(*Paper No. 1881.*)

“On the Recent Landslips in the Salt Districts of Cheshire.”

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THE large landslips of recent occurrence in the neighbourhood of Northwich, and the more gradual subsidence that has been going on for the last fifty years in the greater part of the Cheshire salt districts, form a subject of considerable interest, particularly when considered in connection with the geology of the country, and the method by which the manufacture of salt is carried on.

Lakes are being formed, part of the towns of Winsford and Northwich have had to be rebuilt, and the locks, weirs, and bridges on the River Weaver Navigation have required to be re-constructed and re-arranged. The whole of the subsidence arises from the rock-salt beds which underlie the district being dissolved, and the brine thus formed being pumped to the surface, where by evaporation it is made into white salt.

Rock-salt has been considered by some geologists to be the product of volcanic agency, but it is now generally believed to be the result of deposit in super-saturated lagoons or lakes.

If a line be drawn from the estuary of the River Mersey through Cheshire, along the valley of the rivers Weaver, Dane, and Wheelock, and be thence continued through Shropshire and Staffordshire, to Stoke and Droitwich in Worcestershire, it will pass through all the principal rock-salt beds in England. This line also continuously traverses the marl and clay beds of the triassic system, formerly called the saliferous marls, which are evidently the result of sedimentary deposit.

There is no evidence of the beds of rock-salt in this country forming continuous strata over large districts; no outcrop of rock-salt is known in England. This has been accounted for on the grounds that the rock-salt has been dissolved; but if this were true, deep subsidence would show the lines of the original outcrops. No such change of surface level is, however, found where the rock-salt beds must have appeared at the surface had they been continuous. Supposing that successive elevations and submergences of the land took place during the formation of the marl and clay beds, and that evaporation at the same time was going on, it is easy to conceive that beds of salt would be formed in lake basins,

and being afterwards subjected to great pressure, would take the form of rock-salt. The alternate beds of marl, clay, and rock-salt, the difference in the thickness of the various strata, and the circumscribed areas in which rock-salt is found, are all corroborative of this theory. The salt-beds would thus be formed at the lowest points of the original drainage area, and they are now principally found in the valleys of the rivers that drain the district.

The salt-beds at Northwich and Winsford occur in the following order, commencing at a level of 80 feet above ordnance datum :—

NORTHWICH.

	Feet.
Drift composed of sand and clay	27
Brown and blue marls with veins of gypsum	106
Rock-salt	84
Hard brown and blue marls	30
Rock-salt	84
Marls with thin veins of rock-salt	87
Rock-salt	3
Marls with thin veins of rock-salt	81
Rock-salt	6
Hard blue marl not sunk through	18
Total depth from surface	526

WINSFORD.

	Feet.
Drift composed of sand and clay	6
Variegated marls, with beds of hard marlstone and veins of gypsum	190
Rock-salt	15
Marlstone	3
Rock-salt	33
Hard blue marl	3
Rock-salt	69
Brown and blue marls with veins of rock-salt	35
Rock-salt	121
Brown and blue marls with veins of rock-salt	30
Rock-salt	3
Marls with veins of rock-salt	35
Total depth from surface	543

The salt district of Cheshire forms a large plain, situated in the new red marls, overlaid with boulder clay or sand.

The main drain is the River Weaver, which falls into the River Mersey near Runcorn. Winsford, now the principal seat of the salt manufacture, is situated on the first-named river, about 18 miles from the Mersey, and is the terminus of the Weaver

Navigation. Northwich is 5 miles lower down the river, where it is joined by the River Dane, which is only navigable for a short distance; but on its banks, and those of its tributary the Wheelock, are the salt-works of Sandbach and Middlewich. Nantwich, originally the main seat of the salt trade, has long ceased to manufacture salt, owing to the brine having become weaker, and not having the great facilities of deep-water carriage that Winsford and Northwich now possess.

Cheshire contains a number of small lakes, locally called meres. Combermere is nearly a mile in length; Rostherne Mere is also of large size, and Tabley Mere, Oakmere, and others are considerable sheets of water. These meres have been considered by some geologists to have been formed by local subsidence, owing to the dissolving of rock-salt. If this were so, and the rock-salt beds were continuous, it might be supposed that the area of these meres would be constantly extending; but this is not the case, and neither by borings or otherwise has proof been given that the rock-salt beds extend so far from Northwich.

Most of the recent landslips are near shafts from which brine is pumped; others can be shown to have connection with them, by lines of subsidence. In addition to land-springs the River Weaver probably supplies water to the rock-salt to form brine. Near Northwich some old shafts are now submerged under the river, and at other places fissures have been formed by the ground sinking, down which river water can find its way. To a small extent, natural causes may induce subsidence in Cheshire, as elsewhere; the rivers carry away considerable quantities of various salts in solution to the sea. No salt-springs, however, now rise to the surface in the sinking districts, and if they did in former times, the land was not injuriously affected as now, the operations of nature being slow and gradual.

Near Nantwich some springs rise to the level of the ground, and flow into the River Weaver, but no subsidence takes place near these springs. The Author found the river, in times of ordinary flow, to contain 8 grains of chloride of sodium to the gallon, or more than eight times the ordinary amount in inland river-water in this country. At Northwich the River Weaver is charged with much more salt; also the River Dane, but this is due to the waste from the salt-works.

The large volume of brine pumped has reduced the height of the brine considerably below sea-level, and consequently in the Northwich and Winsford districts there can be no direct or indirect flow to the sea. The constantly decreasing height of the brine is

shown by the records kept by Mr. H. E. Falk, at the Meadow Bank Works, near Winsford, which prove that the abstraction of brine by pumping is greater than the rainfall. The level in February 1865 was 99 feet below the surface; in February 1870, 118 feet; in February 1875, 132 feet; and in February 1880, 144 feet; the rate at which the brine lowers in level being almost uniform.

At Winsford twenty-eight and at Northwich eleven brine-shafts are worked, the brine being pumped to the surface by steam-power. Nine rock-salt mines are also worked, eight of which are near Northwich, and one near Winsford.

The brine used for salt-making, when of proper strength, contains about 2 lbs. 8 oz. of salt to the gallon, or 25 per cent., being nearly a saturated solution. It is more economical to pump the brine and evaporate it, than to raise the rock-salt, with its various impurities, and dissolve it on the surface. Its composition is as follows:—

	Per cent.
Chloride of sodium	96·70
„ calcium	0·68
Sulphate of lime	0·25
Water	0·63
Insoluble matter	1·74
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	100·00

The proportion of chloride of sodium varies, to a small extent, and traces of magnesium and potassium are sometimes noticed.

The iron pans used for evaporating the brine are from 40 to 60 feet long by 20 to 30 feet wide. The most simple arrangement of flues is used, the plan generally adopted being the same as shown by drawings dated 1740. Many inventions have been tried at great cost, but only a few have been found capable of being worked economically. Different temperatures are employed in salt-making, varying from 100° Fahrenheit to the boiling point, according to the degree of fineness required; coarse salt is only drained on being taken from the pan; fine salt is dried in box moulds, and afterwards crushed.

The brine shafts are cased with iron cylinders; where brine is got from old mines, a shaft is sunk through the unworked rock-salt, from which a drift is made towards the mine. Owing to the great depth of brine considerable danger was formerly incurred when the drift approached the brine. This was generally let into the mine through a bore-hole, which gave the men just time to escape up the shaft before it filled. Of late, however, the borings

have been made through an iron pipe, with a stop-valve and stuffing-box at the outer end, so as to prevent the brine escaping while the hole is being bored. When the boring is completed, the valve is closed and the stuffing-box removed; pipes are then led off to the pumps, the stop-valve remaining to regulate the supply of brine.

The quantity of salt manufactured increases yearly; the proportion made in the district is

	Tons per Annum.
Winsford	1,000,000
Northwich	500,000
Wheelock and Lawton	100,000
Middlewich	30,000
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	1,630,000

The greater part is shipped at Liverpool for India, America, and the Continent. The average shipments to the East Indies alone are 1,000 tons per day throughout the year.

As it takes about 10 cwt. of coal to manufacture 1 ton of salt, the consumption of coal in the salt districts is very large. The cost of making salt varies with the cost of fuel, but it may be taken at present at about 5s. 6d. per ton; the royalty being 6d., labour 1s., rent and repairs 9d., and coal 3s. 3d.

The weight of 1 cubic yard of rock-salt is 32 cwt., and a large quantity of brine is wasted in the manufacture. Taking the total weight of salt made, the loss of underground support, 1 yard deep removed yearly by pumping, covers an area of 250 acres. With so great an amount of abstraction going on constantly, without any supports being left, it is obvious that landslips must continually occur, and large tracts of land be brought below the drainage level of the district. As far back as 1873 the sinking was so extensive that the Home Office instructed Mr. Joseph Dickinson, Inspector of Mines, to inquire into the matter, and the result was a detailed and valuable report.¹

The area affected by sinking, excluding some outlying portions, extends from Marston through Northwich and Winsford, towards Nantwich, mainly along the valley of the River Weaver. The subsidence is not continuous, and some parts sink much faster than others. The subsidence extends over a district about 16 miles in length, and 1 mile to 4 miles in width. As most of the land is agricultural, and is at present above the drainage outfall, it is not yet seriously damaged; but near Northwich and Winsford some

¹ Also Mr. Dickinson's report on the Inspection of Mines, Cheshire, 1881.

hundreds of acres are submerged below the level of the River Weaver.

In addition to the general subsidence a number of old rock-salt mines have fallen in near Northwich, through brine having found its way into the mines. In the town of Northwich streets and houses are continually giving way; many of the buildings have been reconstructed on timber sills, and are tied together with bond timbers and iron rods, to enable them to be periodically lifted. Special by-laws have been sanctioned by the Local Government Board to meet the case. The streets are raised by the local authorities without reference to the owners of the adjoining buildings, who, under a late decision of the High Court of Justice, have to lift their houses to the altered level of the streets without compensation.

In 1860 the Author reported that the stone bridge over the River Weaver was in danger, and he constructed a wrought-iron girder bridge in its place, to enable the bridge to be raised when required. This latter operation has just been successfully carried out by Mr. L. B. Wells, M. Inst. C.E. The bridge over the River Dane has also been rebuilt with girders, and has since been twice lifted. The extensive landslip of December 1880 occurred at Dunkirk, near a point where the Wincham brook joins the River Weaver. This brook formerly ran into the river $\frac{1}{2}$ mile lower down the valley, but its course is now lost in the bed of a sheet of water, over 100 acres in extent, formed by subsidence.

Fifty years ago a canal, with locks, ran close to the brook, and was used for conveying salt and coals to and from the river; it is now submerged, and the largest ship afloat might safely anchor there. Many landslips have occurred near here, but the one of 1880 was the most serious subsidence since 1838, when an old rock pit fell in, carrying with it part of some salt works, causing the loss of seven lives. Adjacent are a number of pits filled with water, the remains of former landslips, and as the brine in 1880 had been getting lower, it was feared that the support afforded by the brine to the upper strata being thus removed other casualties would occur.

The site of the new landslip is near the Wincham brook, underneath which the Platts Hill rock-salt mine, 15 acres in extent, was being worked. The mine was quite dry, and had no connection with any brine shaft; yet the effect of the landslip was not only to fill the mine, but also to raise the level of the brine in the neighbouring shafts 220 feet. The slip took the usual form of an inverted cone, and was about 200 feet in diameter. Down this

chasm the brook commenced running, and as from previous sinking the level of the bed of the brook had fallen below the level of the River Weaver, that river commenced flowing up the brook to the land-slip. The scour of the stream gradually cut out the bed of the brook, until it was 10 feet deep and 40 feet in width. Along this channel the whole of the flow of the river passed into the landslip for twelve hours. Moreover, part of the navigation, 160 acres in extent, was lowered nearly 1 foot; about 1,000,000 cubic yards of water and 50,000 cubic yards of earth disappeared in the landslip, the site of which is now a sheet of water. The expulsion of a great body of air from below caused some singular phenomena. Water and mud were blown up 20 to 30 feet high, while for a considerable distance round small geysers threw up the soil. Air also escaped through the earth into the adjacent water-pits, which are several acres in extent, the water being kept in a state of ebullition, as if fires were burning beneath. This continued active for many hours, and did not altogether cease for several days. Large cracks opened out in the surrounding ground, and the high chimney-shaft, and part of the buildings of the adjoining salt-works of Messrs. Ashton, fell down. It might have been expected that such a great influx of water would weaken the brine. This, however, did not occur; the rapid solution of rock-salt soon restored the brine to its ordinary strength. The salt-works consequently were only stopped for a short time to allow of the brine becoming clear, and the loss of property was confined to Messrs. Ashton's salt-works, and the wagons, rails, and other plant in Platt Hill mine.

During the year 1881 the subsidences continued, and this year one of the principal brine-shafts, that of Messrs. Marshall, has fallen in, but no landslip has taken place on so extensive a scale as that of December 1880. At Winsford the streets and houses sink even more than at Northwich. The church has been lately taken down. A girder bridge, constructed in 1865 to replace a stone bridge, was lifted 4 feet in 1877, 9 feet 6 inches in 1879, and is now about to be lifted again 4 feet 6 inches, or altogether 18 feet in five years. Above this bridge two sheets of water have been formed by subsidence in the valley of the River Weaver, this area being over 100 acres; and another lake is now forming on the branch of the Cheshire Lines Railway.

The railways through the district suffer considerably. Part of the London and North-Western Railway between Winsford and Crewe has been repeatedly raised. The Winsford branch of the Cheshire Lines Railway was constructed so recently as 1866, and yet part of the line, originally level with the land, is now on an

embankment 30 feet high, which is being continually raised. The Trent and Mersey, and the Shropshire Union Canals, have required constant care to maintain the bridges and embankments; but the River Weaver navigation has suffered most by subsidence, the works near Northwich having undergone great modifications in consequence of the sinking, and of the greater liability to flooding thus caused.

In 1790 the Marston salt-works were connected with the River Weaver by a canal, the water being maintained at a higher level by a lock and weir. In 1811 the lock and weir were removed, as the level had so altered that they were not required, and there is now 60-feet depth of water where this canal formerly existed, the total subsidence having been nearly 100 feet.

The Northwich pound of the navigation was maintained with great difficulty; three times the lock and weir sunk so as to be useless. These were rebuilt on different sites in 1827, 1836, and 1843. In 1859 the Author advised the removal of the last-constructed lock and weir, making the Northwich and Winnington pounds into one long level, also doubling the length of the weir at Winnington to facilitate the passage of flood-water. The constant sinking of the town of Northwich, and the improvement of the navigation, has caused a large outlay on the river works. In 1865, and again in 1871, the Author was instructed to report to the River Weaver trustees on the question of improvement that would allow of coasting vessels passing up to the salt-works; and the works then recommended are now drawing near completion under the charge of Mr. L. B. Wells, the total cost having exceeded £600,000.¹

The result of the improvements has been to reduce the cost of carriage, and to lessen the height of floods. The subsidence of the salt districts, however, continues, and, as there is no remedy for the evil but ceasing to pump brine, the mischief will probably go on until great part of the land near the river is submerged.

¹ "The River Weaver Navigation." By John Watt Sandeman, M. Inst. C.E. Minutes of Proceedings Inst. C.E., vol. lxiii., p. 261.