Relationship Between Mining and Ground Water Within the Dolomites of Ireland

By J.E. Dodds[1], E.P. Daly[2] and K.T. Cullen[3]

[1] Steffen, Robertson and Kirsten (UK) Ltd, 9/10 Windsor Place, Cardiff, Wales
[2] Geological Survey of Ireland, Beggars Bush, Dublin, Ireland
[3] K T Cullen and Co, Parkview House, Beech Hill, Clonskeagh, Dublin, Ireland

ABSTRACT

Recent exploration for lead and zinc within the Carboniferous limestones and dolomites of Ireland has led to the discovery of two major new deposits within the Rathdowney Trend. In addition to the new deposits there is an existing mine at Navan and abandoned mines at Silvermines and Tynagh.

The work within the Rathdowney Trend has shown that ground water is a significant aspect of mine planning and permitting, in terms of the overall water control systems. In the experience of the authors, this was not the case in the other lead/zinc mining areas.

This paper examines the differences between the geology of the areas and the fundamental controls on the hydrogeological process and discusses the implications in terms of the effect on mining and the effect of mining on the ground water system.

INTRODUCTION

There is extensive base metal mineralisation in the Lower Carboniferous limestones in Ireland. Significant orebodies have been discovered at over 20 locations and eight of these deposits are commercial deposits.

This paper examines five of these orebodies with mainly lead/zinc mineralisation. The orebodies considered are those at Silvermines and Tynagh which have been worked out, Navan (Tara Mines) which is currently in production and the recently discovered deposits within the Rathdowney Trend, which are at different stages of the permitting process. The locations of the orebodies are shown on Figure 1. There are differences in the hydrogeology of these areas and thus the implications for mining are different. In order to understand the differences between the hydrogeological settings and the effects of ground water on mining and vice versa, the various controls on ground water occurrence are examined.

The details presented in this paper are based on the experience of the authors working in Ireland and in limestone/dolomite mining areas in other countries. The comments made and conclusions drawn are personal to the authors at the time of writing and do not necessarily represent the views of employers or clients.

GEOMORPHOLOGY

The ore bodies at Tynagh, Navan and Galmoy are situated in gently rolling productive farmland. Parts of the Rathdowney Trend occupies low lying ground much of which is covered by a large commercially operated peat bog. The mining district at Silvermines occurs on the north facing slopes of the Slieve Phelim–Keeper Hill Upland and is covered in rough pasture. Although the geomorphological setting differs between sites, the differences are not thought to significantly effect the occurrence of ground water.

GEOLOGY

The Lower Carboniferous (Dinantian) limestones underlie about half the land area of Ireland and dominate its geology (Figure 1). The limestone succession is generally between 200 and 2 000m thick and has been divided into 6 chronostratigraphic stages (George, *et al* 1976). The stages relevant to this discussion are shown on Figure 2. Most of the base metal orebodies are situated in the Courceyan, the older, thickest and most extensively exposed of these stages.

The Courceyan limestones overlie a variety of Lower Palaeozoic rocks and were laid down in a shallow sea which transgressed northwards during the Carboniferous period. During the transgression there were marked lateral changes of facies and thickness, with thick deposits accumulating in subsiding basins and thinner deposits on structural highs and more extensive stable shelves (Sevastopulo, 1981). Variations in the Courceyan succession are described by Philcox (1984) who divides the strata into a number of stratigraphic provinces.

Shales dominate the lower part of the Courceyan succession. They are overlain by a very variable succession of generally thinly bedded muddy or clean limestones, shales, oolites or calcareous sandstones called locally, either the Ballysteen Formation or Argillaceous Bioclastic Limestones (ABL). There was a widespread development of Waulsortian bank limestones ("reef limestones") in the later part of the Courceyan. These are pure, fine grained, unbedded limestones with a rich fauna. In some areas the succession is extensively dolomitised.

The Courceyan is overlain by the Asbianian to Brigantian succession, characterised by thick units of shelf or basinal limestones except for the margins in the north and northwest where the succession is quite different. The differences are not, however relevant to this discussion.

A variable thickness of Quaternary deposits of till, peat and sands and gravels overlies much of the bedrock in the low lying ground throughout Ireland.

The geology of the five orebodies described in this paper are broadly similar, however there are significant differences. All but the succession at Navan are in the so called Limerick stratigraphic province (Philcox, 1984) and lie within Gill's tectonic zone 2 (Sevastopulo, 1981), as shown on Figure 3.

TECTONIC SETTING

The Carboniferous rocks of Ireland have undergone extensive Hercynian deformation. The impact is greatest in the south of the country and decreases northwards. The associated folding, faulting and jointing is an important factor in the development of permeability in Irish Limestones. The main structural trends are generally East/West in the south of the country and swing to a more ENE/WSW direction to the north. NNW/SSE faulting is also common in association with the above.

All of the orebodies described here lie along the north or northwestern side of major east to northeastern trending fault zones. The mode of occurrence of the orebodies is closely related to structure. This and other aspects of the geology are discussed in detail by the various authors listed in the references.

INDIVIDUAL OREBODIES

Tynagh and Silvermines

The geological setting of the orebodies at Tynagh and Silvermines are broadly similar. Both orebodies are situated on the southern limbs of gently folded synclines and along major fault zones that form the northern boundaries of inliers of Lower Palaeozoic and Old Red Sandstone rocks. In the mine areas the Waulsortian and dolomitisation of the succession is only locally developed.

At Silvermines the mineralisation occurs at every stratigraphic level up to the base of the Waulsortian and its equivalents (Andrews 1986). The deposit is located along the Silvermines Fault. This is a complex fault zone, broadly ENE trending, with associated minor WNW branch faults. This combination forms the horsetail structural pattern which dominates the Silvermines area. The main faults are tight, gouge–filled structures rarely exceeding 1m in width. Most of the faulting is normal in nature and the branch faults have a close spatial association with the mineralisation. At Silvermines deep weathering extends, in one area, to a depth of over 150 m (E.Grenmon, Pers Comm).

At Tynagh most of the mineralisation is confined to the Waulsortian and its equivalents the top of which may be Chadian in age (Clifford et al 1986). The upper portion of the orebody is unconsolidated and occupies a large karstic trench or sinkhole which formed during the Tertiary and is elongated along the North Tynagh Fault. This zone of weathering extends to a depth of some 75m. The principal fault is, a complex structure composed of an en echelon series of normal faults with each branch terminating in a splay zone. Again the mineralisation is closely related to the faulting.

Navan

The succession at Navan is part of the North Midlands stratigraphic province (Philcox, 1984) and is different in detail to that of the other mine areas. The Waulsortian is not present in the mine area. The mineralisation extends from the lower to middle part of the Courceyan, is structurally controlled and is accompanied locally by intense dolomitisation (Ashton et al 1986).

The deposit occurs along the northwestern flank of a complex NE trending anticlinal structure. This structure is dislocated by a parallel fault system called the A–C–D Fault Complex which is considered to be the reactivation of an earlier feature. There are also a number of ENE normal faults which terminate in the mine area against the fault complex.

Rathdowney Trend

The succession in the Rathdowney Trend (Figure 2) is characterised by an extensive (up to 100m) development of oolites (Lisduff Oolite Member, Sleeman, 1990) in the middle of the Ballysteen Formation and a Waulsortian sequence up to 200 m thick. The Waulsortian is overlain by a cherty bioclastic limestone (Crosspatrick Formation) of Chadian age. The commercial mineralisation is situated mainly at the base of the Waulsortian and in more than one individual orebody at each location.

The orebodies lie along the western edge of a broad area of regional dolomitisation (Hitzman, et al., 1992) which affects these strata throughout the southeast of Ireland (Daly, 1993). In the Rathdowney Trend the dolomitisation is most intense in the cleaner strata and along faults. At the orebody locations the dolomitisation covers the full Waulsortian sequence. At these locations there is some additional dolomitisation of hydrothermal origin which is associated with the mineralisation. Regular jointing and deep weathering are thought to be associated with the dolomitisation.

Both potential mining areas lie to the north of an inlier of the Ballysteen Formation which is bounded by a complex ENE fault zone. WNW faults splay off the main ENE features and may post date them (Doyle et al 1992).

HYDROLOGY

Rainfall at the five locations varies from 830mm/y at Navan to around 1,100mm/y at Silvermines and is spread evenly throughout the year. The variation in rainfall reflects the different aspects and altitudes of the sites. The rainfall across Ireland generally decreases from west to east.

There is little variation in the amount of actual evapotranspiration which is estimated to range from 420–450mm/y. Owing to the varying soil types, topographic situation, etc, in the mine areas only a proportion of potential recharge is available for recharge. The available recharge is estimated to vary from 200mm/y within the Rathdowney Trend and Silvermines to 370mm/y at Tynagh (Table 1). The bulk of the recharge occurs between late October and early March, when rainfall exceeds evapotranspiration. Owing to the generally shallow water tables and low storage in the bedrock strata much of the recharge cannot be retained and is rejected, under normal hydraulic conditions, to the surface water system. The variation in the hydrology across the country is small when compared to the potential for ground water inflow into mines.

HYDROGEOLOGY

The Courceyan succession in Ireland consists of rocks with a very low, or negligible, primary permeability. However, in some areas the cleaner, coarser limestones have been preconditioned by geological processes such as dolomitisation and intense structural deformation, that provide ready avenues for solute attack and make them susceptible to karstification.

Significant secondary permeability has developed in the southeast of Ireland, owing to dolomitisation (Daly, 1993). In the Rathdowney Trend the dolomitised Waulsortian has been classified as a major aquifer and the Lisduff Oolite Member and Crosspatrick Formation as minor aquifers (Daly, 1994) again due primarily to dolomitisation and structural deformation..

Investigations in the Irish midlands, by the Geological Survey of Ireland and others, have shown that hydraulic conditions are quite variable over short distances although unconfined conditions are dominant in the main, rock aquifers. The majority of ground water movement tends to occur at shallow depths, with rapid flow along short flow paths and discharge into the normally effluent streams which cross the aquifers (Daly, 1994). A small amount of flow occurs at depth (>100 m) in these aquifers, mainly along faults.

In aquitard strata, as opposed to the main aquifers, ground water flow is generally restricted to the upper weathered zone, more permeable beds of limited extent or fault and fracture zones. Circulation is restricted to these types of areas with shallow and short localised flow systems and with very little continuity between them.

The orebodies at Tynagh and Navan, are hosted by low permeability rocks. During operations they were/are essentially dry mines. Where water did/does occur, then it was/is associated with well defined faults. At Navan a significant part of the total pumping drains through the B Fault system (one of the ENE faults). Here an elongate shaped cone of depression has developed to the southwest and to a depth of 400m in the mine area (Barrow, et al., 1991).

Although also hosted by low permeability strata, the mine at Silvermines must be considered wet, as it had a pumping rate of between 11 000 and 13 000 m^3/day while it was producing (McKay. Pers. Comm). A significant proportion of this flow came from a fault zone at 60 m. The high pumping rates have been attributed to the more extensive faulting in comparison to Tynagh and Navan, as well as deep mineralisation and deep weathering. Ground water control was managed by deep level drainage to a depth of 300 m. This together with the presence of old, shallow, abandoned mines in the area would further exacerbate the inflow amounts.

Mines operated in the Rathdowney Trend are likely to be much wetter than those elsewhere as the orebodies are located in a major aquifer (Table 1). Water is likely to be encountered throughout the mine with increases to the background inflow associated with faults or highly weathered zones. The results of a long term pumping test at Galmoy (Arcon, 1992) showed the NW trending faults to be highly transmissive and the ENE fault to act as a no flow boundary.

TABLE 1: SUMMARY OF HYDROGEOLOGY IN EACH MINING AREA

	Deposit Size Mt[1]	Depth of Main Ore (m)	Pumping Rate[2] m^3/d	Actual Recharge mm/y	Status
Silvermines	17.7	10 – 250	>11,000[3]	200	Closed 1982
Tynagh	9.9	0 – 200	>3,000	370	Closed 1980
Navan	70	20 – 400	6,000	250	Opened 1977
Galmoy	6.5	70 – 90	12,000[+]	300	Permits 1994

Key To Table 1

[1] Details from, Mining Journal, 1994
[2] Estimates of average volumes
[3] Additional dewatering from nearby barite mine and also from a number of large wells
[+] Predicted Values
The water table at all five sites is less than 15m

Investigations carried out at some of the orebodies have shown evidence of additional solution of the carbonates in the vicinity of the orebodies. Acid waters were generated by the weathering of iron and other sulphides associated with the orebody. The resulting acidity attacks the carbonate host rock and increases the permeability. The higher permeability zones then provide path ways for more conventional karstic processes to act.

The data available on the hydrogeology of the mines specifically shows that ground water flows are closely related to structure. This is particularly the case at Silvermines, Tynagh and Navan. In the case of the Rathdowney Trend regional dolomitisation has enhanced the mass permeability of the rock by increasing the joint density as a result of the rock weakening which occurs in the dolomitisation process. The increase in jointing and acid generation from weathered pyrite associated with the ore has resulted in an increase in the bulk permeability and storage of the dolomitised limestone. Karstification processes in the Tertiary have enhanced the permeability even further and provide vertical path ways for recharge.

IMPACT ON MINING

Ground water inflow has a serious impact on mining in terms of safety and costs. The main costs are in the pumping of water from the workings and dewatering boreholes and the cost associated with treatment prior to discharge to surface water, or possible use. The cost of treatment can be extreamly high, especially in countries like Ireland that place very stringent conditions on discharge licenses in order to protect salmonid fisheries. It is therefore important that knowledge of the ground water situation is gained prior to mine development or prior to remedial action should ground water be encountered unexpectedly. The management of the ground water inflow is important in order that the majority of pumped water is maintained as close as possible to background quality levels.

The information on Irish mining environments shows that the occurrence of ground water is very variable. It is evident that the water is associated with structural features, dolomitisation and zones of karstification and deep weathering. In terms of the mining environment this poses a hazard of sudden inflow, if the presence of the features is not known in advance. It is therefore important that the mine planning team have knowledge of the occurrence of such features and the ground water associated with them in order that pumping and management systems can be put in place.

IMPACT ON GROUND WATER

The type of ground water environment being described above has advantages in terms of the environmental impact of a dewatering system. The aquifers are highly anisotropic, due to differences in the transmissive properties of structural features trending in different directions. A cone of influence produced by pumping will elongate along the direction of high transmissivity. This limits the area of influence in the low transmissivity direction. The impact of this factor is described by Barrow, *et al (1991)* for Tara Mine and in the planning application for Galmoy (ARCON, 1992).

The nature of the limestone sequence in Ireland and the strong structural influences results in the low permeability material eg. Ballysteen Formation, often being faulted against the karstified/faulted reef limestone. These boundaries form hydraulic barriers, further limiting the cone of influence of a dewatering system.

Ireland has a high potential recharge, which in the undeveloped situation is limited as much of the actual recharge is immediately rejected to ground water influent streams. Under developed conditions where water tables are depressed the actual recharge may be increased as a larger proportion moves downward and out of the capture zone of the streams. This increase in recharge will also act to limit the spread of the cone of depression. It must also be noted that the additional recharge under pumping conditions will also increase the volume of water pumped.

CONCLUSIONS

This discussion on the occurrence of ground water in some of the mining areas in Ireland has shown that inflows into underground mines located within the Carboniferous limestones is very variable. The principal controls on inflow are dolomitisation and structure. In the northern and western mining areas away from the main dolomite zones, inflows are less and almost exclusively related to one or more faults. In the Rathdowney Trend which is within the dolomitised region, inflows are likely to be much higher, although no active mining is presently taking place. The increase in inflow can be attributed to increased fracturing and karstification, associated with the dolomitisation. Other contributory factors include the enhanced karstification as a result of sulphide oxidation.

The differences in the hydrogeology of the Carboniferous limestone/dolomite of Ireland need careful and considered planning by both developers and regulators when considering the present and future mining operations. In general terms however, the hydrogeological setting of the mines results in the impact of ground water control being limited naturally.

REFERENCES

1 Andrew, C.J., 1986. The tectono–stratigraphic controls to mineralisation in the Silvermines area, County Tipperary, Ireland. pp. 377–408 in Geology and Genesis of Mineral Deposits in Ireland. Edited by C.J. Andrew, R.W.A. Crowe, S. Finlay, W.M. Pennell and J.F. Pyne, IAEG, Dublin.

2 ARCON, 1992. Environmental Impact Statement, Galmoy Mine Project. Dublin.

3 Ashton, J.H., D.T. Downing and S. Finlay, 1986. The geology of the Navan Zn–Pb orebody. pp. 243–259 in Geology and Genesis of Mineral deposits in Ireland. Edited by C.J. Andrew, R.W.A. Crow, S. Finlay, W.M. Pennell and J.F. Pyne, IAEG Dublin.

4 Barrow, N. C.F.C. Pearson, P. Powell, and J. Edwards, 1991. The source and extent of hydrogen gas occurrences near to an underground zinc mine at Navan, Co, Meath, Ireland. Methane, facing the problems, second symposium and exhibition. Nottingham.

5 Clifford, J.A., P. Ryan, and H. Kucha, 1986. A review of the geological setting of the Tynagh orebody, Co. Galway. pp. 419–439 in Geology and Genesis of Mineral Deposits in Ireland. Edited by C.J. Andrew, R.W.A. Crowe, S. Finlay, W.M. Pennell and J.F. Pyne, IAEG, Dublin.

6 Daly E.P, 1994. The groundwater resources of the Nore River Basin. Geological Survey of Ireland, Report Series, RS 94/1.

7 Daly, E.P., 1993. Hydrogeology of the dolomite aquifer in the southeast of Ireland. Proc. IAH seminar, Portlaoise.

8 Doyle, E., A.A. Bowden, G.V. Jones, and G.A. Stanley, 1992. The geology of the Galmoy zinc-lead deposits, Co. Kilkenny. pp 211–225, in The Irish Minerals Industry, 1980–100. Edited by A.A. Bowden, G. Earls, P.G. O'Connor and J.F. Pyne, IAEG, Dublin. IAEG Dublin.

9 George, T. N. , G.A.L. Johnson, M. Mitchell, J.E. Prentice, W.M.C. Ramsbottom, G.D. Sevestopulo & R.B. Wilson, 1976. A correlation of Dinantian rocks in the Brtish Isles. Special Report No 7, Geological Society, London.

10 Hitzman, M.W., P. O'Connor, E. Shearley, C. Schaffialitsky, D.W. Beaty, J.R. Allan, and T. Thompson, 1992. Discovery and geology of the Lisheen Zn–Pb–Ag prospect, Rathdowny Trend, Ireland. pp 227–246 in The Irish Minerals Industry, 1980–1990. Edited by A.A. Bowden, G. Earls, P.G. O'Connor and J.F. Pyne, IAEG, Dublin.

11 Ivernia West plc & CMCI, 1992. Lisheen Proect. Unpublished Information Memorandum.

12 Mining Journal, 1994. Ireland. Country supplement, vol 322, no. 8271, London.

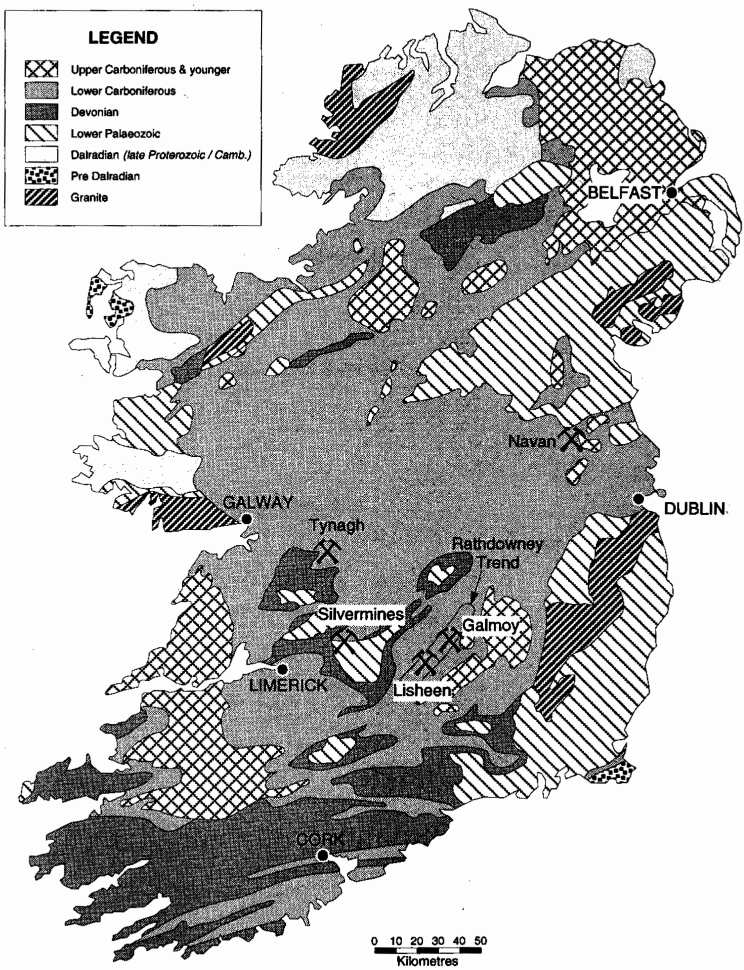
13 Philcox, M.E. 1984. The Lower Carboniferous Lithostratigraphy of the Irish Midlands. I.A.E.G.

14 Phillips, W.E.A and G.D. Sevastopulo, 1986. The Startigraphic And Structural Setting Of Irish Mineral Deposits. pp 1–30. In Geology and Genesis Of Mineral Depsoits in Ireland. Edited by C.J. Andrew, R.W.A. Crowe, S. Finlay, W.M. Pannell and J.F. Pyne. IAEG, Dublin.

15 Sevastopulo, G.D. 1981. Lower Carboniferous. pp 141–171. In, A Geology of Ireland. Ed. C.H. Holland. Scottish Academic Press.

16 Sleeman, A. 1990. Preliminary geological map of the Rathdowney district, 1:100,000. Geological Survey of Ireland.

Geology Map of Ireland



After CSA Computing Services Ltd.

Figure 1

Lower Carboniferous Succession in Rathdowney Trend
(After Doyle et al., 1992)

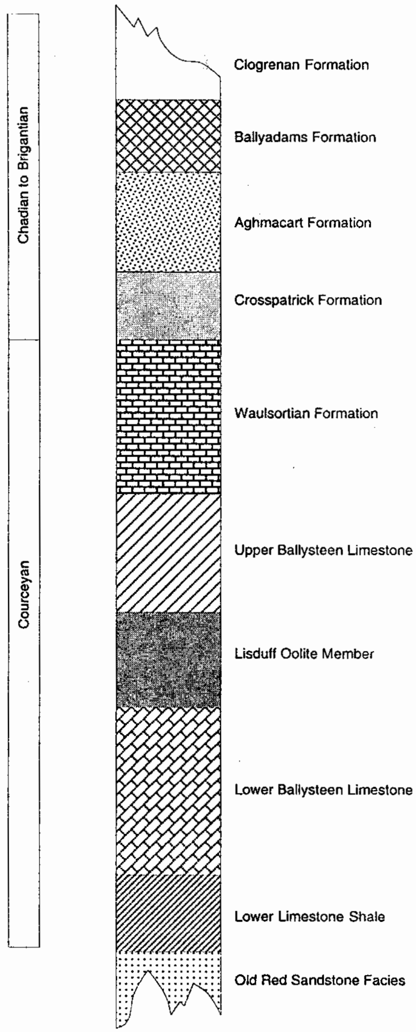


Figure 2

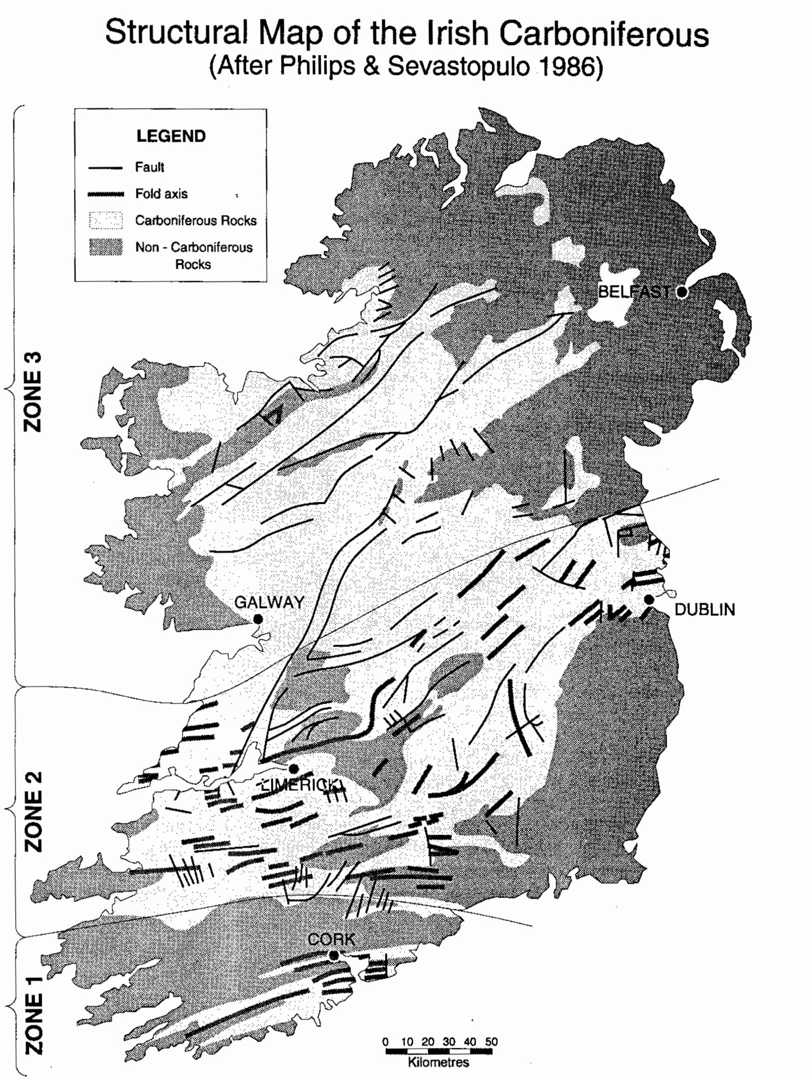

Structural Map of the Irish Carboniferous
(After Philips & Sevastopulo 1986)
LEGEND
Fault
Fold axis
Carboniferous Rocks
Non - Carboniferous Rocks
ZONE 3
ZONE 2
ZONE 1
BELFAST
GALWAY
DUBLIN
LIMERICK
CORK
0 10 20 30 40 50
Kilometres

Figure 3