

POTASH DEPOSITS IN SPAIN.

By HOYT S. GALE.

INTRODUCTION.

The announcement of the discovery of potash in deposits in the Province of Barcelona, in Catalonia, in the northeast corner of Spain, appeared in print in 1913 with the publication of the first of two excellent reports on the subject by engineers of the Instituto geológico de España.¹ There has been much discussion of the salt deposits of the region, which have long attracted attention as showing very remarkable features, and the series of publications concerning them includes papers by Trail in 1814, Cordier in 1817, Dufrénoy in 1831, Toschi in 1845, and numerous others in a series reaching down to the present time. The potash associated with these salt deposits was recognized in 1912, and then only by accident as a result of development to enlarge the production of salt.

LOCATION AND ACCESS.

The Spanish potash field, as now defined, lies north to northwest of Barcelona, in an area extending approximately from east to west between the towns of Vich and Balaguer. The area thus defined is about 75 miles long, and the claims or concessions, though of irregular shape, form a practically continuous belt with a maximum width between Manresa and Cardona of about 15 to 18 miles. The general situation of the field is represented on the accompanying index map (fig. 1).

The principal discoveries of potash have been made in the immediate vicinity of the villages of Cardona and Suria. These places are 40 to 45 miles in a direct line northwest of Barcelona. One of the two main lines of railway between Barcelona and Zaragoza, which are the direct routes between Barcelona and Madrid, is the Ferrocarril del Norte, which skirts the southern border of the potash field. This line runs northward from Barcelona through Sabadell

¹ Rubio, César, and Marín, Agustín, Sales potásicas en Cataluña: Inst. geol. España Bol., vol. 34, pp. 173-280, 1913; Sales potásicas de Cataluña: Idem, vol. 39, pp. 1-38, 1918.

and Tarrasa to Manresa, all important cotton-weaving and manufacturing communities. At Manresa the railway turns west, passing through Lerida. Both Cardona and Suria, where the potash has been found, lie in the valley of Cardoner River and are reached by motor omnibus or "diligence" over an ordinary country road following the river. Manresa is 40 miles by rail from Barcelona, and train service is frequent and fairly satisfactory. Suria is 9 miles and Cardona about 20 miles north of Manresa. A branch railway is

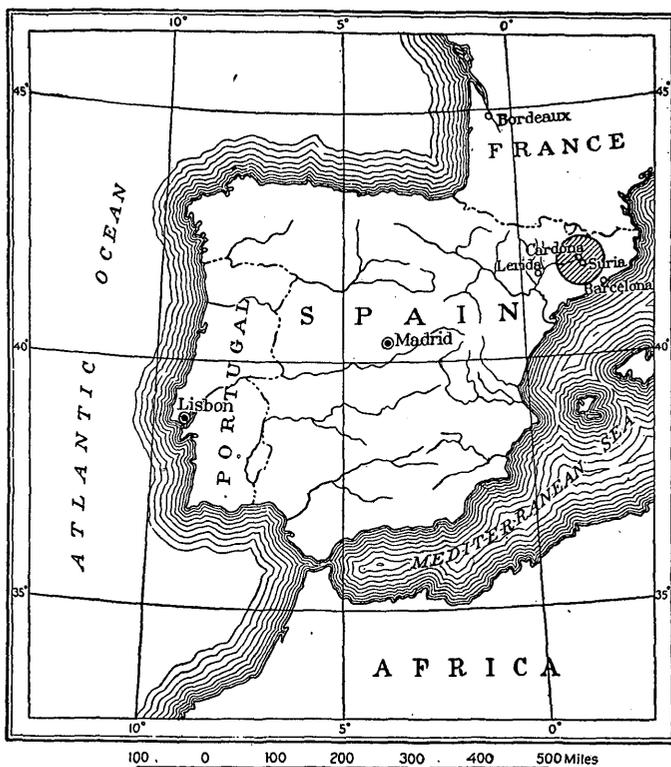


FIGURE 1.—Index map of Spain showing the situation of the potash deposits of Catalonia.

now under construction from Manresa to Suria, put in primarily on account of the potash developments now going on at Suria.

There is a comfortable hotel of the local country type at Manresa, and a similar smaller one at Cardona. In 1919 automobiles were to be hired at Manresa for 1.25 to 1.50 pesetas a kilometer, which is equivalent to about 40 cents or more in United States money for each mile traveled, no account being taken of the time required for stops if these are not considered out of proportion to the length of the trip. Roads through the country are passable for automobiles, but that is about as far as a recommendation can go.

OWNERSHIP.

A large area of concessions has already been ceded to private claimants by the Spanish Government. After the first rush to appropriate these mineral lands restriction was put on the granting of further rights. A tract reserved by the State is defined as that included by straight boundaries joining the towns of Vich, Berga, Isona, Balaguer, Tarrega, Igualada, and Manresa. This includes a total area of about 1,800 square miles. Much of this tract is undoubtedly not potash bearing, but it includes in a general way the formations similar to those containing the salts at Cardona and Suria and is a provisionally outlined field reserved for further exploration. An area of 350 to 400 square miles is outlined in the map of concessions already granted. Private interests or foreign governments are invited to participate in the development or operation of the field, under specific regulations of the State and local governments as to manner and regularity of operation and the price and distribution of the product. This phase of the subject is discussed more at length in the section entitled "Spanish legislation" (p. 15).

The principal owners of concessions in the Spanish potash field are as follows:

Solvay & Cie., 33 Rue du Prince Albert, Brussels, Belgium. This is the well-known Franco-Belgian syndicate which already operates in Spain in the subsidiary soda works at Santander. The local representatives of the potash properties are Eudoro G. Lefèvre, Belgian consul at Barcelona, and Luis Dupont, local director of the property at Suria.

La Sociedad Fodina, which has engaged in exploring concessions ceded to Francisco Ripoll and Ignacio Marinello, of Barcelona. This concern is understood to be a subsidiary of or closely allied to the Sociedad Electro-Química de Flix, Calle de la Princesa 21, Barcelona. The last-named company is listed as a manufacturer of caustic and industrial chemical products, presumably fertilizer materials, and is said to have strong German affiliations.

La Sociedad General de Industria y Comercio, a Spanish and French company, with headquarters at Villanueva 11, Madrid. This company is engaged in the manufacture of fertilizers, explosives, and other chemical products, and has plants at Balboa, Barcelona, and in other parts of Spain.

La Compañía de la Salina de Cardona is the old salt company that has been mining and shipping rock salt for many years from the celebrated salt mountain of Cardona. The property belongs to the Duque de Tarifa. The local administrator is Juan Ratera Cendra, at Cardona.

La Minera, a German organization, is reported to be a subsidiary of one of the potash companies in Germany and therefore allied to the German Kali-syndikat. La Minera controls an extensive area of concessions in various parts of the Spanish field.

The American Agricultural Chemical Co., 92 State Street, Boston, Mass., holds concessions in the name of Roberto Sturz Bradley. Two properties called the Filadelfia and the Boston cover territory adjacent to or intermediate between areas in which the recorded discoveries of potash salts have been made.

Besides those named above there are other less extensive holdings, listed under the names of Juan Vives, René Paulus, and Demetrio Castellana Moreno, and there are also some concessions originally held for coal that may include potash.

A quotation from a royal order of December 14, 1918,¹ gives a list of concessionaires containing only three names, one of which is not included in the foregoing record, as follows:

Solvay & Cie., Minas de Suria, Santander, Spain.

Sociedad Anónima Fodina, Lauria 21, Barcelona, Spain.

Sociedad Anónima La Sevillana, Trafalgar 11, Barcelona, Spain.

It is not clear whether this is a revision or curtailment of the list of concessionaires or whether the quotation referred to is incomplete.

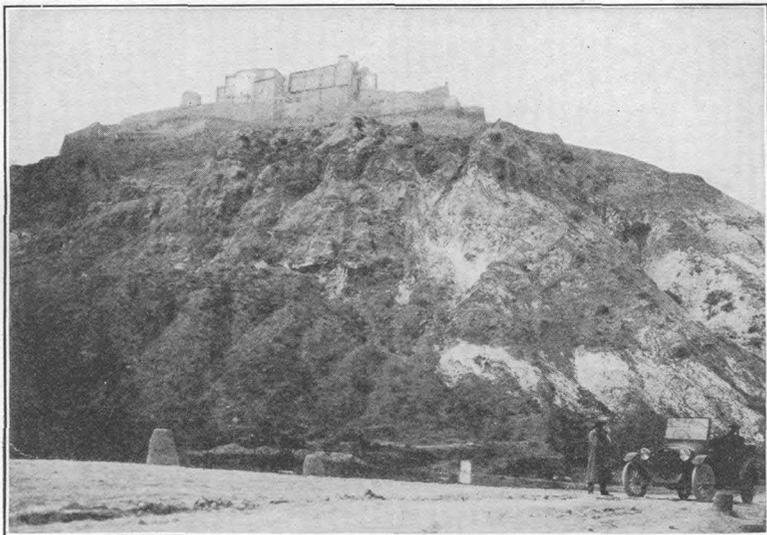
THE SALT MOUNTAIN AT CARDONA.

"La montaña de sal de Cardona," described by Calderón² as a veritable mountain of salt 80 meters high and 4 kilometers in circumference, has been one of the renowned natural features of Catalonia since a very early date. (See Pl. I, B.) Baedeker says that this phenomenon is mentioned by Strabo, quoting a reference to Book III of his geographic works, which the writer has not been able to verify. The occurrence of mineral salt in Turdetania is mentioned by Strabo also, but this is the region about Cordoba and Cadiz. The mining of salt from the Cardona deposit is a very old industry and is still carried on, both for local consumption and for export. The title to this property is apparently a local hereditary right, having recently passed from the Duque de Medinaceli to the Duque de Tarifa.

Cardona (judicial district of Berga, Province of Barcelona) is an old fortified town perched on the summit of an almost isolated hill in a bend of Cardoner River, 600 feet above the river level. The town is surrounded by a wall and dominated at the very summit by an interesting old castle (el castillo). (See Pl. I, A.) The wagon road encircles the base of the hill and climbs the steep north slope, entering the town through a gate. Trails descend the precipitous south slope from a gate in the wall on the south side. In clear weather there is a wonderful view from the old castle, with Cardoner River stretching away in either direction in the foreground, and beyond it, to the north, the distant snow-capped peaks of the Pyrenees. To the south and southwest the town overlooks, at the very foot of the hill on which it is situated, a peculiar depression, which is the salt basin, the "salina de Cardona." At the farther end of this basin is a great whitish-looking scar lying against the mountain side, and this is the famous mountain of salt. It is a great natural out-

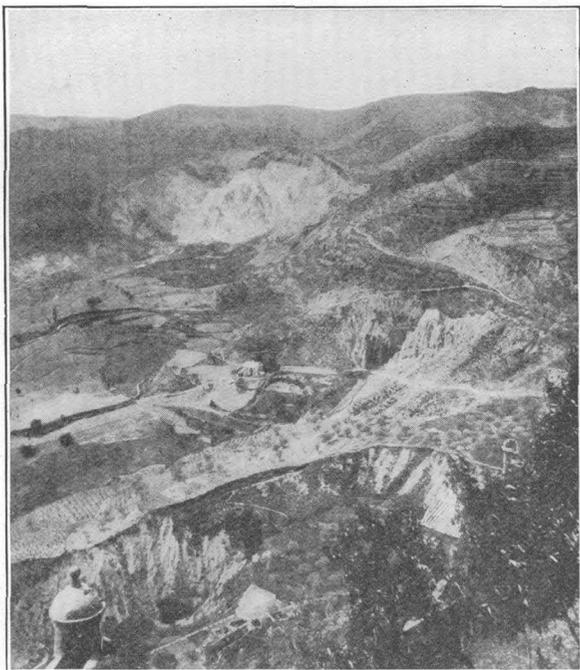
¹ Commerce Repts., Apr. 10, 1919.

² Los minerales de España, vol. 1, p. 385, 1910.



A. OUTCROP OF ROCK SALT BY THE ROADSIDE AT THE FOOT OF THE BLUFF BELOW THE OLD CASTLE, CARDONA, SPAIN.

The beds overlying the salt are exposed in the slopes above. Kilometer post 30, from Manresa, by roadside.



B. THE SALT MOUNTAIN AT CARDONA, SPAIN, FROM THE CASTLE OVERLOOKING THE SALT BASIN.

The white mass at the farther end of the low basin-like valley is a natural exposure of massive bedded rock salt, the basin being the excavation by solution of the salt exposed along an anticlinal axis that plunges at either end. (See fig. 2.)

crop of rock salt which occurs as an interstratified part of the sedimentary rock section. It is brought to the surface along the crest of a distinct anticlinal fold, the structure of which is perfectly evident in the dip and stratification of the series of sandstones and shales which overlie it and whose outcrops encircle the basin in regular form. Smaller exposures of rock salt occur at many places in the bottom or on the lower slopes of the basin. Just at the foot of the hill below the castle is a large funnel-shaped sink hole.

The salt is mined in solid form and is sawed or hewn into regular-sized blocks for shipment. The Spanish yearbook (*Anuario general de España*) for 1917 says in reference to Cardona: "It owes its renown to its famous mountains of salt, from which there are extracted 40,000 quintals annually." The salt blocks are said to be chiefly exported to Africa, where salt is prized in this form. The industry is limited, however, by the cost of transportation. Salt from this source was supplied to the American Army in France during the recent war, and it is said that production was pushed to the capacity of the equipment.

The upper layers of the deposit are a composite of relatively thin bands of variously colored salts and interstratified layers of gypsum and clay. Red and white are the prevailing colors, but there is much gray and some orange or salmon-yellow. (See p. 8.) These upper salt layers appear in a strangely contorted mass. Under them there is a great compact mass of white transparent salt which is very pure. The salt mined is obtained from the lower layers. According to report, the mining was formerly done in a large open pit, the salt being cut in steps or terraces, but now it is obtained by underground mining. These workings now have a depth of 50 meters, and the whole depth, it is claimed, is cut in solid salt without the intercalation of any other substance.

The accompanying sketch map (fig. 2) was prepared by the writer from a pocket-compass traverse made at the time of his visit. It shows the general outline of the outcrop of the salt and the situation of the basin with respect to the valley of Cardoner River and the town of Cardona.

The salt basin is the eroded axis of a well-defined anticline. Apparently the massive rock salt is the lowest member of the section exposed by erosion and solution along the axis of this fold. The center of the valley is to a considerable extent covered by detritus of red clay, but the salt shows at the surface in many places. The topographic basin thus formed is almost surrounded by rugged walls exhibiting the dark-red sandstone ledges, which dip outward in all directions from the axis. At the east end the valley opens by a relatively narrow gap into the valley of the Cardoner, which is almost a gorge at this place. The axis of the fold apparently

plunges here, but the outcrop of the salts clearly has been intersected by the river channel, where the salt has of course been dissolved away. Singularly, however, the salt is exposed in massive ledges at the base of the hill below the castle, just above the level of the river. The Cardoner is a full-flowing stream of fresh water, and the region is very far from having the appearance of a desert. The river derives its water mainly from the higher mountains to the north, and the rainfall in this particular region must be slight, or so much salt would not be preserved at the surface. A small

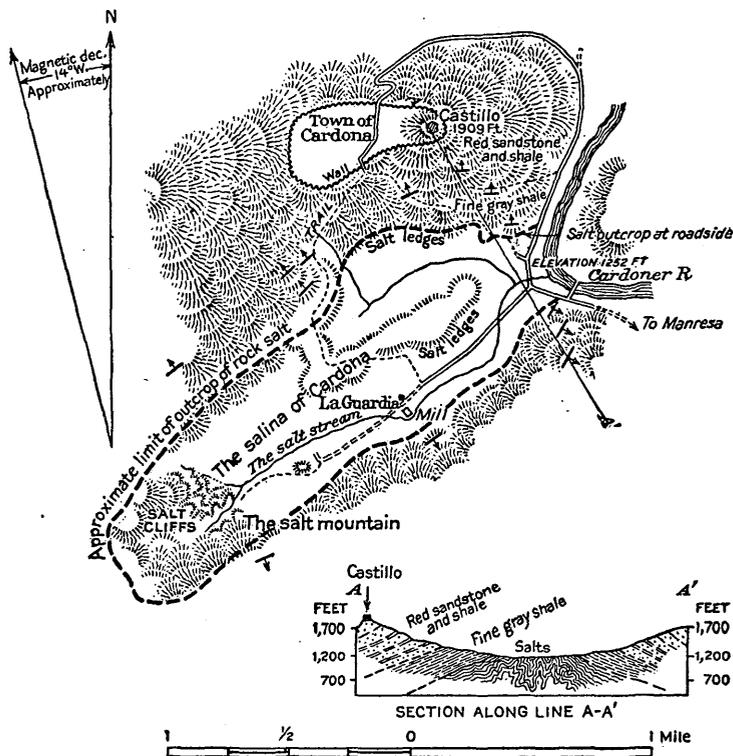
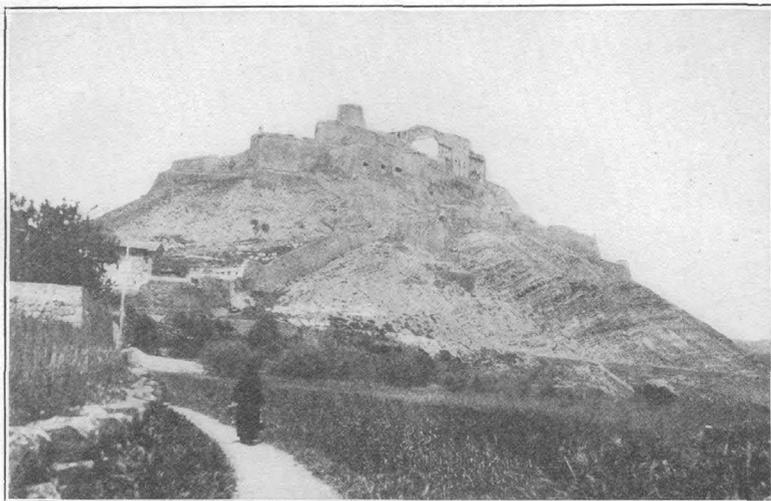


FIGURE 2.—Sketch map of the "salina de Cardona," Spain.

stream, which is a saturated solution of salts, flows from the salt outcrops down through the salt basin and enters Cardoner River.

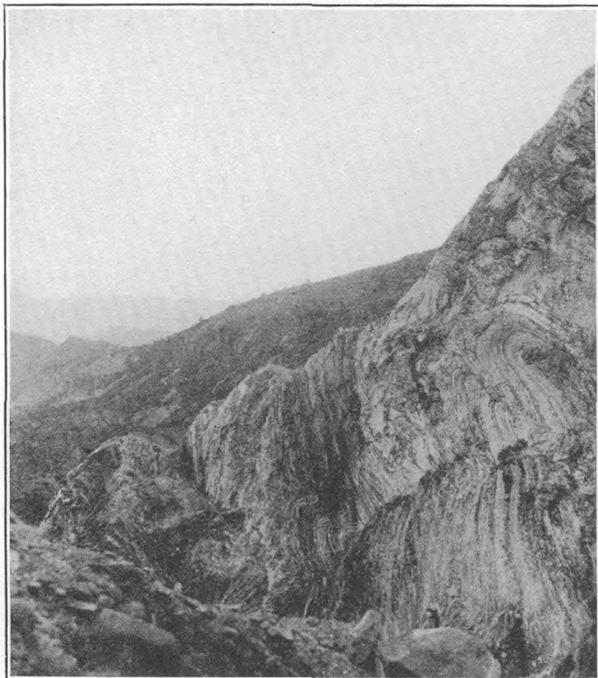
The view in Plate II, A, shows the outcrops of salt and the overlying shales, gypsum, and sandstone in the bluff at the base of the hill below the castle, at the outlet to the salt basin.

The stratigraphic section exposed in the bluff below the castle is represented in the cross section attached to the sketch map of the salt basin. This section apparently represents at least those members numbered 4 to 8, inclusive, of the general section given on page 13. By rough computation from the data obtained in making the sketch map, the section exposed here totals about 1,800 feet of



A. OUTCROP OF TILTED SANDSTONES OVERLYING THE LIGHT-COLORED SHALE AND SALT BEDS, AS EXPOSED IN THE BLUFF BELOW THE OLD CASTLE AT CARDONA, SPAIN.

View from the trail on a level with the lower part of town just outside the south gate.



B. CONTORTED BEDDING OF THE SALT IN THE CLIFFS AT THE HEAD OF THE SALT BASIN OF CARDONA, SPAIN

stratigraphic thickness, but the thickness can be obtained very much more accurately with more careful measurements.

Little seems to be known about the total thickness of the salt beds. The cliff at the head of the salt basin is made up of banded salts in a strangely contorted mass. The convolutions of the bedding of the salt are exhibited by distinct color banding of the salt layers and by the interlaminated seams of clay and gypsum, so that in parts of the mass the display is very fantastic. This contortion illustrates the plasticity of salt under such compression as has been exerted on it in the folding of these rocks. No estimate of the normal thickness of the whole could be obtained from such a mass. Such folding is probably extreme in the axis of the fold and possibly would not extend far on either flank of the simple anticline. The sandstones and interbedded shales that overlie the salt appear to be quite normal and regular at either side of the valley.

Plate II, *B*, is a view of the contorted bedding in the salt cliffs at the head of the salt basin. It also shows farther in the distance the profile of the slope bordering the south side of the basin, with the salt and soft shale below the cap of the more resistant sandstones above.

The evidence of the existence of potash in the Cardona deposit is not very definite. This may be because of lack of adequate investigation at this locality or the potash may not be present in large amount in this part of the field. As has been said, this exposure gives one of the most favorable opportunities in the field for observation of the general relations of the salt and the overlying beds. It is an epitome of the Spanish field, whether the potash is found in commercial quantity at this locality or not.

Rubio, in his report already referred to, quotes some analyses of samples from both red and white specimens from the Cardona deposit, which shows the existence of very pure chloride of potassium at this locality. He states, however, that these were found only in a small area, and it was said locally that the potash had so far been found only in very thin seams in this deposit. Analysis of the salts in solution in the little brine stream that flows from the big salt cliff is stated to have shown 81.65 grams of potassium chloride per liter of the solution. This seems to be saturation with respect to potassium chloride, but in any solution this depends on the amount and nature of the other salts present, particularly magnesium chloride, the amount of which is not stated in this analysis. The amount of the potash indicated is high in any case. Samples of the rusty-red and white banded salts (*B* in the following table) collected by the writer have given no significant test for potash, and the same is true of a sample of a clear granular salmon-colored salt (*A* in the following table) which is conspicuous in the outcrops.

Composition of two samples from upper colored part of the salt deposit at Cardona.

[Collected by Hoyt S. Gale; analyzed by E. Theodore Erickson.]

Determinations.			Calculated salts.		
	A.	B.		A.	B.
K.....	0.12	0.10	KCl.....	0.23	0.19
Na.....	39.00	37.98	NaCl.....	99.03	96.38
Ca.....	.08	.54	MgCl ₂.....	.12	.08
Mg.....	.03	.02	Na ₂ SO ₄.....	.12	1.19
Cl.....	60.27	58.61	CaSO ₄.....	.27	1.83
SO ₄.....	.27	1.42	Undetermined (moisture and insoluble matter).	.23	1.33
Undetermined (moisture and insoluble matter).	.23	1.33			
	100.00	100.00		100.00	100.00

These samples are therefore without special significance of positive value. They show that some of the red and white banded salts so conspicuous in the deposit at Cardona and some of the clear salmon-colored bands are essentially sodium chloride, the red and white salts carrying a little gypsum and insoluble matter.

The value and workability of the potash beds in the Cardona region are therefore still problematic, but there is an excellent prospect at this locality that seems worthy of exploration.

POTASH PROSPECTS AT SURIA.

The discovery of potash in the Spanish field was first made at Suria in 1912, by accident. In attempting to open a mine for common salt, at a site where there had been some ancient salt workings, Macary & Viader sunk some borings and a shaft that revealed the potash salts, and it appears that these were very shortly recognized as potash. An investigation carried out in 1913-14 by a French association resulted in the application for and granting of a concession near the village of Suria, which was later enlarged, and concessions in other parts of the field were added to it. This group combined interest with the Belgian Solvay Co., and the subsequent explorations in the field have been conducted by the Solvay Co., principally in the immediate vicinity of Suria. The discoveries at Suria, of which there are now available only the records of the old shaft sunk for salt, and the borings sunk on the Solvay Co.'s concessions constitute about the only evidence of the existence of potash in quantity in the Spanish field. These holes have been filled and carefully sealed to prevent damage to the deposit by water, and no new evidence is to be had from them. The records available have been published in the reports of Rubio and Marín already referred to. Such records are difficult to interpret correctly, even when all the evidence concerning them is at hand, but there is no doubt that the existence of potash in considerable masses has been demonstrated.

The valley of Cardoner River broadens in the vicinity of Suria in a way that is very clearly related to the structural geology. The gentle undulations of the strata bordering the valley below Suria give place to a marked flexure with steeply tilted bedding as the town is approached from the south. Sharp folds and an overthrust fault, the axes of which lie directly in the channel of the river or branch from that channel as a center, have brought the lower part of the Tertiary section, including the gypsum and the salts, together with the potash salts, close to the surface. The southern flank of the southern of two anticlines, which is itself a somewhat cross-folded structure, overrides a distinct and regular anticlinal axis to the north. The overthrust on the south is the greater of the two uplifts and would undoubtedly reveal the salt and potash beds in natural outcrops in much the same way as at Cardona, except that at Suria the river has had much more effective access to the axes of these folds and has naturally dissolved and carried off practically all the evidence of the salt at the surface. The broadening of the valley of Cardoner River at Suria, as also of the valley of its little tributary the Rivera de Terdell, is the result of the removal of the salts and the soft shales overlying them through solution and erosion by the river water.

The description of the old shaft sunk for salt and the record that has been published and repeatedly quoted are complete, so far as that evidence goes. This shaft was sunk at the edge of the river-bottom lands, only a few yards above the water level. It is surprising that the strata cut were so impervious that water did not at once filter into the hole, but on the contrary the shaft remained open long enough for the cutting of a cross gallery and the later boring of drill holes to extend the exploration in the bottom and at the end of the gallery. The shaft was subsequently flooded from some unknown cause and has now been filled and sealed.

This working is near an axis of prominent folding of the strata, and it is to be expected that the salts encountered would be found to be extremely contorted, as they are in the axis of the fold at Cardona. The record of the old shaft and of the adjacent borings bears out this supposition, as illustrated by the following quotation:¹

The principal pit cut the salt at 68 meters. At 66 meters a cross gallery was started in the direction N. 25° W. Thus far the shaft was cut through shale, as also was the first 2 meters of the gallery. Beyond the shale, in the gallery, there was encountered 2 meters of salt and anhydrite, and then 6 to 8 meters of impure common salt mixed with anhydrite, and beyond this the first portion of potash salts. In the plan [accompanying the report referred to] the details of this section are given, but it should be explained that these layers are by no means regular or susceptible of being exactly gaged. They are found at places in bands, and at other places in irregularly folded bands, and in many places they appear as a cement between fragments of salt. In the

¹ Rubio, César, and Marín, Agustín, *op. cit.* (vol. 34), p. 192.

latter the carnallite has filled up the crevices in the salt, showing the existence of areas of secondary deposition. The formation in the cross gallery has a very pronounced dip to the south of about 70° , which is believed to be due to undulations or secondary folds like those at Cardona.

This shaft has now been supplemented by some 15 borings, mostly in the immediate vicinity of Suria, and nearly all of these are reported to have shown sylvinite and carnallite in fairly regular beds, so that in the main these beds could be correlated from place to place. The contorted beds, it is said, are confined to the axes of the folds. There are in general two beds of carnallite and a lower bed, in some places two, of sylvinite. The carnallite zone, containing workable beds 3 meters or more in thickness, averages 12 per cent potash (K_2O) as shown by taking a weighted average from the core samples so as to represent all the material removed from the section indicated. The sylvinite, in beds of 2 meters or more in thickness, is reported as averaging at least 20 per cent potash, and certain portions containing much purer material were found. Tonnage estimates of the reserve supply in the concession at Suria have been based on the evidence that is summarized above. The evidence was deemed sufficiently good to justify a company with a reputation for competence and conservatism in proceeding with some rather extensive plans for actual commercial operation in its property.

At the time of the writer's visit, in May, 1919, a standard mining shaft, which was begun in April, 1918, had reached a depth of about 60 meters. Permanent foundations for a refining plant and substantial dwellings and offices for staff and employees were also being erected. The shaft has not yet reached the depth at which it was expected to encounter the potash, but water was flowing from a zone at about the level of the river, and the work going on at the time consisted chiefly in the attempt to seal this out.

The new shaft at Suria is about 1,500 feet a little west of north from the old shaft but is started farther from the river and on higher ground. It lies in approximately the same stratigraphic position as the old working and probably encounters a similar section, with some variation in detail. This work is being started on the border of the zone of most intensive folding, near the axes of the anticlines, and the salt beds may be expected to show more or less folded and contorted structure. Probably it will be possible to extend the workings underground laterally until areas of more regular structure are reached, if complications are found to interfere with the mining of the potash.

The area at Suria considered as proved by these prospects is about 3,500 hectares (8,648.6 acres), which according to optimistic reports of interested engineers establishes the existence of potash-bearing strata of an aggregate thickness of 80 to 200 meters, having a potential production of 200,000,000 tons of pure potash (K_2O).

OTHER DEPOSITS.

Aside from the two localities at Suria and Cardona, which are only 7 or 8 miles apart in an air line, the field covered by concessions reaches about 30 miles to the east and 45 miles to the west, the locations being based rather on the extension of similar geologic formations with some evidence of salt, gypsum, and the shales associated with the salt, than on specific discoveries of the potash. A good deal of boring has already been done throughout this area, mostly with essentially negative results, but a few more positive indications have been found. The principal evidence of the existence of potash outside the valley of Cardoner River is at Villanueva de la Aguda, a village situated near a locally well-known brine spring a little over 20 miles west of Cardona. The brine is reported to carry 4.1 grams of potassium chloride per liter, which is not necessarily an exceptional indication. However, a boring put down by La Sociedad Fodina is reported to have cut two layers of potash salts, the first at a depth of 303 meters and the second at 654 meters. The boring was continued to a depth of 737 meters and was discontinued while still penetrating massive salt. The information as to the thickness or character of the potash seems to be rather meager.

Many of the borings have shown the extension of the massive rock salt deposits or of gypsum and salt mixed, and there is always the possibility that the record is incomplete through failure to reach sufficient depth or for other reasons.

GENERAL GEOLOGY OF THE FIELD.

An extensive basin of Tertiary sediments in northeastern Spain is limited on the north by the east-west axis of the Pyrenees Mountains, which is a well-defined anticlinal fold exposing the Paleozoic rocks, gneisses, and granitic rocks along its crest. This great low area extends eastward from the valley of Ebro River and is sharply delimited on the south by the coast ranges of Catalonia. The Mediterranean coast is bordered by a belt of low but rugged mountains, which is clearly an upfaulted mass of the older sediments and igneous rocks, complex in details but forming a distinct structural unit. The interior basin is bounded on the west by the midland plateau of Spain, but it reaches far to the northwest up the present valley of the Ebro. This area of the younger (Tertiary) sediments reaches eastward into a triangular apex north of Barcelona, practically inclosed between the two mountain belts of older rocks. The drainage of this great interior basin combines along its axis into a few major streams, which break through the coast ranges in narrow channels, to the Mediterranean. These features are represented on the accompanying map (fig. 3) showing in a generalized way the geology of this region.

From these conditions it seems quite likely that during some portion of earlier Tertiary time in this region the Ebro basin may have been occupied either by a continental sea or by a great gulf with narrow passages connecting it with the ocean. According to the observations of European geologists the uplifting of the great anticlinal folds that give rise to the Pyrenees Mountains began in the Eocene but took place principally in Oligocene time. Thick salt and gypsum deposits are found among the sediments laid down in this basin during Eocene and Oligocene time. Thus the earth movements gave rise to inclosed areas where the evaporation of saline waters left thick deposits of crystallized salts, and in at least some

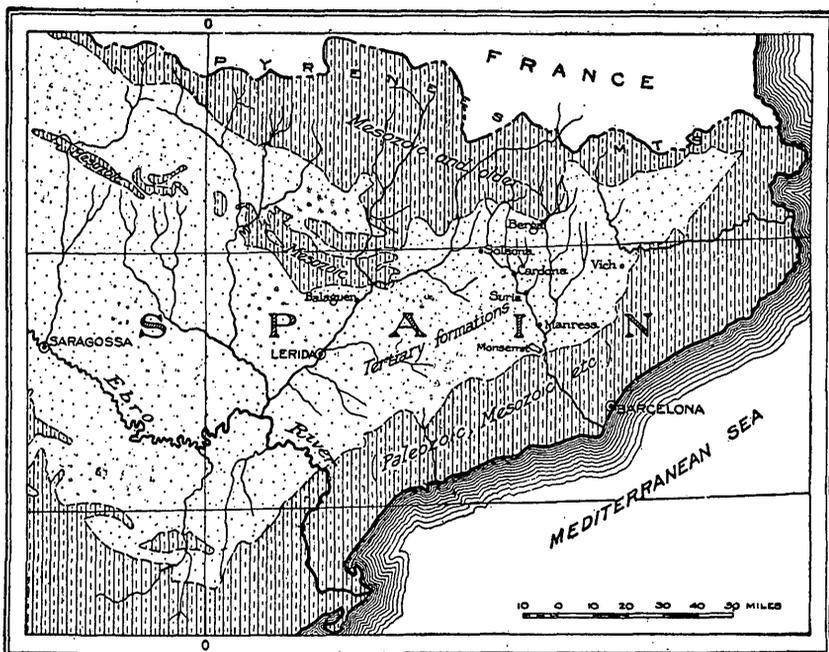
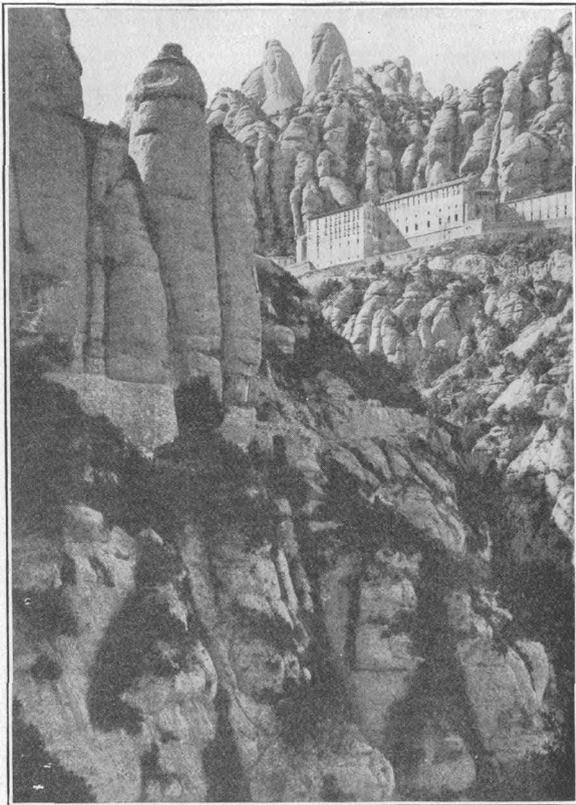


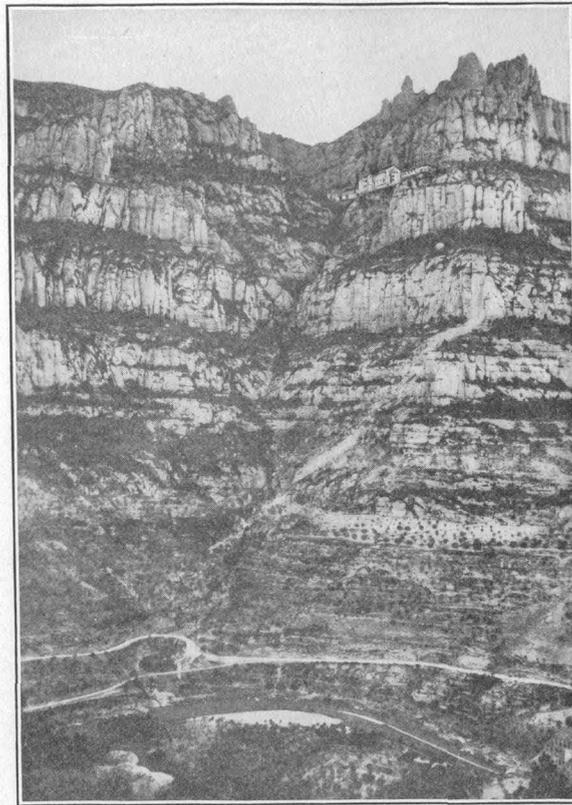
FIGURE 3.—Map of the northeastern part of Spain, with geology generalized from the Carte géologique internationale de l'Europe.

parts of these areas this process was continued to a stage at which the potash and magnesian residues of the mother liquor brines were also crystallized. The historical record seems fairly clear in its major aspects.

The section of Tertiary rocks, which is well exhibited, includes near its base a great mass of thick-bedded sandstones and conglomerates with interbedded shales. These are conspicuously exposed in the Monserrat, a prominent landmark northwest of Barcelona. This escarpment of massive beds dipping gently toward the north is the approximate southern margin of the basin of Tertiary rocks. On the south slope of the Monserrat the rocks tilt up sharply to a vertical position and the section is cut off by the fault-



A. THE MONASTERY.



B. SECTION OF CONGLOMERATE AND SANDSTONE LEDGES THAT FORM THE LOWER PART OF THE TERTIARY SECTION.

THE MONSERRAT ESCARPMENT NEAR MANRESA, SPAIN.

ing up of the older schists and formations involved in the coast belt. From Monistrol, on the railway between Barcelona and Manresa, a fine view of the Monserrat is obtained, showing an extensive cross section of the massive sandstone and conglomerates. (See Pl. III.)

The base of this whole series is found at Olesa, where the Monserrat sandstones, conglomerates, and red shales bend sharply into a vertical position and grade downward into ribs of massive limestone and intervening bands of deep maroon-red shale, which traverse the hills from east to west and evidently terminate against a fault. From the Monserrat to Manresa the section seems to be continuous. The summit topography, formed on the massive sandstone section, gradually dips with the dip of the strata, and the strata of the Monserrat summit reach and dip below the level of the river. The conglomerates grade into finer materials toward the north, indicating that the source of these sediments was to the south, and the Monserrat cliffs are evidently an enlarged development which may be represented by a much thinner section of sediments in the interior of the basin of deposition.

In order to identify the position of the salt beds and the associated potash, and to trace the extent of the field in which they will be found, it seems necessary that the section beginning with the sandstones and shales exposed at Manresa as a base and extending to the top of the series represented in the field should be studied in detail. The following section is given as it is published by the Spanish geologists and paleontologists.¹ The youngest beds are at the top of the section.

Stratigraphic section in potash region of Spain.

1. "Molasas," soft gray and red shales, as represented by an exposure at Lerida.
2. "Molasas" and limestone with fossil bones, as represented by an exposure at Tarrega.
3. Reddish sandstones, with brown coal and fossils, represented by an exposure at Calaf.
4. "Molasas," limestones, shales with fossil *Melania*, *Planorbis*, *Limnea*, and a layer with *Melanoides albigensis*.
5. Sandstone, conglomerate, shale, and red clay.
6. Red gypsiferous shale and gypsum.
7. Bluish-gray shale, which overlies the salts at Suria and Cardona and is also exposed at Tora and Villanueva de la Aguda.
8. Massive rock salt, with portions consisting of salts of potash and magnesia, the latter perhaps less extensively distributed than the salt and presumably found on the upper part of this section.
9. Shales, defined as marine Eocene, represented in exposures at Manresa, Vich, Igualada, and other places.

¹ Rubio, César, and Marín, Agustín, Sales potásicas en Cataluña: Inst. geol. España Bol., vol. 34, pp. 173-230, 1913; Sales potásicas de Cataluña; Idem, vol. 39, pp. 1-38, 1918.

The brief time spent by the writer in this field was not sufficient to permit the compilation of an independent stratigraphic classification, but it would undoubtedly be possible to trace and map certain lithologic units which would give valuable clues as to the depth and distribution of the salts. Figures showing thickness of the units in this section are not given and could not be obtained but are important now for practical considerations.

The section of these Tertiary rocks is made conspicuous by a prevailing deep-red color in the weathered surfaces, so that the series superficially resembles the so-called red beds of the Triassic or Permo-Triassic of the United States. Aside from the general similarity of the rocks and their manner of exposure, both periods were characterized by the deposition of salts and gypsum.

As will be seen from the detailed stratigraphic section, the salt, including the potash, occurs rather low in a complex series of sandstones, conglomerates, shales, clays, and some limestone and gypsum. Several of these zones are convenient markers by which to trace from the surface the position of the underlying salts. Immediately over the salt beds is a section of 50 to 100 feet or more of bluish-gray shale, that readily disintegrates on exposure into a very light colored, almost white mud, and where this shale crops out the proximity of the salt may be assumed. In the rocks overlying this shale there is, at both Suria and Cardona and apparently elsewhere, a prominent bed of gypsum, and above that a bed of fossiliferous limestone. The whole section overlying the salts is made conspicuous by the presence of many massive sandstone members, and these chiefly determine the topography of the region. The structure as a whole is that of gently dipping beds with slight undulations, so that the higher sandstones and conglomerates, by their resistance to erosion, have produced an upland of generally level tops, divided by the steep-sided valley walls, which are rimmed with outcropping ledges. There is seldom found a more favorable field for the study of both structure and stratigraphy.

Although there appears to be little information about the total thickness of the beds overlying the salts, it seems likely that this section is thick enough to bury the salts very deeply in a great part of the Tertiary basin. There are, however, several belts of sharp folding and overthrust faulting, which are described by the Spanish geologists as continuous from east to west across the area outlined as the potash field. In at least the two places that have been described these folds have brought the salts to the surface along the Cardoner River channel, and the salts are relatively shallow in other parts of the field. The Cardona and Suria districts have been described, but structure of the same sort occurs elsewhere, although apparently it is not of sufficient intensity to cause the salt beds to crop out.

SPANISH LEGISLATION CONCERNING THE POTASH LANDS.

Soon after the general announcement of the discovery of potash in Catalonia, efforts were made to put through special legislation concerning these deposits. This was in principle a perfectly natural and appropriate step, as applications for extensive areas and rights of a class without precedent in the country would naturally require special consideration.

In 1915 a bill was presented to the Cortes, the national legislature of Spain, by the minister of public works. This bill seemed to place such restrictions on ownership, development, and operations that it aroused protest, and apparently was not passed. It was replaced, however, by a royal order dated June 10, 1915, which was in harmony with the general provisions of the bill still pending. It provided that the concessionaires in the potash field must work uninterruptedly either in exploration or by mining. According to this order, if regular production had been established under it, the concessionaires would have been obliged to reserve for consumption in Spain such part of the potash recovered as the Government might require.

Another royal decree, published October 1, 1914, permitted the Spanish Government to reserve the right of private concession in the potash field until investigations by the technical departments of the Government had been carried out. This also granted a right for permanent withholding of land in the field for operation by the Government, if that should seem desirable. Rewards for further discoveries of value in this field were offered.

These orders remained in force until increasing activity in the developments at Suria during the early part of 1918 again attracted attention to the subject, and on May 2, 1918, another potash bill was published in the *Gaceta de Madrid*. This contained much of the original bill of 1915, including the obligation on the part of concessionaires to continuous operation, protective measures in favor of internal consumption of potash, a provision that export prices for the potash produced shall be greater than the domestic, and annual regulation of the maximum price for the home market and the minimum price for export. The Government is also directed to fix the maximum and minimum annual output of each mine. The Spanish Government assumes supervisory control of all mining concessions granted or to be granted, and work on such properties must be under the supervision of the mining inspector of the district in which the concessions are located. Provision is made that the Government shall own a share in a syndicate of owners of the mines and shall have a voice in the administration of this syndicate—regulations evidently patterned after those of the German *Kalisyndikat*.

Quotations from a royal order dated December 14, 1918, state that conditions have been specified under which foreign and Spanish companies can compete for concessions to work the potash deposits.

The restrictions placed by the acts of the Spanish Government have undoubtedly impeded progress in the development of the field, and the price-fixing feature of the present act must prove a deterrent to foreign capitalists desiring to enter the field. It is of course fair that Spain should safeguard her own interests, as, for instance, in providing against passing the ownership of these properties too largely into foreign hands and in insuring preferential treatment for domestic potash requirements from these deposits. However, assurance is needed that the conditions under which developments in the field are undertaken will be stable.

PROSPECTS FOR PRODUCTION.

Production of potash for commercial use from the Spanish field was not expected during 1919, and even with good fortune attending the work now going on it seems unlikely that potash will be shipped from these deposits before the middle of 1920 at the earliest. It is still too early to estimate with much confidence what the future of the Spanish field as a factor in the world production of potash will be. The prospects of production to meet Spanish needs seem promising, particularly as the lower grades of crude salts that may be obtained at first may be available locally before it may be possible to carry out the refining processes successfully.

Statements estimating tonnage reserves are accepted with considerable reservation until some verification is obtained from underground development by mining. Well records in regions of such structural complications as are exhibited in these salt deposits must be very difficult of interpretation, and the thicknesses recorded for the potash beds encountered must be largely dependent upon the angle at which these beds are penetrated, which is often not determinable. It appears that the more regular parts of the deposits, if such exist, have not been explored.

For the reasons stated above, it still seems necessary to reserve judgment as to the magnitude or importance of the Spanish potash field. The prospects are excellent, and the development now going on should settle the matter in a practical way very soon. Although there is abundant potash in both the German and the Alsatian potash fields and in other possible sources to supply the world's needs for as long as there is now need of estimating, it is far to be preferred that the world should be supplied from numerous and abundant sources than that there should be any danger of monopolizing this resource. Further news of the success attending the development of this field is awaited with interest.