and 815 m deep. Further east, Ojo Guarena is the longest cave in Spain with a rambling maze of 97 km of mapped passages beneath a low escarpment.

Away from the main alpine fold mountains, the high Sierras of southern Spain are formed on huge tracts of limestone with karst landforms that are generally poorly developed in the hot and semi-arid climate. In the high Sierrania de Ronda, behind Malaga, the shafts and meanders of Sima GESM drop to a depth of 1098 m, while, along the coast to the east, the show cave of Nerja is noted for its very large stalactites.

Recent geomorphological and speleogenetic studies seems to confirm that the oldest generation of karst landforms was developed in the late Miocene. These include caves that survive only as tunnel fragments or as roofless caves. The Messinian regression rejuvenated the Western Alps with a lowering of the base level of karstification. In the Eastern Alps, it appears that a paleosurface developed by the early Oligocene has been preserved with minimal modification on some of the elevated karst plateaux. There are many detailed studies of the karst and caves in all parts of the Alps, but much remains to be explored and studied, and valuable results are coming from comparisons of the geomorphologies in the different areas of the region.

HUBERT TRIMMEL AND TONY WALTHAM

Further Reading

Audra, P. 1994. *Karsts alpins. Genèse de grands réseaux souterrains. Exemples: le Tennengebirge (Autriche), l'Ile de Crémieu, la Chartreuse et le Vercors (France), Thesis*, Paris: Fédération française de spéléologie and Bordeaux: Association française de karstologie (Karstologia Mémoires, 5)

Avias, J. 1972. Karst of France. In *Karst: Important Karst Regions of the Northern Hemisphere*, edited by M. Herak & V.T. Stringfield, Amsterdam and New York: Elsevier

Courbon, P., Chabert, C., Bosted, P. & Lindsley, K.1989. *Atlas of the Great Caves of the World*, St Louis, Missouri: Cave Books

Forti, P. & Sauro, U. 1996. The gypsum karst of Italy. *International Journal of Speleology*, 25(1–2): 239–50

Frisch, W., Kuhlemann, J., Dunkl, I. & Székely, B. 2001. The Dachstein paleosurface and the Augenstein Formation in the Northern Calcareous Alps: A mosaic stone in the geomorphological evolution of the Eastern Alps. *International Journal of Earth Sciences*, 90: 500–18

Kusch, H. & Kusch, I. 1998. *Höhlen der Steiermark: phantastische Welten*, Graz: Steirische erlagsgesellschaft

Salzburger Höhlenbuch, 1975–96. 6 vols. Salzburg: Landesverein für Höhlenkunde in Salzburg

Pavuza, R. (editor) 1993. *Akten des Symposiums über die Karstgebiete der Alpen: Gegenwart und Zukunft, Bad Aussee 1991*, Vienna: Verband Österreichischer Höhlenforscher

Puch, C. 1998. *Grandes cuevas y simas de España*, Barcelona: Espeleo Club de Gràcia

Wildberger A. & Preiswerk C. 1997. *Karst and Caves of Switzerland*, Basel: Speleo Projects

See also **Alpine Karst; Calcareous Alps, Austria**

EUROPE, BALKANS

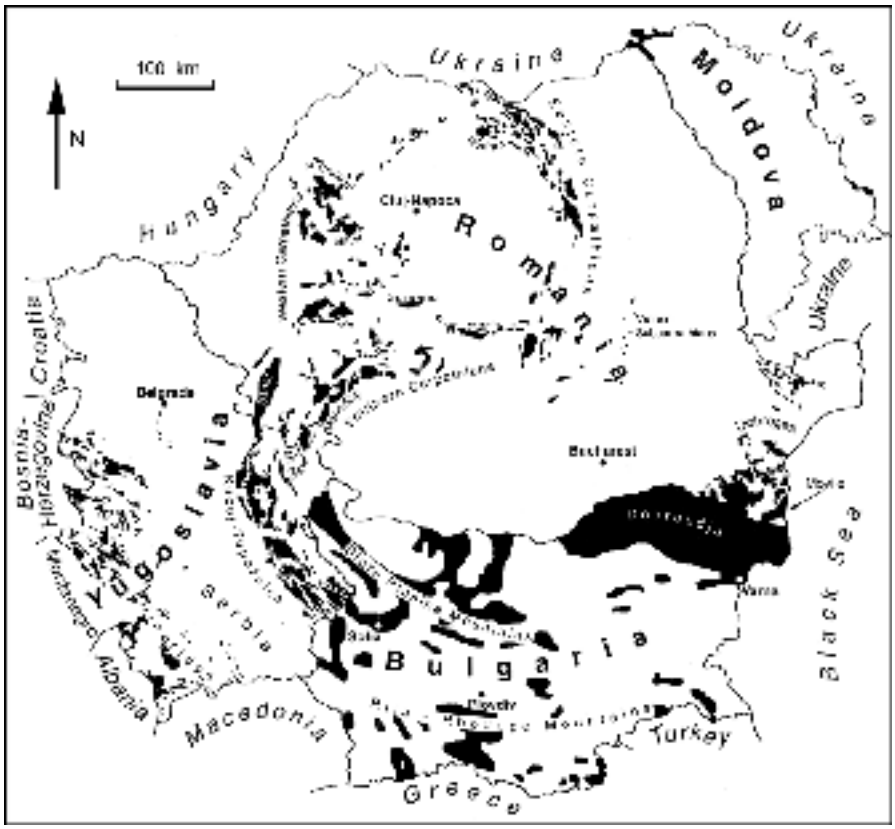
A long temperate karst belt extends through Romania, Moldova, Bulgaria, and former Yugoslavia (Figure 1). However, in the southernmost parts of Serbia and Bulgaria the climate is transitional between Mediterranean type and fully temperate continental type. Despite the complex geological background and the relatively low proportion of karst outcrops, more than 20 000 caves have been explored and mapped within this region. This figure may be due to a long tradition of speleological exploration and research. Notable scientists from the above-mentioned countries include Jovan Cviji[c3] (see Geoscientists) and Emil Racovi[t1][a5] (see Biospeleologists). In Bulgaria, where karst is widespread, the study of caves began early in 1878 when the Shkorpil brothers (Karel and Herman) wrote *Krazhki yavlenia*—the first book describing some of the Bulgarian caves. In Romania, by the end of the 1980s, a network of caving clubs had explored more than 12 000 caves. This shows that there may be great speleological potential in regions where there is only a relatively small area of exposed karst rocks.

The type of cave encountered in the Balkan region is related to the overall geological history of the area. Apart from the gypsum-karst area of Moldova, whose geological evolution is connected with a transition zone between the East European Platform and the Carpathian foredeep, the karst was strongly influenced by Tertiary uplift of the Carpathians and Balkans. This uplift has broken the unity of most stratigraphic units; thus breaking up the limestone outcrops between the high ridges and the slopes. In only a few cases was this continuity preserved, favouring deep drainage as within the Piatra Craiului Mountains of Romania, where *Avenul din Grind* (−540 m) is the deepest pothole in the region. For most mountain ranges in the area, an igneous or metamorphic core is surrounded by limestone. This setting favours the formation of relatively long caves with active passageways, often tiered and sometimes including mazes of relict passages richly decorated with speleothems.

Romania

About 2% of the exposed land surface of Romania consists of karst (Onac & Cocean, 1996), but this figure is misleading, as in many cases Neogene or Quaternary deposits overlie older formations, which include carbonate and evaporate karst-forming rocks. The most important karst rocks are Mesozoic limestones, but caves are also recorded in dolomites, halite, conglomerates, and sandstones. In Romania, karst is mainly developed in the southern and western Carpathians, with the largest limestone area being located in the Banat Mountains (adjacent to the border with the former Yugoslavia).

The karst plateaux contain karren, dolines, uvalas, and poljes, whose development was favoured by the great thickness of carbonate deposits (600 to 2000 m). These plateaus may be found at 800 to 1200 m altitude in the P[a5]durea Craiului, Mehedin[t1]i, and Bihor Mountains, and also at 1800 to 2200 m in the Retezat Mountains, which show typical alpine karst (Onac & Cocean, 1996). Karst ridges are mostly located on the slopes of the Carpathians, and they consist of long limestone ridges, isolated during the uplift of the mountain range. Surface rivers, formed on the crystalline basement, cut through the limestone ridges in spectacular gorges or, in many cases, through long caves. The most typical karst systems of this type appear in



Europe, Balkans: Figure 1. Map of the major karst areas in southeastern Europe.

Europe, Balkans: Figure 2. Phosphate deposits in Ciclovina Cave (the upper level of the deposit is covered by flowstone (Photo: Art Palmer).

Europe, Balkans The longest and deepest caves in southeastern Europe.

Length (m)			Depth (m)	
Romania				
1	Pe[s1]tera Vântului	48 000	1 Avenul din Grind	−540
2	Sistemul Humpleu[−] Poieni[t1]a	39 000	2 Pe[s1]tera T[a5]u[s1]oare	479 ([−] 373; +106)
3	Pe[s1]tera Hodobana	22 142	3 Avenul din Stanu Foncii	−339
Serbia				
1	Velika Klisura	8500	1 Velika Klisura	310 (+296; [−]14)
2	U[s2]a[c2]ki Pe[c3]inski Sistem	6185	2 Rakin Ponor	[−]285
3	Cerjanska Pe[c3]ina	6025	3 Jama na Duba[s2]nici	−276
Bulgaria				
1	Douhlata	18 000	1 Raytchova Doupka	−377
2	Orlova Chouka	13 437	2 Barkite 14	−350
3	Jagodinskata	8 501	3 Yamata	350
Moldova				
1	Zoloushka (Pe[s1]tera "Emil Racovi[t1][a5]")	92 000	1 Zoloushka (Pe[s1]tera "Emil Racovi[t1][a5]")	30

the Piatra Craiului, V[i3]lcan, Mehedin[t1]i, and [S1]ureanu Mountains of the southern Carpathians.

The most important karst of Romania is located in the western Carpathians, mainly in the P[a5]durea Craiului and Bihor Mountains. Bihor Mountains includes a high plateau with many 200–300-m deep potholes. Some of the potholes contain river passages that are several kilometres long; Avenul V5 is 225 m deep and 10 km long. The second longest cave of Romania is the Humpleu–Poieni[t1][a5] system (39 km, −308 m), which includes a 5-km long underground stream with more than 30 sumps. The main features of this cave are the huge rooms (the Giants Room is 573 × 111 × 35 m), as well as the richness and the variety of the speleothems. Among these are the remarkable calcite scalenohedron crystals, 30–80 cm long, which may weigh over 50 kg. Oxygen-isotope ratios reveal that they are of hydrothermal origin. Valea Rea Cave (19 km long), in the western Bihor Mountains is considered to be one of the world's richest cave with respect to its mineralogy. The 35 minerals described from this cave include barite, celestine, quartz, dickite, metatyuyamunite, gypsum, and malachite, with most of these supporting a hydrothermal genesis. In addition, the Bihor Mountains also host five caves with perennial ice deposits. The most famous is Ghe[t1]arul de la Sc[a5]ri[s1]oara, which contains an ice mass 75 000 cubic metres in volume. Pollen extracted from the lower part of the ice block gave an estimated age of 3500 years (Racovita & Onac, 2000).

The P[a5]durea Craiului Mountains have a karst terrain at altitudes of 400–800 m, where sinking streams follow long, branching, gently sloping caves, including Ciur Ponor (−203 m, 17 km) and Ponora[s1] (−211 m, 6 km). Pe[s1]tera Vântului (Wind Cave), Romania's longest cave, is a resurgence with over 50 km of passages. It is basically a single-stream passage paralleled by three relict levels displaying outstanding horizontal and vertical meanders, and is also notable for its mineralogy (Onac, 1996), and geomicrobiology (Manolache & Onac, 2000).

In the Eastern Carpathians, the only significant karst area is the Rodnei Mountains—a network of alpine ridges. Here several Eocene limestone bodies contain influent caves, including T[a5]u[s1]oare Cave (470 m deep and 16 km long), famous for its strange limestone balls, gypsum speleothems, and rare mirabilite, leonite, konyaite, and syngenite minerals (Onac *et al.*, 2001). Halite and gypsum occur in Miocene salt domes, diapirs, and massive salt beds protected by cap rocks. In the Vrancei Subcarpathians, the Pe[s1]tera 6S de la Mânz[a5]le[s1]ti (3234 m long) is the second-longest salt cave in the world. In the southeast of Dobrogea, Movile Cave, Romania (see separate entry) is a unique chemoautotrophically based cave ecosystem in which 34 invertebrate species are endemic.

In the [S1]ureanu Mountains, a high karst plateau (at an altitude of 800 to 1200 m) is divided into two by the deep Strei Gorge. The main underground system is the 10 km long [S1]ura Mare resurgence cave with a vertical range of 405 m. In the same area, Ciclovina Cave has been known since the late 19th century, when scientists visited it to search for cave bear bones and to investigate the 15–20-m thick phosphate deposit (Figure 2). Between 1912 and 1941 over 30 000 m^3 of guano phosphate were mined out and used as fertilizer, and thousands of cave bear skeletons from within the phosphate were ground up for the same purpose. In the upper layer of the phosphate deposit, Hallstadt ceramics, as well as skulls of *Homo sapiens fossilis* were found, and the cave is also famous for its many rare phosphate minerals, including crandallite, paratacamite, taranakite, collinsite, hydroxylellestadite, and berlinite.

On the Mehedin[t1]i Plateau in the southwestern Carpathians, the major cave system is Topolni[t1]a (20.5 km, −127 m), a three-level streamway that underlies a vast network of older passages. Spectacular karst landforms are concentrated at Ponoarele, including dissected limestone pavements, a natural bridge carrying a motor road, and the great lake of Z[a5]ton which is drained by the 5-km long Bulba Cave. In the same area, the richly decorated Cloa[s1]ni Cave is used by the Institute of Speleology as an underground laboratory.

Yugoslavia (Serbia, Kosovo)

In Serbia, carbonate rocks crop out over a total area of *c.*7803 km^2 in the Carpatho-Balkanides (eastern Serbia), and in the Inner Dinarides in the west (Figure 1). The most extensive karst, in Eastern Serbia, has swift-flowing springs (flow rates of 0.5–2 $m^2\ s^{-1}$), which drain massifs of Mesozoic limestone. The greatest concentration of long and deep caves occurs within the Miro[c3] carbonate platform—an impressive karst plateau cut by deep dolines, on the right bank of the Danube Gorge. Six small parallel streams, originating on the impervious basement, sink into the limestone, forming essentially vertical caves with some large active passages. Among them, Rakin Ponor is the second deepest cave in the country (−285 m) and Buronov Ponor (2.4 km, −187 m) is a beautiful cave, richly decorated, that intercepts the principal river with an average flow of *c.* 1 $m^3\ s^{-1}$ (Zlokolica *et al.*, 1996). The resurgence lies 5 m below the present level of Danube in the artificial lake of the Iron Gates Dam.

The Ku[c2]aj–Tupa[z1]nica carbonate platform is the continuation of the Banat karst in Romania, and contains most of Serbia's caves. In the Ku[c2]aj Mountains, the Duba[s2]nica pothole (−276 m) consists of large shafts, including a single drop of 120 m. In the same area, Bogovinska Pe[c3]ina (5842 m long) is a complex resurgence cave developed on three levels. The vauclusian karst spring, Vrelo Krupac, at the foot of Mount Svrliji[s2]ke Planine, discharges 150 $l\ s^{-1}$ and has been explored by diving down to −83 m. On Mount Kalafat, the third-longest Serbian cave, Cerjanska Pe[c3]ina (6025 m), is an active swallet with extensive allogenic sediments.

In the Inner Dinarides, the limestones are Triassic in age, and important karst areas include Leli[c3] and the Gilijeva mountain. The karst of Pe[s2]ter plateau contains the U[s2]a[c2]ki Pe[c3]-inski system (6185 m), which includes an active passage from sink to resurgence.

The western part of Kosovo seems to be the area with the greatest speleological potential—not yet explored due to political instability in the area. Velika Klisura (8500 m long, 310 m deep), is the most important major cave, situated close to the border with Montenegro.

Bulgaria

Bulgaria has outcrops of carbonate rocks across 24% of its territory, hosting over 5000 caves. Mesozoic carbonate rocks form the main karst in the Stara Planina Mountains. There is a marked distinction between the karst and caves of the Stara Planina, in the central part of Bulgaria, and those of the Rilo-Rhodopes Mountains in the south. The most important caves in Bulgaria, including the longest (Douhlata Cave which is 18 km long) and

the deepest (Raitchova Doupka, −377 m) are located in the western and central part of Stara Planina. The Shopov cave system (in the western part of Stara Planina) is considered to be one of the world's most mineralogically rich caves, with 41 mineral species, 18 of these being described only from that locality (Shopov, 1988). The upper part of the cave has a hydrothermal origin, while the lower levels are formed by the dissolution of sulfuric acid produced by oxidation of iron sulfides in the upper part of the cave.

The large unbroken covered karst of the Dobroudja is characterized by a few short caves, dry valleys and the presence of a sulfidic water aquifer at a depth of 400 m. Along the Danube Plain, Orlova Chuka Cave (near Ruse) in Lower Cretaceous limestone is 13 437 m long, and Magura Cave (2500 m long, near Vidin) is renowned for its wonderful Neolithic and bronze age guano paintings.

In the western part of the Rhodopes Mountains and the northern part of the Pirin Mountains, karst develops on the Proterozoic marbles. Of the 50 known caves in the area, more than 10 are of hydrothermal origin. Historically, the Romans mined these for lead ore. The marble sequence in the Pirin Mountains is over 2000 m thick, with the potential for hosting some of the world's deepest caves. The Pirin National Park was founded in 1963 and added to UNESCO's World Heritage List in 1983. It hosts diverse and unique landscapes, including some 70 glacial lakes, caves, waterfalls, and pine forests. It is also the home to hundreds of endemic and rare species, many of which are representative of the Balkan Pleistocene flora. Unfortunately cave ice seals all of the high-altitude caves. In the eastern part of Rhodopes Mountains, more than 250 caves are known. The largest karst area in the Rilo-Rhodopes is south of Plovdiv, where the Trigrad Plateau (at an altitude of 1500 m) is an old corrosion surface that is now breached by hundreds of dolines and cut by several canyons 300 to 400 m deep (Nicod, 1982). The largest cave in the region is Jagodinskata (8500 m long).

Paleokarst is widely documented in Bulgaria, mainly from boreholes and mining activities. Mineral deposits connected with paleokarst include metasomatic lead–zinc ores, bauxites, gypsum, kaolin, and iron ore.

Moldova

Karst research in Moldova has received little attention, because the rocks that are susceptible to karstification crop out only in small areas in the northwest of the country and along the Nistru Valley in the east (Figure 1). The karst features develop on Miocene gypsum (10–40 m thick) (Andrejchuk & Klimchouk, 1996) and the development of caves began under deep-seated conditions during the Pliocene. Following the Prut Valley entrenchment into the gypsum during the Late Pleistocene, karstification processes were stimulated. Apart from the Zoloushka Cave (known as "Emil Racovi[t1][a5]" Cave by the Moldavian speleologists), which is 92 km in length (and similar to the Ukraine gypsum caves), all of the other caves are small.

BOGDAN P. ONAC AND SILVIU CONSTANTIN

Works Cited

Andrejchuk, V. & Klimchouk, A. 1996. Gypsum karst of the Eastern-European Plain. *International Journal of Speleology*, 25(3–4): 251–61

Manolache, E. & Onac, B.P. 2000. Geomicrobiology of black sediments in Vântului Cave (Romania): Preliminary results. *Cave and Karst Science*, 27(3): 109–12

Nicod, J. 1982. Canyons et grottes du plateau de Trigrad (Rhodope central, Bulgarie). *Revue de Géographie Alpine*, 70(3): 227–31

Onac, B.P. 1996. Mineralogy of speleothems from caves in P[a5]durea Craiului Mountains (Romania), and their palaeoclimatic significance. *Cave Science*, 24(3): 109–24

Onac, B.P. & Cocean, P. 1996. Une vue global sur le karst roumain. *Kras i Speleologia*, 8(17): 105–12

Onac, B.P., White, W.B. & Viehmann, I. 2001. Leonite [$K_2Mg(SO_4)_24H_2O$], konyaite [$Na_2Mg(SO_4)_25H_2O$] and syngenite [$K_2Ca(SO_4)_2H_2O$] from Tausoare Cave, Rodnei Mts, Romania. *Mineralogical Magazine*, 65(1): 103–09

Racovita, G. & Onac, B.P. 2000. *Scarisoara Glacier Cave Monographic Study*, Cluj-Napoca: Editoria Carpatica

Shopov, Y.Y. 1988. Bulgarian cave minerals. *National Speleological Society Bulletin*, 50: 21–24

Zlokolica, M., Mandi[c3], M. & Ljubojevi[c3], V. 1996. Some significant caves at the western rim of the Miro[c3] karst (Yugoslavia). *Theoretical and Applied Karstology*, 9: 77–88

Further Reading

Bleahu, M.D. 1972. Karst of Rumania. In *Important Karst Regions of the Northern Hemisphere*, edited by M. Herak & V.T. Stringfield, Amsterdam and New York: Elsevier

Constantin, S. & Mitrofan, H. 1994. Romania. *The International Caver*, 12: 26–30

Djurovi[c3], P. (editor) 1999. *Speleological Atlas of Serbia*, Belgrade: Jovan Cviji[c3] Geographical Institute of the Serbian Academy of Sciences (in Serbian and English)

Gavrilovi[c3], D. 1976. The karst of Serbia. *Memoires of the Serbian Geographical Society*, 13: 1–28

Goran, C. 1983. Les types de relief karstique de Roumanie. *Travaux de l'Institute de Spéologie "Emile Racovitza"*, 12: 91–102

Jalov, A. 1993. La spéléologie en Bulgarie. *Spelunca*, 52: 23–26

Stevanovi[c3], Z., Dragisi[c3], V., Dokmanovi[c3], P., & Mandi[c3], M. 1996. Hydrogeology of Miro[c3] karst massif, eastern Serbia, Yugoslavia. *Theoretical and Applied Karstology*, 9: 89–96

See also **Dinaric Karst; Europe, Mediterranean**

EUROPE, CENTRAL

Central Europe covers Austria outside the Alps, Czechia, Hungary, Poland, and Slovakia. The region is a complex of karst areas covering the old Middle European Platform as well as the younger Western Carpathians and Carpathian Basin. Karst and cave areas are irregularly distributed (see Figure). The largest carbonate karst areas outcropping on the surface occur in southern Poland and in Slovakia (8000 km^2 and 2700 km^2, respectively). Although 15% of Austria is underlain by karstified rocks, only a tiny part of this karst lies outside the Alps. Carbonate rocks crop out over some 1.5% (1350 km^2) of Hungary. In Czechia, limestone and dolomite outcrops support karsts of minor importance (less than 0.4% of territory, about 300 km^2),