-60 m^3/km^2. Sometimes more than 100 m^3/km^2 in a certain small area, which has much annual

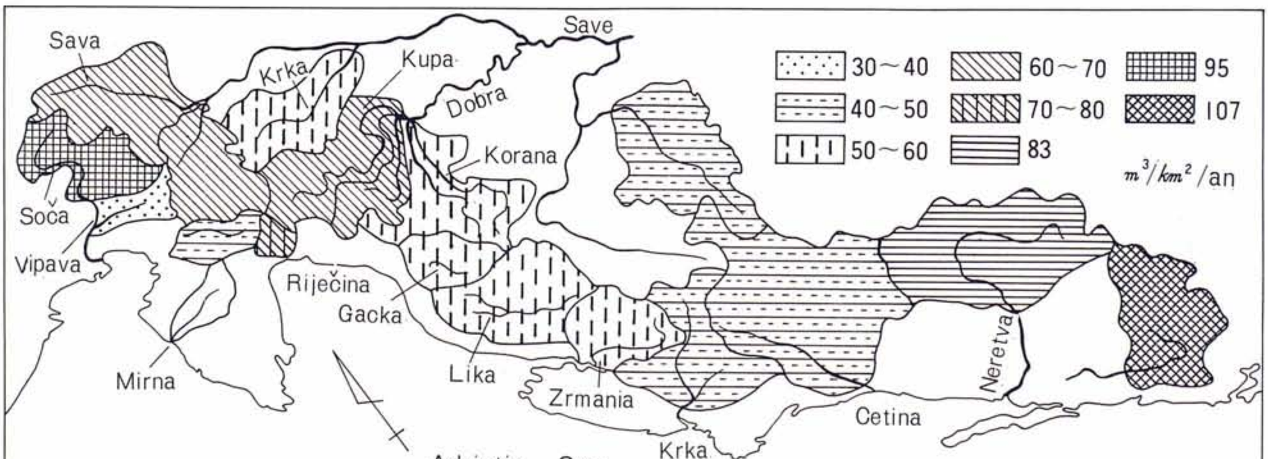

Figure 10. Regional distribution of solution in Karst region, Yugoslavia (by Prof. I. Gams).

A		B	C	D	E	F
Wien		Danube	—	—	4	—
Maribor		Drava	0.121	0.57	29	1/1,850
Radece		Sava	0.215	0.57	28	1/1,400
Metlika		Kupa	0.151	0.61	81	—
Martin Brod		Una	0.179	1.12	53	—
Banja Luka		Vrbas	0.107	0.76	27	—
Usora		Bosna	0.109	0.59	57	—
Zvornik		Drina	0.133	0.85	26	—
Ljub Most		V. Morava	0.242	0.33	36	—
Solkan		Soča	0.188	0.80	91	—
Konjic		Neretva	0.244	0.94	55	1/460
Radusa		Vardar	0.266	0.80	11	1/500
Basel	Europe, America	Rhein	—	—	14	—
París		Seine	—	—	34	—
Dresden		Elbe	—	—	82	—
Pittsburgh		Ohio	—	—	364	—
Minnesota		Mississippi	—	—	119	—
Kawaguchi	Japan	Arakawa	0.177	0.78	149	—
Tome		Kitakami	—	—	223	—
Kajikasawa		Fujikawa	—	—	400	—
Kurihashi		Tonegawa	—	—	850	—

Table 1: River regimes of the main rivers in Yugoslavia and others
A. observation place
B. river name
C. ratio of seasonal changes of run-off amount of rivers
D. run-off percentage
E. coefficient of the river regime
F. river-bed slope

	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO_3 mg/l	HCO_3 me/l	SO_4 mg/l	Cl mg/l	SiO_2 mg/l	Fe mg/l	PO_4 mg/l	NO_3-N mg/l	NH_4-N mg/l	evaporation residue mg/l	suspended matter mg/l
Hokkaido (22 rivers)	8.3	2.3	9.2	1.45	33.9	0.55	10.7	9.0	23.6	0.50	0.01	0.54	0.06	87.9	76.9
Tohoku (35 rivers)	7.7	1.9	7.3	1.06	19.9	0.33	17.6	7.9	21.5	0.49	0.01	0.26	0.06	79.1	18.6
Kanto (11 rivers)	12.7	2.9	7.3	1.43	42.4	0.69	15.9	6.1	23.1	0.23	0.03	0.29	0.08	93.5	22.1
Chubu (central part) (42 rivers)	8.9	1.7	4.8	1.05	30.1	0.49	7.7	3.9	13.7	0.14	0.02	0.18	0.05	62.0	26.9
Kinki (28 rivers)	7.6	1.3	5.5	1.04	27.4	0.45	7.4	5.3	12.1	0.11	0.01	0.21	0.04	56.8	20.0
Chugoku (western part) (25 rivers)	6.7	1.1	6.5	0.94	27.2	0.45	4.4	6.6	14.1	0.05	0.00	0.20	0.03	56.7	7.4
Shikoku (19 rivers)	10.6	1.5	3.8	0.66	37.2	0.61	5.7	2.4	9.8	0.01	0.00	0.12	0.02	57.0	6.1
Kyusyu (43 rivers)	10.0	2.7	8.6	1.84	40.9	0.67	13.1	4.6	32.2	0.13	0.04	0.20	0.04	106.0	29.8
All Japan (225 rivers)	8.8	1.9	6.7	1.19	31.0	0.51	10.6	5.8	19.1	0.24	0.02	0.26	0.05	74.8	29.2

Table 2: Average river water quality of each region in Japan
(by J. Kobayashi, 1960)

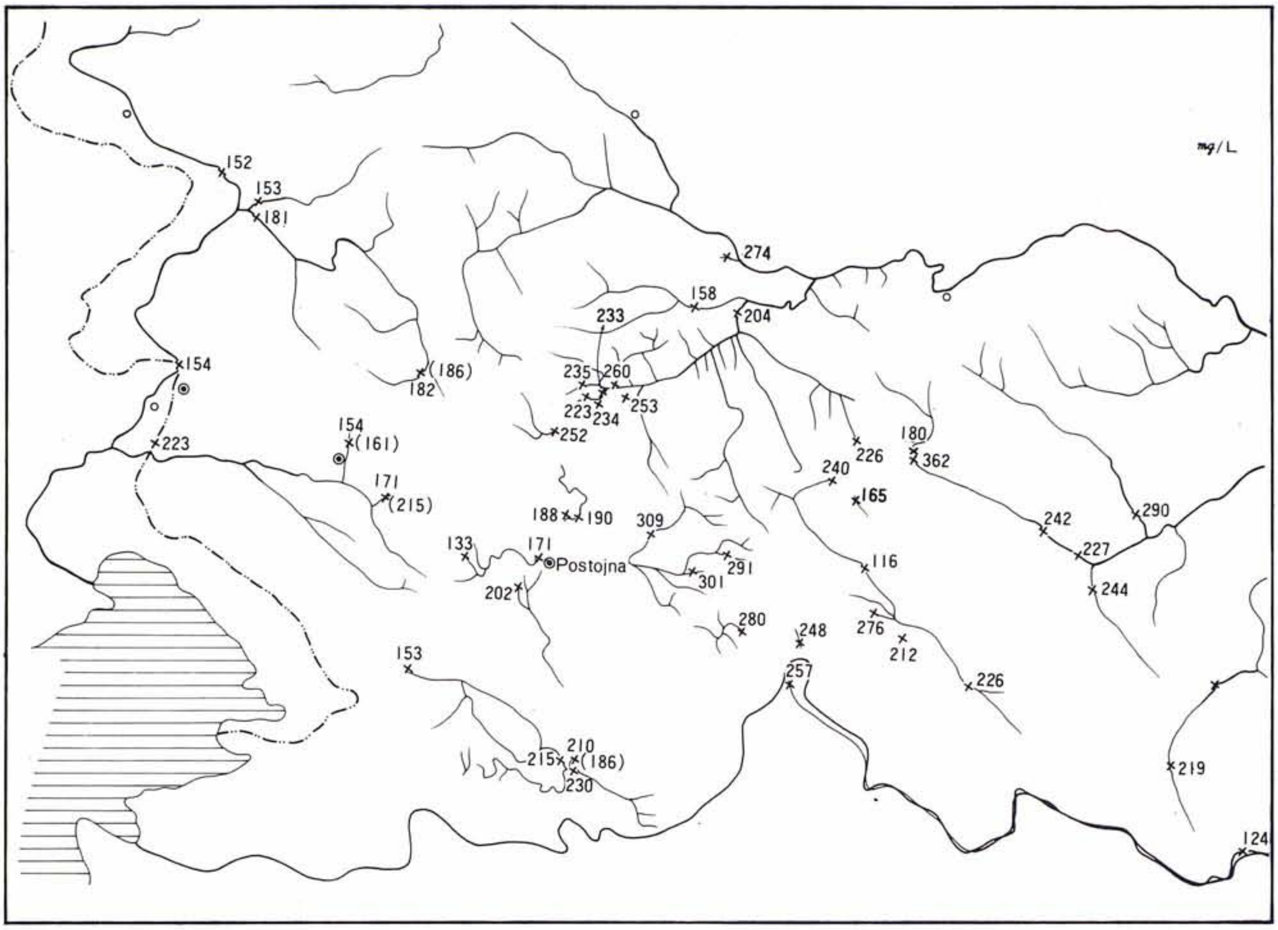

Figure 11. Distribution of evaporation residue of the rivers in Slovenia (in winter, 1970).

rainfall and dense forests (Figs. 10, 11).

7. Even in a country town like Ajdovščina, the river water is polluted to a great extent, when it flows through the urban area. However, it is self-purified and becomes as clean as it was during the time flowing down several kilometers, because the pollution load is not very great at present.

8. Similar characteristics to these are found in Akiyoshi Cave, a typical karst region of Japan. But these similarities are small, if we compare them in detail with those in the whole region of Slovenia.

SOME PLANNING REQUIREMENTS PRIOR TO FOREST INDUSTRY DEVELOPMENT OF CARBONATE LANDSCAPES

by Kevin KIERNAN (*)

Resum

Per a qualsevol projecte d'aprofitament dels recursos naturals és fonamental un correcte inventari dels possibles perills per al medi ambient. L'aprofitament dels paratges calcaris es complica per la complexitat morfològica i de drenatge que resulta del substrat geològic. De l'establiment d'un inventari correcte i de mesures per la protecció ambiental en surt una posició crítica envers el millorar l'ús d'aquestes zones per la producció de fusta a llarg termini. Crítica igualment ho és envers la protecció i el manteniment de molts d'altres recursos naturals i d'altres oportunitats oferides pels paratges calcaris. Aquest treball proposa un conjunt de procediments adequats al desenvolupament de paratges calcaris semblants als de Tasmània, particularment al desenvolupament de zones, abans remotes, on és probable que s'hi estenguin les activitats forestals en els anys vinents. Aquests procediments destaquen la protecció dels recursos del sòl i de l'aigua, cercant la protecció dels valors econòmics, ambientals, científics i d'esbargiment.

Abstract

An adequate resource and environmental hazard inventory is fundamental to any natural resource development project. Development of carbonate landscapes for forestry purposes is complicated by the landforms and drainage complexities that commonly arise due to the solubility of the geological substrate. The development of appropriate inventories and measures for environmental protection are both critical to optimising the long term use of such areas for wood production. They are also critical to protecting and maintaining the many other natural resources and other opportunities offered by carbonate landscapes. This paper proposes a set of procedures appropriate to the development of carbonate landscapes similar to those in Tasmania, and in particular to the development of previously remote areas where forestry development is likely to extend in the next few years. These procedures emphasise the protection of soil and water resources in seeking to safeguard economic, environmental, scientific and recreational values.

Preamble

Karst environments are characterised by landforms such as sinkholes and caverns which primarily result from the solution of a soluble rock such as limestone or dolomite by natural waters. In such a landscape difficulties may be posed for developers due to an absence of surface water storage; in the maintenance of ground-water supply and ground-water quality; as a result of ground surface instability; and because of the other resource utilisation opportunities with which their own activities must co-exist. The soil mantle commonly varies due to such factors as topography, environmental change over the geologically recent past and the possible deposition upon the karst surface of sediments derived from another location. Some residual limestone soils are sensitive to erosion and may take centuries or more to recover if eroded. The maintenance of the natural movement of water, air and food supply into caves is basic to maintaining many of the various values which karst offers for economic, scientific, educational and recreational users. An adequate inventory of each karst landscape together with an understanding of the processes involved in a karst landscape is also an important

(*) Department of Geography, University of Tasmania (formerly Division of Engineering & Operations, Forestry Commission, Tasmania).

factor in optimising the long term use of any karst area for purposes of wood production.

This paper proposes a policy and a set of specific procedures appropriate to the development of karst lands similar to those in Tasmania for forestry purposes. Sound planning is essential to forestry operations in any area (Forestry Comission 1981). The proposals outlined in this paper are geared to the role of an hypothetical government agency responsible for ensuring the proper conduct of such developments. In the Tasmanian context, fire is an important tool in forest management hence some attention is given to this in addition to the other aspects of forest management with which overseas readers may be more familiar. The development of a road and track network in virgin native forests planned for logging is also an important part of Tasmanian logging.

1. A draft Karst policy for the «X Y Z Forestry Department»

(a) Policy goals and objectives

I. to aid in the identification and protection of the natural resources which are offered by the karst landscapes which are under the control of the forest authority and in particular karst water, soils, caves and life forms;

II. to ensure that any presence of karst in areas likely to be subject to forestry operations will be recognised;

III. to ensure that assessment of each karst and the probable impact of forestry operations becomes a routine prelude to logging;

IV. to provide a mechanism for the identification, ranking and management of caves and other karst landforms in areas of government land and such areas of private land as may fall within the influence of the authority;

V. to minimise the physical danger to which forestry workers may be exposed when working upon karst landscapes;

VI. to minimise economic losses (e.g. by road failure) caused by inadequate management;

VII. to responsibly contribute to wider endeavours to improve the management of karst generally.

(b) Terminology

For the purposes of this document the following definitions are assumed:

Karst: a landscape generally formed on limestone or dolomite rock; the result of a high degree of rock solubility in natural waters; characterised by various distinctive landforms.

Mantled Karst: a karst landscape in which the soluble bedrock is mantled by an accumulation of materials which have been transported from elsewhere by the agency of running water, frost, glaciers, wind, gravity, or other influences; these deposits form the parent material from which local soils have been derived.

Bare Karst: a karst landscape in which the soluble bedrock is not mantled by any transported material and in which the only available mineral base for soil development is the insoluble residue remaining after solution of the bedrock.

Karst Water: all water in a karst landscape including seepage and stream water.

Karst Catchment: an area which may neither be underlain by karst rocks nor exhibit any karst landforms but which forms the catchment of streams which flow to a karst area.

Karst Reserve: a reserve to protect a karst watercourse, or other karst feature, or to otherwise aid in karst forest management.

(c) Legal basis for this policy

This will vary from country to country but is likely to involve statutes related not only to forestry operations in particular, but also to Waters, Pollution, Highways and Roads, Archaeology, Scenery Preservation, Wildlife Conservation, Public Safety, Health, Fisheries, Recreation and other matters. These should be identified and their implications specified in the development of a karst management policy.

2. General strategies

(a) To establish formal mechanisms for the routine assessment of karst in areas to be subject at some time to forestry operations, and to oversee data gathering, devise management, operational and restoration procedures and monitor the results of karst management programmes. Within the authority one approach might be to establish some form of consultative group, which would meet regularly, and which might consist of:

I. senior authority officer concerned with operations,
II. senior authority officer concerned with management,
III. senior authority officer concerned with environment protection,
IV. a karst scientist,
V. District Foresters as appropriate
VI. a representative of recreational caving groups.

(b) To facilitate the compilation of karst inventories by:

I. authority staff,
II. consultants,
III. formally engaged volunteers (as appropriate)

(c) To establish and monitor a sequence for the investigation of karst areas - e.g.

I. karst area identification,
II. baseline monitoring as appropriate,
III. deliberate search for karst landforms within each area,
IV. detailed recording of each inventoried site,
V. co-ordination, conduct of or support for any other necessary research,
VI. assessment of management requirements,
VII. implementation of management programs.

(d) To provide maps of karst area locations to regional and district officers to alert them to possible karst implications in their area; and to maintain a central register to be called upon for detailed information when specific logging plans are prepared.

(e) To co-ordinate general resource management within karst forests including produce such as earth materials.

(f) To facilitate communication between the authority and other karst users.

(g) To take such steps as are necessary to safeguard karst resources on authority land, including where appropriate the designation of specific sites as karst reserves or the limitation of access to sensitive sites through gating or other means.

(h) To review and issue delegated management authorities to other bodies where appropriate. This would involve the prior review of proposals for use of karst features on authority land, including the development of educational facilities, the acquisition of caves for tourist development and the use of caves by adventure tourism companies. In rare cases it might also be necessary to consider agreements with recognised bodies such as the relevant Speleological organisation for short term control of particular caves gated by the authority although ideally management should remain with government.

(i) To prepare and implement karst forest management plans.

(j) To manage other use of karst features including recreational use of caves in accordance with the forest management plan.

(k) To maintain cave and surface landform records within the context of (d) above. Locational information should be locked and generally unavailable to the general public and uninvolved government employees except insofar as may appear appropriate to the consultative group in specific cases after consultation with other involved parties such as the Speleological organisation.

(l) The authority will not advertise cave locations or otherwise encourage access to caves except in accordance with the specific initiative of the consultative committee following assessment of their values for particular purposes and the compatibility of those different uses.

(m) The authority will demand that persons visiting authority controlled sites, particularly caves, adhere to the spirit of the Speleological organisation Code of Ethics with respect to their impact upon the area.

(n) To specify appropriate responsibilities at forest managerial and operator/contractor levels.

(o) To facilitate the transfer of specific sites to the administration of alternative management authorities in any cases where the conservation significance of a particular site is high and the intensity of management required exceeds that which can reasonably be provided by the authority.

(p) To monitor and review the effectiveness of the foregoing procedures.

(q) To support research into karst environments.

3. Implementation

(a) Compilation of a data base

To enable better management of its karst forests the authority needs to gather two types of information. The first type of information consists of inventories of karst landforms and resources. These should be prepared for any areas which are likely to be subject to intensive forestry operations. Detailed operational planning and management can then be guided by these inventories. The second need is for information on the natural processes within the karst areas, upon the basis of which attempts may be made to gauge the magnitude of the impact of forestry operations. Karst areas generally facilitate the gathering of more complete quantitative data on overall erosion rates than do most other types of landscape hence more useful information with direct relevance to management can be compiled.

I. Karst inventories

(a) The following inventory sequence will be followed:

1. The karst area location maps provided to regional offices will be consulted by them as a matter of course and as early as possible in forest planning, and where this or some other factor gives reasonable grounds to believe that forestry operations may impinge upon karst lands or karst catchments the consultative group will be informed of this possibility.
2. Where the likely extension of forestry operations in or close to karst areas is confirmed, inventory procedures will be initiated involving firstly the location of karst landforms and secondly an assessment of site significance.
3. The inventory procedure will be initiated within the authority and co-ordinated by a designated authority officer.
4. Each site will be classified by the inventory coordinator after consultation with appropriate parties and subject to verification by the consultative group.
5. The consultative group will be responsible for the preparation, implementation and monitoring of surface management plans, and any detailed cave management plans.
6. Consideration will be given to the feasibility and desirability of integrating this data base with that of the relevant speleological organisation.

(b) The following inventory procedures will be adopted:

1. Surface landform details and specific cave details will be recorded on standard proformas.
2. These specific site inventories will not be considered complete until all spaces are notated.
3. There will be a need for regular review and updating of the proformas.
4. A permanent reference file will be established and retained only at Head Office and will include such things as:
   - inventory form
   - history
   - access details
   - cave maps
   - photographic record
   - entry records
   - management records
   - any other relevant data.
5. Cave entrances will be physically tagged with a corresponding file number in all cases where the continuation or otherwise of the cave cannot readily be ascertained from the surface. This numbering system will be integrated with that of the relevant speleological organisation.
6. Inventory data will be synthesised to provide the following data for management planning:
   I) the distribution of karst land forms, including the location, extent and directional trend of cave development;
   II) the pattern of apparent karst drainage, preferably with confirmation by water tracing experiments;
   III) the nature, thickness, stability and transmissivity of the surficial mantle;
   IV) the significance of the sites with respect to the values listed on the inventory form;
   V) the proposed classification of each site.
7. Detailed operational planning will not be implemented until stage (6) above has been attained.
8. Monitoring will be maintained with respect to the discovery of any new sites, new developments regarding the significance of known sites, and the effectiveness of management strategies implemented.

(c) The authority will encourage liaison and communication between itself and other karst users by:

1. Ensuring that both karst scientists and also recreational cavers are included in the consultative group, together with such other interests as may be appropriate in particular circumstances (e.g. water supply authorities; farmers).
2. Encouraging direct communication between other karst users (e.g. karst scientists and forestry companies) with the aim of minimising unnecessary adverse impacts and adversary relationships.
3. Appointing local and head office contact persons who will be responsible for initiating action on karst management issues and to liaise with various karst users.

II. Baseline data and monitoring procedures

1. The authority recognises the need for baseline data on undisturbed karst areas against which the impact of logging can be judged.
2. To this end the authority recognises that there exists a need to investigate the effects of forestry operations upon karst environments and in particular upon the stability of karst soils, upon the quantity, distribution and character of cave waters and upon cave organisms.
3. The authority will make every reasonable attempt to fully characterise a number of carefully selected and apparently representative drainage basins, caves and other sites; the need to record such information on a stable and long term basis is acknowledged.

4. The authority will also consider the establishment of experimental catchments to be harvested and monitored following an initial period of data collection under undisturbed conditions.

(b) Protection of soil and water values

Residual limestone soils on bare karst are commonly thin, slow to form and easily eroded.

While trees are a renewable resource, the soil in which they must grow is not, at least over a human time scale. Thin limestone soils cannot sustain pressure. On the other hand, some of the soils which form on some transported materials carried by natural agencies onto karst landscapes («mantled karst») are sufficiently thick to sustain some erosion, and even effect a moderately rapid recovery. But even here though there is need for caution. In both situations the soil mantle performs a vital role in regulating the flow of water which infiltrates underground and also determines its chemistry (important for instance in maintaining underground water supplies and in maintaining the attractive character of cave decoration and enabling the continued existance of cave fauna). The soil grains eroded from hillslopes might conceivably even block underground drainage routes in some circumstances, diverting streams and drying up springs or perhaps causing further erosion elsewhere by diverted water. The authority recognises that:

I. The maintenance of natural water flows and storages and the protection of soils is a fundamental requirement.

II. The possibility of soil erosion being caused by progressive site degeneration due to fires, insect and disease infestation and poor vegetation cover due to low soil nutrient status means that particular care needs to be exercised in forest management and monitoring in karst areas.

III. Disturbance by machinery is likely to be the most common cause of erosion and warrants particular attention.

IV. Limestone derived soils («bare karst» soils) are highly susceptible to erosion and if lost will not redevelop over a human time scale; transported mantle soils («mantled karst») may pose a lesser risk in some cases, but because of the karst context no covering mantle should be managed as if posing less than a moderate erosion risk even if soils formed on its dominant rock constituent are normally considered of low erosion risk.

V. Every effort will be made to ensure that steep exposed slopes and long exposed slopes are minimised; to adequately drain site works to prevent erosion and cave siltation; and to take every care to avoid landslides and other forms of slope failure which may damage karst soils and silt karst streams or block the exchange of air between caves and the outside environment.

VI. Works which will disturb the ground surface will be timed to coincide with periods when the risk of heavy rains is least; burning plans also need to minimise the risk of post-fire erosion.

VII. Because clearfelling may produce higher erosion potential than selective extraction, the latter may be preferable in sensitive karst areas.

VIII. The degree of site disturbance will be a function of the type of logging system used. Unplanned operations will not be permitted in karst forests or in sensitive karst catchment areas.

(c) Karst Reserves

I. The functions of karst reserves are to:

1. Maintain infiltration flows to underground conduits.
2. Maintain streamsink flows to underground conduits.
3. Filter out unnatural sediment and logging debris.
4. Ensure streambanks are not destabilised.
5. Give protection to shallow or otherwise delicate caves and underground watercourses.
6. Maintain stream shade and natural water temperatures to protect aquatic fauna.
7. Minimise ionic imbalance in karst waters which might adversely affect fauna and speleothems.
8. Ensure an adequate food supply is available for those cave species which feed outside and bring energy back to cave food chains.
9. Afford protection to significant surface karst plant and animal communities.
10. Prevent the clogging of air exchange between caves and the external environment or the opening up of new pathways for air movement.
11. Provide a mechanism for zoning hazardous areas «off limits» to forestry workers.
12. Protect the recreational, scientific or other potential of particular surface karst features.

II. Karst reserves should be established in the following cases:

1. All surface stream channels should be managed as «Defined Streams» irrespective of the length of the surface portion of their cour-

se, and irrespective of whether the channel conducts a permanent intermittent or ephemeral flow; any watercourse lying in a karst catchment area where logging over an area in excess of 20 ha is to occur within 2 km of the karst should also be defined.

2. Within reason, where natural standing water bodies occur.
3. Where sinkholes or other karst landforms have been assessed as significant to the local drainage.
4. Where thin cave roofs or unstable terrain susceptible to collapse makes logging operations potentially dangerous to a significant cave or to forestry workers.
5. Where the transmission of shock waves may cause damage to a significant cave.
6. In such other cases as may arise.

III. Appropriate sizes for karst reserves in particular circumstances involves all that land:

1. Within 60 metres of an active surface watercourse or within 40 metres of an inactive watercourse.
2. Within 40 m of any natural standing water body of significance.
3. Within 40 m of any sinkhole assessed to be significant.
4. Within 100 m of any significant cave.
5. Of such size over the roof of any significant cave as is necessary to protect the cave structure or any cave contents susceptible to vibration or other damage (eg. dehydration).
6. Of such size as is necessary or desirable to safeguard forestry workers in unstable or otherwise hazardous country.
7. These proposals represent standard minimum sizes adequate to ameliorate adverse environmental impacts when development is to occur. It is recognised that in some cases it will be appropriate to reserve larger areas (e.g. protection of complete drainage basins where the retention of baseline sites for scientific study or preservation of very important cave systems is required).

IV. Restrictions on karst reserves

1. No tree should be felled within any karst reserve, nor into any karst reserve.
2. Fire should not be permitted in any karst reserve (within reason).
3. No logging machinery or roads should enter karst reserves other than at designed and constructed stream crossings if these are totally unavoidable.
4. All care should be taken to minimise ground disturbance in the construction of stream crossings.
5. All care should be taken to ensure that human wastes, petroleum products, litter, herbicides and other pollutants (particularly eroded silt) do not enter karst reserves.

(d) Timber Harvesting

I. No roading or logging operation will commence until completion of the karst inventory and assessment procedures.

II. Roading operations will take into account the need for particular care to be taken in karst areas; road planners will be familiarised with the contents of this draft policy and necessary considerations for infrastructure development (Kiernan, this vol.).

III. Snig track planning should be fully integrated with road planning so as to minimise soil disturbance.

IV. Forest operators and contractors and (authority) field officers who are active in karst areas will be familiarised with the general contents and intent of this policy, and particularly operational guidelines to inform them of ways in which they may minimise their adverse impact upon the karst and also minimise the risk to their personal safety which may stem from working in such an environment.

V. In view of the risk inexperienced persons put themselves to in entering unknown caves, forest workers will be discouraged from entering caves; they will be encouraged to report their existance.

VI. No camps or living quarters will be established in karst forest areas, except where an existting settlement is present in which case all care should be taken to minimise any detrimental environmental impact even if the impact of other development is already severe. Any new development in such circumstances should aim to reduce the adverse impact of earlier development wherever possible.

VII. All waste materials sould be removed from karst areas. No dumping of refuse or ballast in sinkholes or other topographic lowpoints will occur.

(e) Forest Maintenance

I. As the soil must provide the medium for growth of forest crops all care will be taken to ensure that it is adequately protected from excessive compaction and redistribution by machine or erosion.

II. While most of Tasmania's commercial native forests are ecological pioneers which require a mineral seed bed and freedom from competing vegetation to establish, the quantity and chemistry of seepage and other waters may be changed as a consequence of regeneration burning. This may have adverse effects upon caves. Karst soils may suffer erosion and nutrient volatilisation. Slash burning should therefore not be carried out within bare karst areas steeper than about 15°, in close proximity to karst reserves or significant sinkholes, or on thinly mantled karst. This may entail the prior preparation of firebreaks.

III. Because the evolution of each karst environment is strongly influenced and controlled by the surface vegetation, and because insufficient data is as yet available on the relationship between tree species and ground water distribution and chemistry to demonstrate that cave decoration or biota will not be adversely affected, no major changes of forest type will be undertaken over significant caves, or in significant cave catchments. Pine plantations appear to have seriously dried out caves in some cases. There may be a case for delaying changes on bare karst or thinly mantled karst other than those which are of assistance to the gathering of process data.

IV. Because of the likelihood of increased evapotranspiration losses ultimately diminishing the supply of water to karst caves, regrowth denser than the natural cover will not be encouraged over known decorated caves.

V. Where slope stability is in question, advanced seedlings of fast growing species should be established after cutting.

VI. Fire management plans should aim to prevent fires extending onto bare karst or any karst reserve, the implications of karst should be considered in planning access routes, backburning and other procedures.

VII. Care is required in the management of animal pests because of the specialised conditions under which cave organisms have evolved and the sensitivity of cave ecosystems to disturbance.

1. Where toxic substances are used to minimise browsing by vertebrate animals or to inhibit insect attack or where herbicides are used, all cave entrances and karst streams should be avoided.
2. Great care is required to minimise the loss of those elements of the cave food web which feed outside as this may have grave implications for cave species with a low number of individuals.

VIII. The thin soils and rapid infiltration of moisture in karst areas may impose water stress, as a consequence the tolerance of tree and shrub species to a certain degree of attack by root rot fungi (e.g. by *Phytoph tora cinnamomi*) may be lower in karst areas. This may be significant both to some residual stands (e.g. on karst reserves) subject to microclimatic change due to adjacent clearfelling, and also to successful regeneration; particular care is warranted with respect to sanitary procedures. Although some evidence suggests that high calcium levels may be antagonistic to *Phytophtora* there may be little calcium in the soils of mantled karst.

IX. Management of pest problems should receive high priority in areas of unstable slopes or severe soil erosion.

(f) Management and Protection of Caves

I. Because cave decoration, certain cave deposits and cave biota are easily damaged by human traffic and because human visitors commonly inflict the greatest damage in this regard, the authority will develop and implement specific management strategies for individual caves: all management decisions will be the responsibility of the consultative group.

A specific cave management policy will need to be developed.

Acknowledgements

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THE PROBLEMS OF SOILS IN LIMESTONE AREA OF THE NANSEI SHOTO, SOUTHWEST JAPAN

by Kazuko URUSHIBARA-YOSHINO *

Resum

En les terrasses formades a Nansei Shoto (SW del Japó) a causa de l'aixecament de l'escull coral·lí, els sòls més antics tenen les següents característiques: tonalitat rojenca, quantitats més altes d'òxids de ferro lliures (Fe_2O_3 %) així com una major intensitat del pic corresponent a l'hematita. En les terrasses més recents els sòls són groguencs, però els òxids de ferro lliures (Fe_2O_3 %) són encara elevats amb una intensitat més alta del pic de la goethita.

Les àrees cobertes per sòls rojos (anomenats *Shimajiri-mâji*) en els esculls coral·lins aixecats, es veuen sovint afectades per la sequedat en les zones de conreu de canya de sucre. Per evitar els danys causats per l'aridesa s'ha mesclat *Jagar* (originat a partir de roques argiloses terciàries) amb els sòls rojos de les àrees de *Shimajiri-mâji*. No obstant això, la introducció de maquinària agrícola, les millores del sòl a gran escala i l'augment de la superfície conreada, han tengut per resultat una erosió accentuada del sòl en aquests camps. Endemés, els sòls arrossegats pels rius resulten perjudicials per a la pesca costanera i ocasionen l'extinció dels corals.

Abstract

Soils on the terraces formed from uplifted coral reef in the Nansei Shoto, SW Japan, have characters that hue of soils is more reddish, amounts of free iron oxides (Fe_2O_3 %) are higher, and peak intensity of hematite is higher on the older terraces. On the younger terraces, soils become yellowish hue, but free iron oxides (Fe_2O_3 %) are still higher with higher peak intensity of goethite.

The areas covered by red soils, called *Shimajiri-mâji*, on the uplifted coral reef suffer frequently from drought on the sugar cane cultivation. For avoid the damages by drought, *Jagar*, originated from Tertiary muddy rock, has been mixed into the red soils in the *Shimajiri-mâji* areas. However, introduction of machines for cultivation, soil amelioration in a large scale, and enlarging unit area of each fields have resulted in a large amount of soil erosion at the fields. Soils flowed from the rivers hinder coastal fishery and corals become extinct.

1. Characteristics of red soils formed from limestone in the Nansei Shoto and their climatic conditions

There are several terraces composed of uplifted coral reef in the Nansei Shoto. The highest coral terraces seem to be formed older than 230,000yr B.P. and then the formed ages of the coral terraces are; 125,000yr B.P., 100,000yr B.P., 80,000yr B.P., 60,000yr B.P. and 38,000yr B.P. Reddish soils are formed on the older terraces, but reddish-yellow soils on the younger terraces formed in the period from 125,000yr B.P. to 38,000yr B.P. Soil layer is thicker on the older, higher terraces and thinner on the younger, lower terraces.

The older the soils are, (I) the more reddish become, (II) the greater the Fe_2O_3 % and (III) the higher the peak intensity of hematite. These relationship between the properties of soils and hue is shown in Fig. 1. On the younger terraces, yellowish hue becomes stronger, but Fe_2O_3 % is still greater and the peak intensity of goethite is higher. From this, it is suggested that the free iron is contained as hematite in the soils on the older terraces, whereas as goethite in the soils on the younger terraces.

Climate conditions in the Nansei Shoto at pre-

* Department of Natural Sciences, The Komazawa University. Komazawa 1-23-1, Setagayaku. Tokyo, 154 Japan

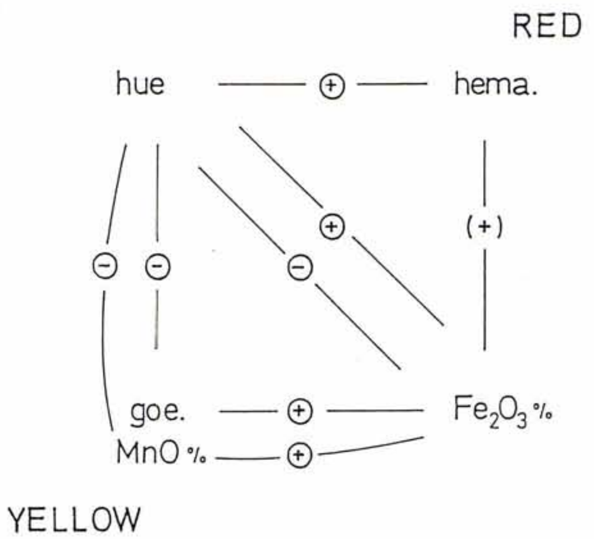

Figure 1. Relationship between hue and properties controlling the hue in the B_2 horizons in the Nansei Shoto.

sent are given by year climate for 1941-1970 by calculating water deficiency for each year based on the method by Thornthwaite (1948). The distribution shown in Fig. 2 reveals a tendency that the water deficiency is greater in the southern part of the Nansei Shoto. The high values of water deficiency in the Nansei Shoto occur in the years with scarce rainfall during the Baiu season, early summer rainy season, and with the infrequent typhoon visit during the months of August and September. If we calculate the normals of water deficiency by the mean values 1941-1970 based on the Thornthwaite's method, it is shown that the whole area of the Nansei Shoto is covered by 0 mm of water deficiency; which means a humid climate as a long-year mean state. However, in some years, there occur water deficiency and drought in the field of the limestone area formed by the uplifted coral reef. This will be dealt with in detail in the next part.

2. Red soils formed from limestone and agriculture

Taking an example from the Okinawa island located in the central part of Nansei Shoto, agricultural landuse is described with special regard to the soil groups. In the Okinawa island, there are four soil groups as shown in Fig. 3(a): (I) the reddish-yellow soil formed from the rocks excepting limestone. This is called «Kunigami-mâji». (II) Red soils formed from limestone. They are called «Shimajiri-mâji». (III) Bluish-brown «Jagar» formed from the Tertiary muddy rock. And (IV) alluvial soil.

Since frequency of drought occurrence is very high in the island in summer, sugar cane, which is

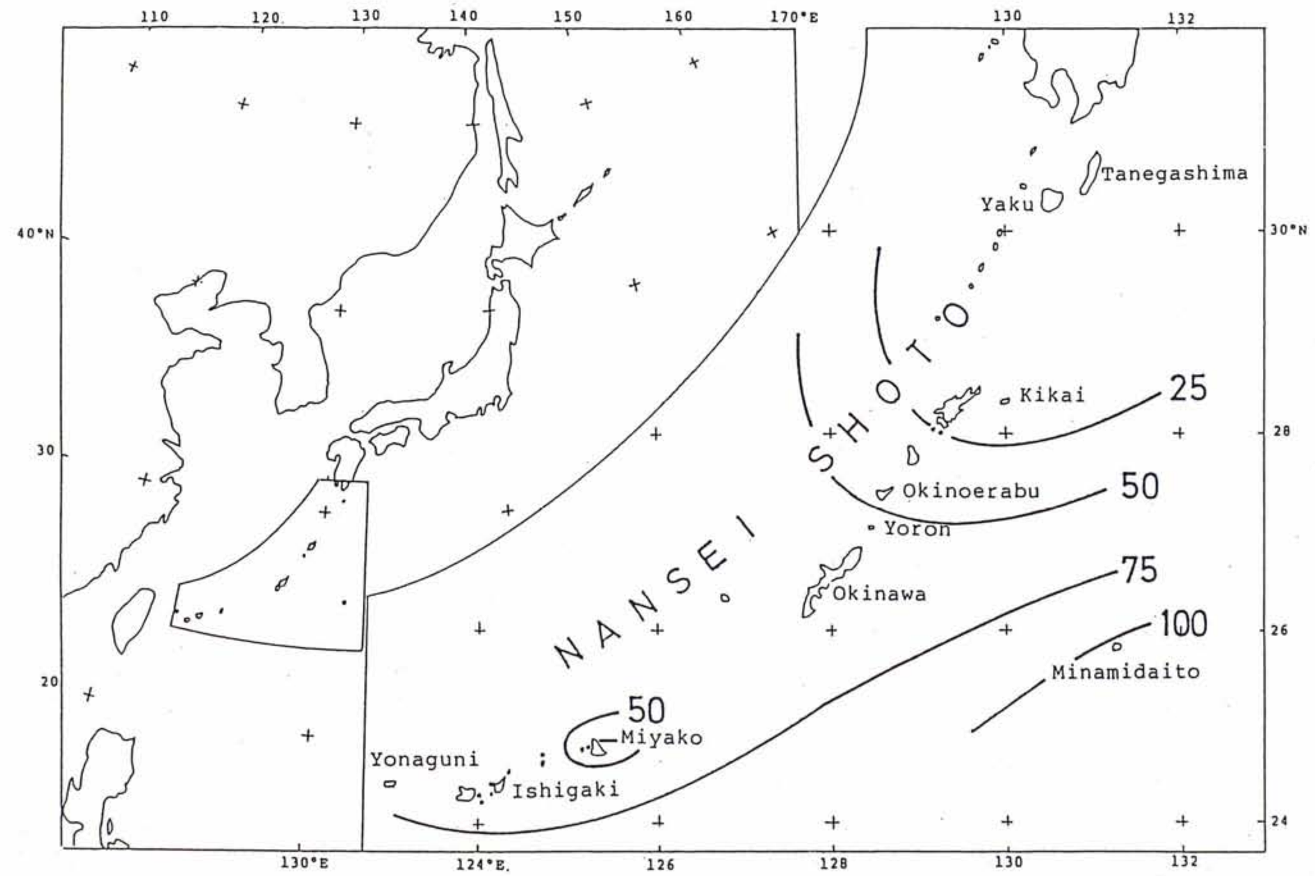

Figure 2. Distribution of water deficiency, d (mm), by the year climates during 1941-1970 around the Nansei Shoto.

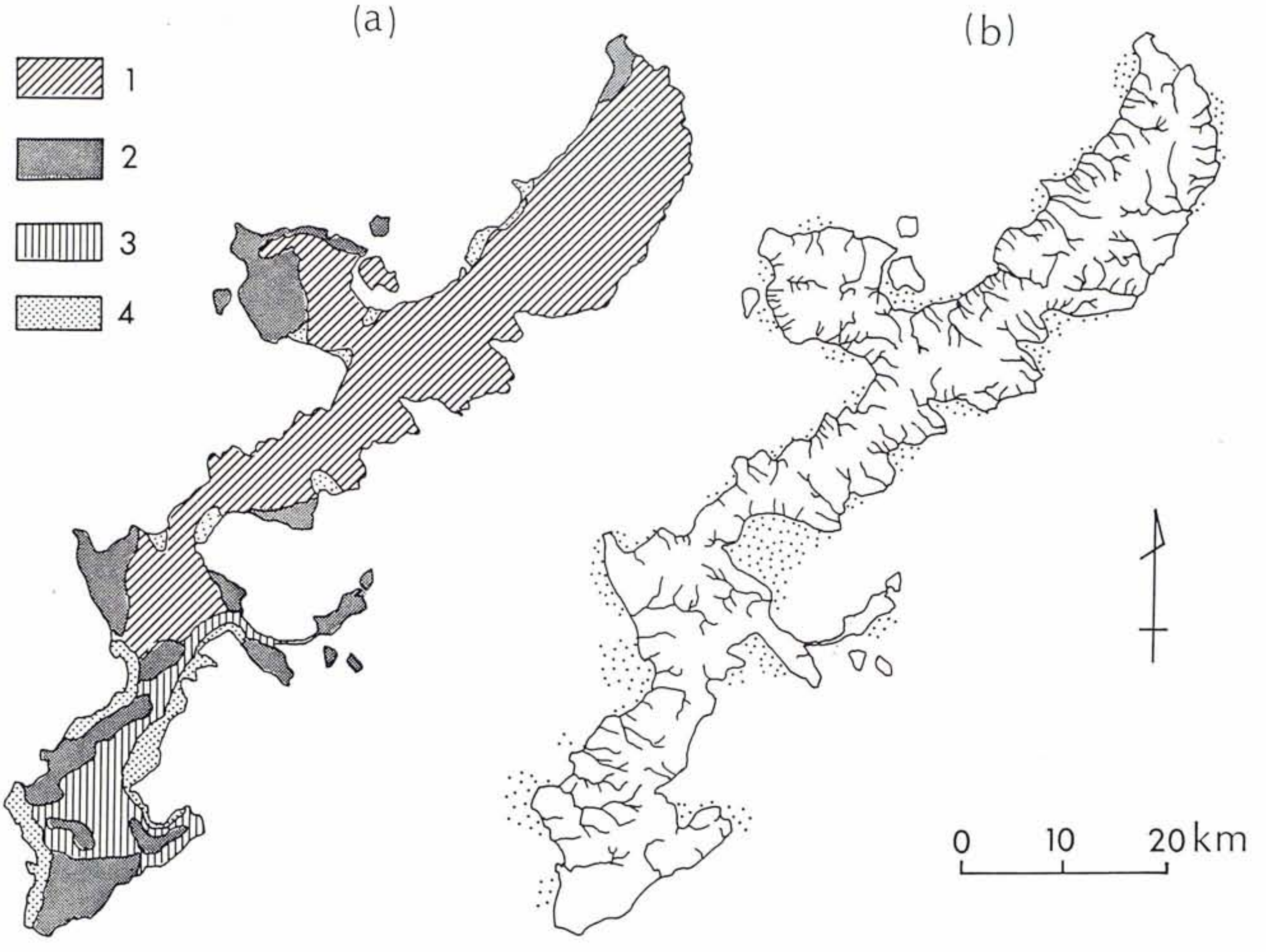

Figure 3. (a) Soil map of the Okinawa island (Okinawa Prefecture, 1978, modified by Urushibara)
1: Kunigami-mâji, 2: Shimajiri-mâji, 3: Jagar, 4: Alluvial soils and others.
(b) The distribution map of the areas where had be polluted with soils (Okinawa Prefecture, 1978).

stronger against drought, has been cultivated in the areas covered by the first three soil groups mentioned above. And rice, the main crops in Japan, cultivated in the area of alluvial soil for long years. However, the relationship between sugar cane yield and precipitation in the areas of each soil groups as shown in Fig. 4. Namely, the yield is the highest in the areas with Jagar, whenever precipitation is scarce or abundant in the summer months from May to September. These months include Baiu season, a rainy season in early summer, and typhoon season from late August to September.

It is said that the Kunigami-mâji is stronger for drought, but yield decreases sharply in the cases more precipitation. The fields in the areas covered by red soils formed from limestone, Karst areas, suffer from drought quite easily, but yield increases gradually up to some amount of precipitation. The Kunigami-mâji has low pH and soil layers are thick. Accordingly, the lower horizon has a higher density. This results in difficulty for drainage and decreases the yield when rainfall is abundant. Mean yield of sugar cane in the areas covered by Kunigami-mâji is 6.44 ton/10a. In this areas, acidophilous crops such as pinapple, tea, and citrus fruits are cultivated in addition to sugar cane.

Shimajiri-mâji in the Karst area shows weak acidity, but the thickness of the soil layer is relatively thin. This makes waterholding-power quite weak. In this connection, drought occurs frequently. Because of thin soil layer, introduction of machines is difficult. Mean yield of sugar cane is 5.07 ton/10a. Crops otherwise sugar cane are sweet potato, tabaco, etc., which have stronger resistance for drought.

Jagar is a weakly alkaline, heavy clay soil. It forms big soil blocks in the case of plowing and becomes very hard under the dry conditions. It is therefore very difficult to introduce machines from the viewpoint of physical features of soil texture. In spite of such unfavorable characteristics, yield of sugar cane in the fields of Jagar is higher; mean

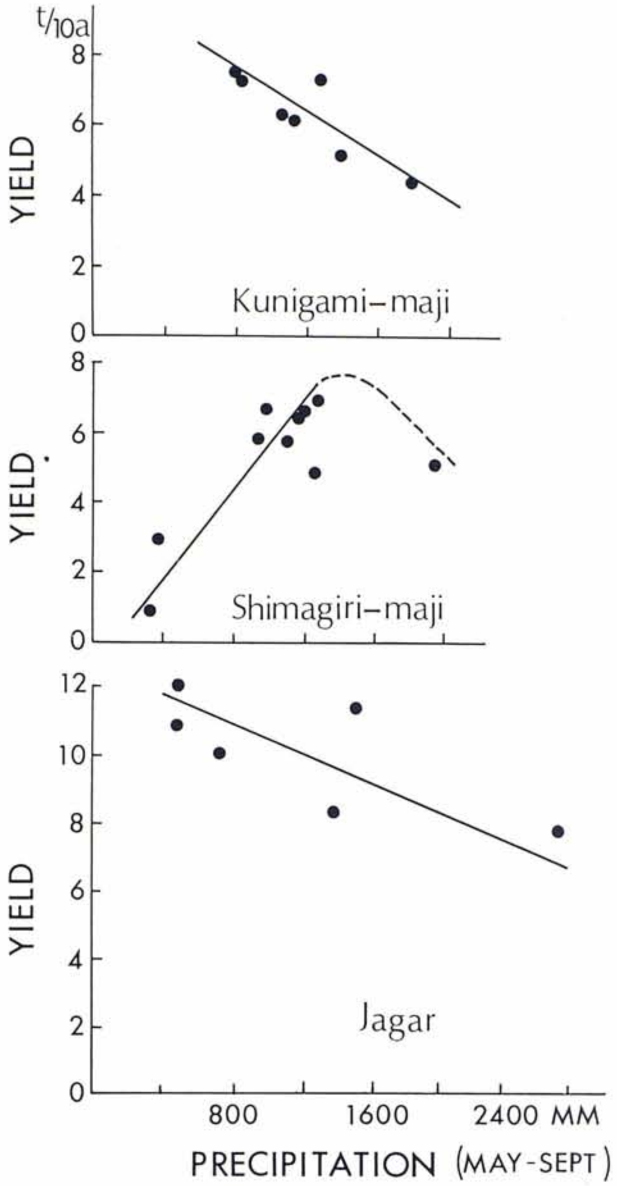

Figure 4. Relationship between yield of sugar canes and the precipitation from May to September (Okinawa Agricultural Cooperative Society, 1977).

yield is 9.64 ton/10a.

In 1950's, compost (artificial manure) was put in this area, but in 1960's, it changed to chemical manure mainly. Accordingly, it caused acidation and serious shortage of organic matters, microelements and available bacteria. Since the later half of 1970's, farmers have been reviving leguminous green manure and dung and urine from animal husbandry.

On the other hand, an attempt has been making to ameliorate soil which is weak to drought since the year about 1976. That is,weathered materials from Tertiary mud was mixed to Shimajiri-mâji in the limestone area where suffers frequently from drought, by the governmental support. These sequence is shown in Fig. 5. As a result, they have

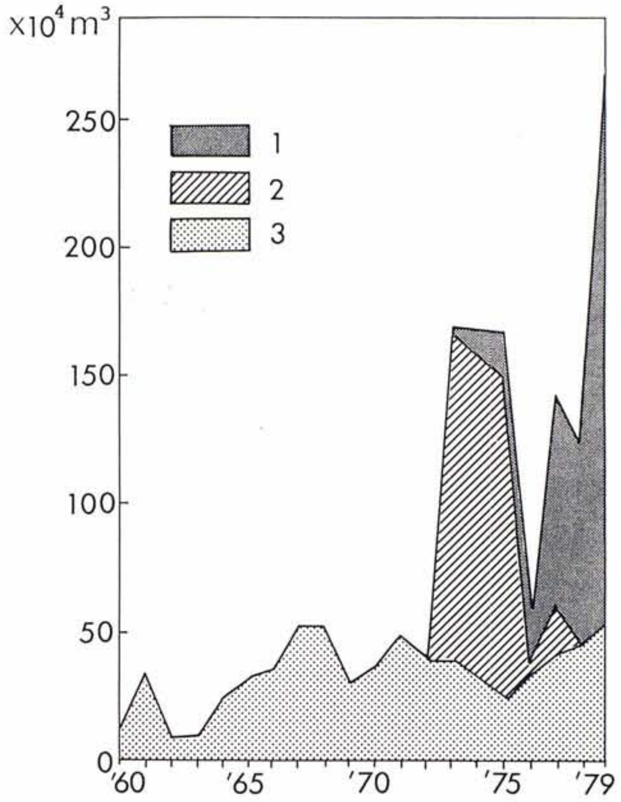

Figure 5. Variation of the estimated volume of transported soils (Mezaki, 1983).
1; caused by soil amelioration
2; from roads etc.
3; from pinapple fields

succeeded amelioration of soil texture and the yields are increasing. When Jagar was brought to improve Shimajiri-mâji, machines were used and the unit areas of the fields were broaden. Traditionally, the unit areas were small and the farmers built stone walls of limestone blocks along the hems of the fields. These way of cultivation protected the soil erosion and prevented the wash-out of soil. In 1980's, the improvement of Jagar into the soils formed from limestone is increasing conspicuously in the other islands in Nansei Shoto.

These result in the following problems: The amount of transported materials, such as sands, soils and muds, through the rivers in the Okinawa Island into the surrounding coast changed as shown in Fig. 5. It is clearly shown in this figure that soil erosion caused by enlarged pinapple fields in the Kunigami-mâji areas since 1960's, washed-out caused by the abrupt development of construction (mainly for Ocean-Expo) during 1972-1975, and washed-out caused by the soil improvement since 1976. The amount of washed-out materials caused by improvement of soils in the Shimajiri-mâji limestone areas is outstanding. These threaten coastal fishery and extinction of coral reef, even though the yields of sugar cane are increasing as a result of soil amelioration.

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