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Structural analysis of the Louisburgh-Clare island succession, Co. Mayo, Ireland

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Abstract: The Late Silurian Louisburgh-Clare Island Succession, south Co. Mayo, Ireland, is located along the Irish tract of the Highland Boundary Fault. This lineament originated in Ordovician times and was reactivated during Late Silurian-Middle Devonian times. Detailed structural analysis of the succession in the section between Turlin Strand and Shlivagh Rocks, south Clew Bay, was performed in order to determine the style and timing of deformation of the Silurian basin. The Louisburgh-Clare Island Succession recorded N-S contraction overprinted by roughly E-W oblique deformations. N-S contraction of the basin probably began before the end of Silurian deposition during pure shear dominated transpressional deformation and was replaced by dominant E-W transtensional deformation in Early/Middle Devonian time.

Keywords: Silurian, N-S shortening, transtension, Caledonides, Ireland.

Clew Bay, Co. Mayo, Ireland, is crossed from east to west by the Clew Bay Fault Zone which is part of one of the main tectonic lineaments of Ireland, the Highland Boundary Fault (Fig. 1). This lineament originated during collision between an Ordovician volcanic arc and the southern passive margin of Laurentia in Ordovician times (Dewey and Ryan, 1990 and references therein) and recorded important reactivation in Late Silurian-Devonian times as a consequence of Laurentia-Avalonia collision and final closure of the Iapetus Ocean (Soper *et al.*, 1992 and references therein).

The Late Silurian non-metamorphic Louisburgh-Clare Island Succession consists of littoral to non-marine deposits exposed along the south coast of Clew Bay and Clare Island (Phillips *et al.*, 1970; Phillips, 1974). The north dipping Emlagh Fault separate the succession, Ludlow-Pridoli in age, from underlying metamorphic rocks of the Clew Bay Supercomplex (Ordovician accretionary complex), to the east, and the Silurian greenschist facies Croagh Patrick Succession, to the south (Fig. 1b).

The considerable thickness of the Louisburgh-Clare Island Succession (about 1700 m) and the relatively narrow area occupied by the Silurian deposits together with the sinistral transtensional kinematics of the Emalgh Fault suggests that the Louisburgh-Clare Island Succession was deposited in a pull-apart basin during regional transpression (Dewey *et al.*, 2005). Complex superposition of structures is a common feature within rocks deposited in syn-tectonic basins along transtensional and/or transpressional lineaments. A detailed structural analysis of the superbly exposed Louisburgh-Clare Island Succession, southern shore of

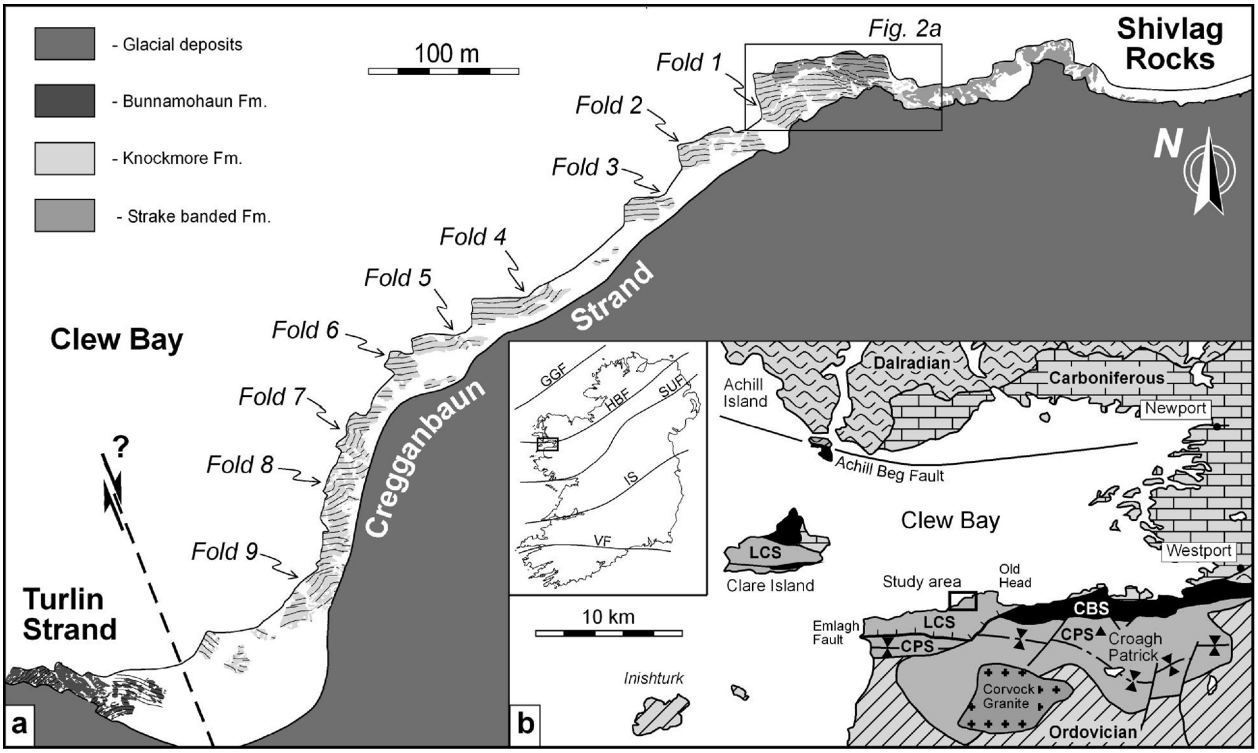

Figure 1. (a) Simplified geological map of the study area. Location of Fig. 2a is shown, (b) summary geology of the Clew Bay area and location of the study area (CBS: Clew Bay Supercomplex; CPS: Croagh Patrick Silurian; GGF: Great Glen Fault; HBF: Highland Boundary Fault; IS: Iapetus Suture; LCS: Louisburgh-Clare Island Silurian; SUF: Southern Upland Fault; VF: Variscan Front).

Clew Bay, was carried out to investigate timing and style of deformation of the Silurian basin during Caledonian reactivation of the Clew Bay Fault Zone.

Structural record

The study area is located along the southern shore of Clew Bay, between Turlin Strand and Shivlagh Rocks, south Co. Mayo, NW Ireland (Fig. 1). In this section, Silurian rocks belonging to the Louisburgh-Clare Island Succession are exposed in erosional surfaces between the high and low tide sea level marks. Detailed structural mapping, carried out subdividing the rock outcrops into rectangular grids, shows that, along the whole section, strata are in general nearly vertical with an overall E-W trend (Fig. 2b-i). The orientation of bedding is related to regional scale E-W folding. The whole study area is located on the northern limb of a kilometric-scale syncline.

Data are presented starting from observations made in the selected outcrop shown in figure 2a. The order of presentation of the structures reflects timing of development as suggested by the observed cross-cutting relationships between them.

Conjugate faults

The whole area is affected by intense faulting. Most of these structures belong to two sets of conjugate faults which predate all other structures recognised in the area (Fig. 2a). Kinematic indicators and offsets of the stratigraphic markers constrain the kinematics and amount of displacement of these structures. Faults showing dextral movement trend NNW-SSE and dip steeply towards the ENE (Fig. 2b-ii). Faults with sinistral offset trend NE-SW and are nearly vertical (Fig. 2b-iii). Between Cregganbaun Strand and Turlin Strand, the occurrence of a major dextral fault is inferred from bed dragging and stratigraphic displacement (Fig. 1a).

Dykes

In proximity of Shivlagh Rocks, Silurian strata are crossed by several serpentinitic dykes trending on average NNW-SSE (Figs. 2a and 2b-iv). These bodies range in size from few centimetres to some decimetres. Dykes were emplaced preferentially along pre-existing dextral faults. Where dykes show complex wall geometry, intrusion along both sets of conjugate faults is usually observed. Phillips *et al.* (1970) suggest that dykes were emplaced at a very low temperature under high gas pressure.

SSW Thrust

A N-dipping thrust structure is exposed in the western half of the selected area (Fig. 2a). The effects on pre-existing passive markers, such as dykes and stratigraphic contacts, define a bulk SSW transport direction and a displacement of about 10 m.

Late sinistral strike-slip faults

Conjugate faults, dykes and thrusts are truncated or reactivated by SE to SSE trending sinistral strike-slip faults. Two main faults have been recognised within the selected outcrop (Fig. 2a). The first structure cuts the eastern half of the area with a NW-SE direction and minimum horizontal displacement of 20 m (Figs. 2a and 2b-v). The second fault, trending on average SSE-NNW, reactivated one of the major pre-existing dextral faults in the western side of the outcrop and it shows a displacement of about 2 m (Figs. 2a and 2b-vi).

Monoclinal folds

The whole study area is crossed by a set of nine monoclinal folds (labelled 1 to 9 in figure 1a). In the selected area, Fold 1 deforms dykes and is not displaced along the thrust surface (Fig. 2a). All over the study area, late fold axes moderately plunge towards the east (Fig. 2b-vii). Axial planes trend NW-SE with moderate dip towards the NE.

Discussion

Geometry and kinematics of the conjugate faults, the oldest structures recognised in the study area, are consistent with either conjugate sets of strike-slip faults reflecting roughly N-S shortening of the basin or syn-sedimentary normal faults developed in a pull-apart basin and passively rotated by E-W sinistral shear and folding. The brittle character of both fault sets and the occurrence of faults with the same orientation and kinematics cutting across Silurian, Ordovician and Dalradian rocks in the whole region suggest that they originated as N-S shortening-related conjugate strike-slip faults after regional E-W folding of the Silurian basin rather than syn-sedimentary normal faults. The

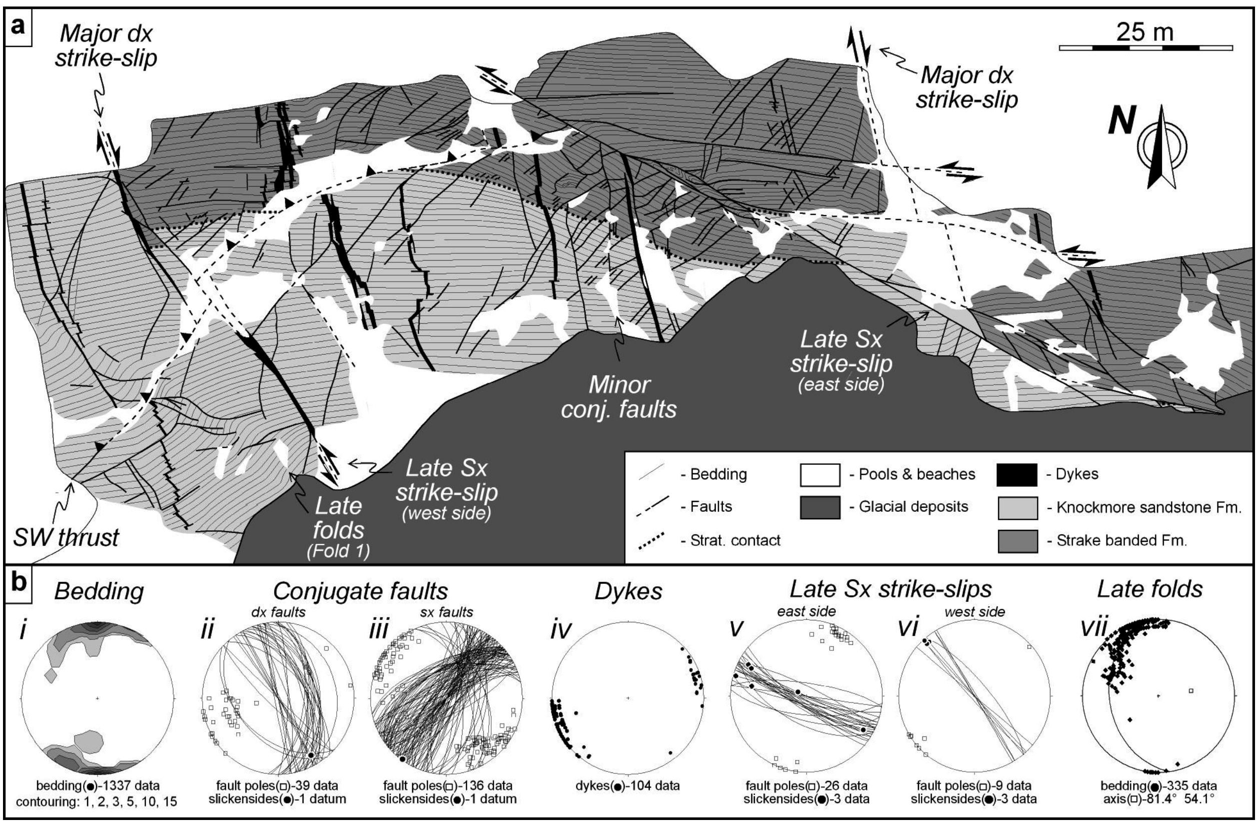

Figure 2. (a) Geological map of the selected outcrop, east end of the Cregganbaun Strand, (b) lower hemisphere equal area projection of the data recorded in the strand.

conjugate strike-slip faults may reflect flattening during the late stages of the E-W folding. It follows that conjugate faults and younger structures developed in nearly vertical E-W trending strata and did not suffer important passive rotation. Conjugate strike-slip faults and regional E-W folding accommodated up to 5% and 30% N-S shortening of the basin respectively.

In turn, kinematics and orientation of late sinistral strike-slip faults and late monoclinal folds are consistent with ca. E-W shortening. Development of these structures may be interpreted in several ways. They may reflect regional change in shortening direction or "local stresses imparted to the adjacent wedge-shaped fault blocks" (from Stubley, 1989) in a continuous N-S compression of the basin. Moderate plunge to the east of the monoclinal fold axes implies that these folds were produced by oblique rather than horizontal deformation. In fact, the overall geometry of the monoclinal folds is consistent with E-W sinistral shear accompanied by vertical shear producing lowering to the north (Fig. 3). This observation suggests that the late stages of deformation of the basin were characterized by sinistral transtensional deformation rather than local layer-parallel shortening in continuous N-S compression. In the studied area, late sinistral strike-slip faults and late folds accommodated 15% and 8% of E-W shortening respectively.

The early and late stages of deformation are separated in time by emplacement of serpentinitic dykes and development of north dipping thrusts. The kinematics of the thrusts is not well documented and only a bulk NE-SW shortening direction can be inferred from offset of passive markers. SW displacement may indicate an intermediate shortening direction between early and late stages of deformation or it may just reflect late sinistral reactivation of an early stage southward thrust.

Several evidence suggest that dykes at Shivlagh Rocks originated from remobilization of underlying serpentinite rocks of the Clew Bay Supercomplex during tectonic deformation, as suggested by Phillips *et al.* (1970). If this is the case, most of the oblique displacement along the Emlagh Fault, separating the non-metamorphic Louisburgh-Clare Island Succession from the metamorphic rocks of the Clew Bay Supercomplex and the Croagh Patrick Succession, was accommodated before dyke emplacement since alignment between dykes and source rocks is still preserved (Fig. 1b).

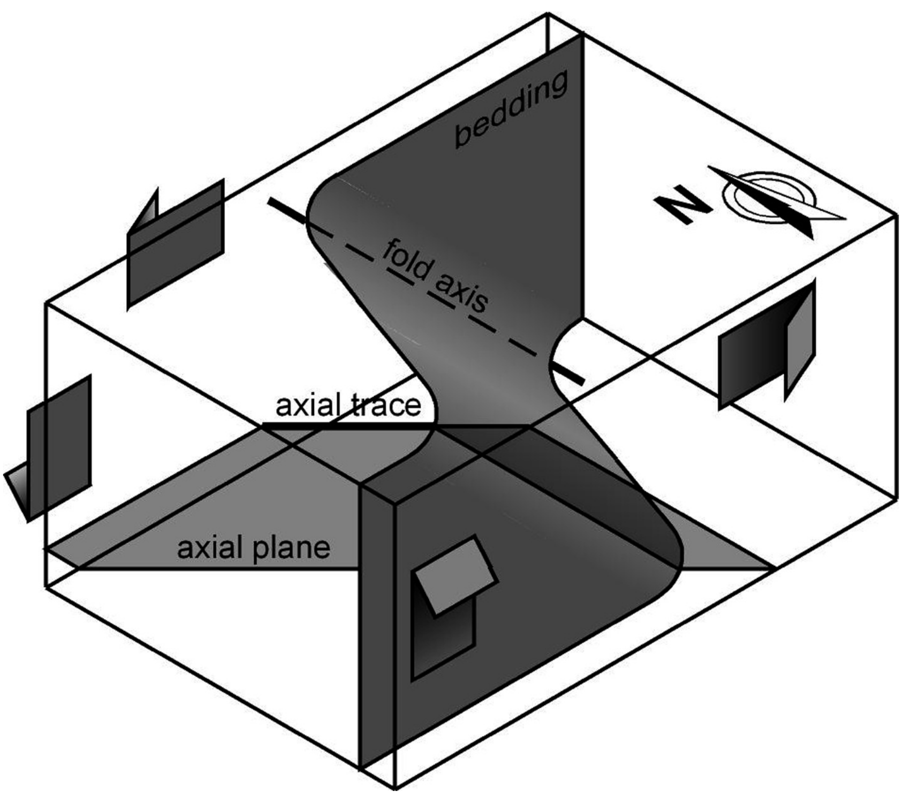

Figure 3. Schematic block diagram representing the monoclinal fold average geometry.

The tectonic record within the Silurian basin may be interpreted as superposition of transtensional deformation on dominant N-S compression, or strong partitioning of the strain during the early stage of a constant transpressional/transtensional deformation. Evidence for late E-W shortening-related structures overprinting early N-S shortening-related structures within the Ordovician rocks of the Central Murrisk, south Co. Mayo (Erriff phase, Dewey, 1967) and in the Croagh Patrick Succession (F2 folds, Long *et al.*, 2005) supports the first hypothesis and suggests that the structural record within the Louisburgh-Clare Island Succession reflects a regional rather than a local tectonic evolution.

Early structures are consistent with the Late Silurian pure-shear dominated convergence documented in the area. Late transtensional deformations were probably contemporaneous to the emplacement of the Ox Mountain syn-tectonic granitic bodies (410-400 Ma; McCaffrey, 1992; Flowerdew *et al.*, 2000) and general transtensional deformation recorded in Early-Middle Devonian times along the main tectonic lineament in northwest Ireland. The undeformed Corvock Granite dated at about 390 Ma (Graham *et al.*, 1989; O'Connor, 1989) record the end of sinistral displacements in the area.

No evidence of syn-sedimentary structures has been found in the section suggesting that, if the Louisburgh-Clare Island Succession deposited in a pull-apart basin, transtensional deformations were probably limited to the basin bounding faults. The kinematics of the Emlagh Fault is consistent with the kinematics of late structures postdating early N-S shortening of the basin. Because no evidence of syn-sedimentary activity of the fault have been documented so far, it is not possible to rule out development and activity of the Emlagh Fault only during the late stages of deformation of the basin.

Conclusions

Structural analysis of the Turlin Strand-Shivlagh Rocks section suggests that the Louisburgh-Clare Island basin experienced two main stages of deformation.

The regional E-W folding of the Late Silurian succession and the extensive conjugate strike-slip faulting are consistent with an early stage of N-S shortening of the basin. The latter structures are interpreted to reflect flattening during the final stage of folding. Late sinistral strike-slip faults and monoclinal folds are interpreted as evidence for the onset of transtensional deformation within the basin during the late stages of deformation. Early structures may have formed in Late Silurian times during a general pure shear dominated convergence (Caledonian Orogeny) while late structures are probably related to Early-Middle Devonian uplift and transtensional reactivation of the area accompanied by intrusion of syn-tectonic granites. Superposition of wrench- on pure shear-dominated deformations probably reflects regional tectonic changes triggered by the peak of the Acadian orogeny in late Lower Devonian times.

Acknowledgements

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References

Dewey, J. F. (1967): The structural and metamorphic history of the Lower Palaeozoic rocks of central Murrisk, Co. Mayo, Eire. *Q. J. Geol. Soc. London*, 123: 125-155.

Dewey, J. F. and Ryan, P. D. (1990): The Ordovician evolution of the South Mayo Trough, western Ireland. *Tectonics*, 9: 887-901.

Dewey, J. F., Mange, M. A. and Ryan, P. D. (2005): The Clare Island-Louisburgh Basin and the Slieve Gramph Plutonic Complex: Silurian transtension in regional transpression. In: *"Recent Developments In The Geological History Of The British Isles – A Tribute To W. Stuart McKerrow", Oxford, January 14th-16th, 2005, Abstracts Book*: 18-19.

Flowerdew, M. J., Daly, J. S., Guise, P. G. and Rex, D. C. (2000): Isotopic dating of overthrusting, collapse and related granitoid intrusion in the Grampian orogenic belt, northwestern Ireland. *Geol. Mag.*, 137: 419-435.

Graham, J. R., Leake, B. E. and Ryan, P. D. (1989): *The Geology of South Mayo, Western Ireland*. Scottish Academic Press, Edinburgh, 75 pp.

Long, C. B., McConnell, B. J. and Philcox, M. E. (2005): Geology of South Mayo. *Geol. Surv. Ireland Bull.,* 164 pp.

McCaffrey, K. J. W. (1992): Igneous emplacement in a transpressive shear zone: Ox Mountains igneous complex. *J. Geol. Soc. London*, 149: 221-235.

O'Connor, P. J. (1989): Chemistry and Rb-Sr age of the Corvock Granite, western Ireland. *Geol. Surv. Ireland Bull.*, 4: 99-105.

Phillips, W. E. A. (1974): The stratigraphy, sedimentary environments and palaeogeography of the Silurian strata of Clare Island, Co. Mayo, Ireland. *J. Geol. Soc. London*, 130: 19-41.

PHILLIPS, W. E. A., RICKARDS, R. B. and DEWEY, J. F. (1970): The Lower Palaeozoic rocks of the Louisburgh area, Co. Mayo. *P. Roy. Irish Acad.*, 70B: 195-209.

SOPER, N. J., STRACHAN, R. A., HOLDSWORTH, R. E., GAYER, R. A. and GREILING, R. O. (1992): Sinistral transpression and the Silurian closure of Iapetus. *J. Geol. Soc. London*, 149: 871-880.

STUBLEY, M. P. (1989): Fault and kink-band relationships at Mystery Bay, Australia. *Tectonophysics*, 158: 75-92.