Rhynie, Aberdeenshire

[NJ 494 277]

Potential ORS GCR site

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Introduction

The Rhynie outlier of Old Red Sandstone strata lies about 50 km WNW of Aberdeen. It has an elongate outcrop measuring about 21 km from north to south and up to 3 km from east to west. Structurally, the inlier has been interpreted as a half-graben, with a major, low-angle extensional fault zone at its western margin and strata generally dipping moderately towards the west from an unconformity at the eastern margin. However, recent re-mapping of the northern part of the basin by Rice and Ashcroft (2004) has demonstrated that faulting and folding can be related to basin formation in an Early Devonian regional strike-slip system. The site lies close to the north of the village of Rhynie (Figure 2.72) on the western margin of the basin. Natural exposure within the site is confined to some tuffaceous sandstone, but the site is an established palaeontological GCR site for the Rhynie cherts and its biota, which comprises the best-preserved and most diverse early terrestrial/freshwater ecosystem in the world. The diverse biota was silicified and exceptionally well-preserved by hot spring activity. It includes plants, together with algae, fungi and cyanobacteria, as well as a number of species of terrestrial and freshwater arthropods. Many of the plants and arthropods are unique to this site. It is a world-renowned lagerstatte that has been of crucial importance in providing insights into plant and arthropod evolution. The plants include *Rhynia,* the type-genus of the Rhyniophytina and widely regarded as the archetypal early land plant, and *Asteroxylon, the* earliest well-documented lycopsid. The arthropods include terrestrial opilionid (harvestman) spiders, trigonotarbids, mites, hexapods, euthycarcinoids, centipedes, freshwater crustacea, and several other arthropods of uncertain affinities. A recent re-examination of *Rhyniognatha hirsti,* a fragmentary fossil from Rhynie, suggests that it may have been not only the earliest true insect, but also the first winged species (Engel and Grimaldi, 2004). *Leverhulmia* has also been re-interpreted as an insect (Fayers and Trewin, in press).

The Rhynie cherts originated as siliceous sinters produced by hot springs. Chen was first recorded as loose blocks at the surface, but the site has since been extensively investigated by trenching and drilling. The international palaeobotanical importance of the site led to it being also selected as a GCR site for its Palaeozoic palaeobotany (see Cleal and Thomas, 1995 and references therein); independently it was selected for the GCR for its fossil arthropods. It is also of great importance as one of the earliest preserved surface expressions of a hydrothermal hot spring system.

Recent studies on the general geology of the area are by Rice and Trewin (1988), Trewin and Rice (1992), Trewin (1994, 1996), Rice *et al.* (1995, 2002), Gould (1997), Trewin *et al.* (2003), Rice and Ashcroft (2004) and Trewin and Wilson (2004). A general account of the Old Red Sandstone is provided by Trewin and Thirlwall (2002). Freshwater and terrestrial arthropod faunas recovered from the nearby Windyfield Chert are described by Anderson and Trewin (2003) and Fayers and Trewin (2004). Recent palaeobotanical discoveries include the recognition of gametophytes of some plants (Remy *et al.,* 1993; Kerp *et* al., 2004), the Zosterophyll plants *Trichopherophyton* (Lyon and Edwards, 1991) and *Ventarura* (Powell *et al.,* 2000a), a parasitic relationship between fungi and green alga (Taylor *et* al., 1992a,b), ascomycete fungi (Taylor *et ed.,* 1999), and the earliest known lichen (Taylor *et al.,* 1997).

The fossiliferous horizons are placed into a context of the evolving geological environments at the margins of a small, active half-graben. The importance of the site lies in the in-situ biota that provides a unique 'snapshot in time' of an Early Devonian terrestrial ecosystem.

Description

The GCR site spans an area of land adjacent to the road from Rhynie to Cabrach (Figure 2.72). Several patches of the distinctive chert have been recorded as float, but there are no natural chert exposures, and the stratigraphical evidence for the position and relationships of the cherts has been obtained from geophysical studies, trenching and drilling. The drilled core and trench samples are housed at the University of Aberdeen. The chert occurs in the highest part of the succession (the Rhynie Chert Member of Gould, 1997; Rhynie Cherts Unit of Rice *et al.,* 2002) in the Rhynie outlier, in a sequence of shales and tuffaceous sandstones comprising the Dryden Flags Formation (Gould, 1997; Rice *et al.,* 2002). The GCR site lies in the Rhynie Block, the southern of two chert-bearing blocks that are separated by the Longcroft Fault (Figure 2.72). The northern (Windyfield) Block lies beyond the boundary of the palaeobotanical GCR site. In this GCR site however, a basin-margin faulted succession older than the cherts comprises about 20 m of lava and 30 m of sandstone and conglomerate. Most of the Old Red Sandstone succession seen elsewhere in the outlier is absent in the palaeobotanical GCR site area. Recently discovered altered lapilli tuffs east of the Longcroft Fault (the Longcroft Tuffs) are unique to the Rhynie Basin and other Devonian basins in north-east Scotland (*Rice et al.,* 2002). Palynological evidence (Richardson, 1967) suggested a Pragian age for the cherts; Wellman (2004), using borehole samples, has placed the Rhynie succession within the *polygonalis–emsiensis* Spore Assemblage Biozone, giving an early (but not earliest) Pragian to earliest Emsian age. Radiometric (Ar–Ar) dating has given an age of 396 ± 12 Ma (Rice *et* al., 1995); the Milton of Noth andesite (Figure 2.73) has yielded an ID-TIMS U–Pb zircon-titanite age of 409.6 ± 1.1 Ma that is probably close to the age of the Rhynie Cherts Unit (Pally, 2004), and consistent with the Pragian age based on palynology.

In the Rhynie area the basement to the Old Red Sandstone succession consists mainly of basic igneous rocks (quartz-biotite norite and minor serpentinite) and some granitoids belonging to the Ordovician Boganclogh intrusion. These are separated by an extensional, basin-margin fault zone from the overlying Old Red Sandstone sedimentary and volcanic rocks. The basin-margin fault zones in the Rhynie and Windyfield blocks comprise faulted slices of the basin-fill, as yet uncorrelated between blocks, although Rice *et al.* (2002) estimate that the Longcroft Fault throws down to the north-east by about 160 m, with chert outcrops in the Windyfield Block lying at a higher level than the Rhynie cherts.

The basal part of the succession in the basin-margin fault zone in the Rhynie Block comprises 30 m of mostly lithic sandstone, pebbly sandstone and conglomerate (Figure 2.73), named the 'Pre-lava Sandstones' by Trewin and Rice (1992) and correlated by Gould (1997) and Rice *et al.* (2002) with the Tillybrachty Sandstone Formation of the southern and eastern parts of the Rhynie Basin. The succession fines upwards, and the sandstones are mostly massive, with some parallel lamination and cross-bedding. The abundant pebbles are locally derived from the underlying igneous rocks, some being up to 10 cm in diameter. A calcareous cement is widespread, some sandstones are silicified, and rare calcrete nodules are present (Trewin and Rice, 1992).

A faulted sliver of purple vesicular, andesitic lava separates the Pre-lava Sandstones from the overlying Dryden Flags Formation. This formation is subdivided informally by Rice *et al*. (2002) into five units (Figure 2.73). It is at least 200 m thick and consists mainly of shales and sandstones with minor cherts. Over 40 m of clean, white, parallel- and ripple-laminated sandstones with some cross-bedding (White Sandstones unit) lie at the base of the formation. Beds have sharp bases resting on erosion surfaces, contain large mudstone rip-up clasts and some pebble beds. Mudstone interbeds become commoner upwards and the unit passes into a thick succession of argillaceous sandstones and mudstones (Shales with Muddy Sandstones unit). The argillaceous sandstones are massive, dark, up to 1 m thick and contain numerous small rip-up clasts. There are also some clean, pale sandstones with sharp bases, parallel- and ripple-lamination, and some pebble beds. Interbeds of laminated mudstone are commonly disrupted and locally burrowed. This unit is overlain by laminated mudstones with thin sandstones, subdivided into lower (Lower Shales) and upper (Upper Shales) units that are separated by the Rhynie Cherts Unit. The Lower Shales unit comprises green to blue-black, laminated, locally burrowed mudstone and fine-grained, pale sandstones. The latter occur in beds up to 0.15 m thick that have basal erosion surfaces and are parallel- and ripple-laminated. They contain rip-up clasts, and there are also some beds of pebbles of granitic basement and volcanic rocks. The Upper Shales unit comprises graded green mudstone and siltstone laminae in couplets up to 10 mm, interbedded with sandstones up to 0.1 m thick. The sandstones are similar to those in the Lower Shales, but in addition contain a few desiccation cracks, carbonaceous plant debris and patchy calcite cement.

The Rhynie Cherts Unit (Rhynie Chert Member of British Geological Survey, 1993 and Gould, 1997) is 35 m thick and contains the Rhynie cherts in a succession of interbedded mudstones, carbonaceous sandstones and minor tuffs. Individual chert beds range up to about 0.5 m thick and contain the remarkably well-preserved plant and arthropod material. Powell *et al*. (2000b) described 53 chert beds (totalling 4.2 m) in 35.41 m of core. One composite bed of 6 cherts is 0.76 m thick. The cherts show a range of laminated, brecciated, vuggy and geopetal textures typical of siliceous sinters (Trewin and Rice, 1992; Trewin *et al.,* 2003). In some of the beds, the plants are preserved partly in growth position, above a substrate of fine-grained sandstone that contains plant rhizomes. Trewin and Wilson (2004) have shown that whereas the chert-bearing unit can be correlated over 45 m to 65 m between three boreholes, individual chert beds are laterally impersistent and there is strong lateral variation in the flora. The published fauna and flora of the site are listed below. Several recent finds, including a nematode worm, a large trigonotarbid, an eoarthropleurid and possible spider remains, await publication (H. Kerp, S.F. Fayers, pers. comm.).

PLANTS

Trachyophytes (Sporophytes)

Rhynia gwynne-vaughanii Kidston & Lang 1917, 1920a; Edwards 1986

Horneophyton lignieri Kidston & Lang 1920a; El-Saadawy & Lacey 1979a

Aglaophyton major (Kidston & Lang 1920a); Edwards 1986

Nothia aphylla Lyon 1964; El Saadawy & Lacey 1979b; Kerp *et al.* 2001

Asteroxylon mackiei Kidston & Lang 1920b; Lyon 1964

Trichopherophyton teuchansii Lyon & Edwards 1991

Ventarura lyonii Powell *et al*. 2000a

Trachyophytes (Gametophytes)

Remyophyton delicatum (■ ■) (of *Rhynia*) Kerp *et al.* (2004)

Langiophyton mackiei (■ ■) (of *Horneophyton*)Remy & Hass 1991a; Kerp *et al.* (2004)

Lyonophyton rhyniensis (■ ■) (of *Aglaophyton*)Remy and Remy 1980; Remy & Hass 1991b; Kerp *et al.* (2004)

Kidstonophyton discoides (■) (of Nothia) Remy & Hass 1991c

Nematophytes

Nematophyton taiti Kidston & Lang 1921

Nematoplexus rhyniensis Lyon 1962

Algae *sensu lato*

Mackiella rotunda Edwards & Lyon 1983

Rhynchertia punctata Edwards & Lyon 1983

Palaeonitella cranii Kidston & Lang 1921; Edwards & Lyon 1983; Kelman *et al.* 2004

Lichen

Winfrenatia reticulata Taylor *et al.* 1997

Cyanobacteria

Archaeothrix contexta Kidston & Lang 1921

Archaeothrix oscillatoriformis Kidston & Lang 1921

Kidstoniella fritschii Croft & George 1959

Langiella scourfteldii Croft & George 1959

Rhyniella vermiformis Croft & George 1959 (generic name pre-occupied by the springtail *Rhyniella praecursor*)

Rhynicoccus uniformis Edwards & Lyon 1983

Fungi

Palaeomyces gordonii (No. 2) var *major* (No. 3) Kidston & Lang 1921

Palaeomyces asteroxyli (No. 7) Kidston & Lang 1921

Palaeomyces horneae (No. 8) Kidston & Lang 1921

Palaeomyces vestita (No. 9) Kidston & Lang 1921

Palaeomyces agglomerata (No. 10) Kidston & Lang 1921

Palaeomyces simpsonii (No. 13) Kidston & Lang 1921

(Kidston & Lang described 15 types of fungi though only 7 were named, 2 being variants of the same species, the others were only given numbers and are not included here)

Glomites rhyniensis Taylor *et al.* 1995

Palaeoblastocladia milleri Remy *et al.* 1994

Milleromyces rhyniensis Taylor *et al.* 1992a

Lyonomyces pyriformis Taylor *et al.* 1992a

Krispiromyces discoides Taylor *et al.* 1992a

Ascomycetes Taylor *et al.* 1999

ANIMALS

'Worms'

Nematoda

Nematode (undescribed) noted in Dunlop *et al.* (2004)

Annelida

Polychaete (undescribed)

Crustaceans

Lepidocaris rhyniensis Scourfield 1926, 1940

Castracollis wilsonae Fayers & Trewin, 2003

Ebullitiocaris oviformis Anderson *et al.* 2004

Nauplii (of *Lepidocaris?*)(Fayers *et al.* in prep.) Noted in Fayers & Trewin 2004

Euthycarcinoid

Heterocrania rhyniensis Hirst & Maulik, 1926a,b;

Anderson & Trewin, 2003

Trigonotarbids

Palaeocharinus rhyniensis Hirst 1923; Shear *et al.* 1987

Palaeocharinus hornet (Hirst 1923); Shear *et al.* 1987

Palaeocharinus tuberculatus Fayers *et al.* (in press)

(*Palaeocharinus hornet* (previously *Palaecharinoides hornet*)and *Palaeocharinus rhyniensis* are probably the only valid species of the five originally described by Hirst)

Unnamed large trigonotarbid Noted in Fayers & Trewin 2004

Araneae (Spiders)

*Palaeocteniza crassipes** Hirst 1923 (*this specimen is now regarded as a juvenile trigonotarbid (Selden *et al.* 1991))

Opilionids

Harvestman spider Dunlop *et al.* 2003

= *Eophalangium sheari* Dunlop *et al.* 2004

Arcari (Mites)

Protacarus crani Hirst 1923

Protospeleorchestes pseudoprotacarus (Hirst 1923); Dubinin 1962

Pseudoprotacarus scoticus (Hirst 1923); Dubinin 1962

Palaeotydeus devonicus (Hirst 1923); Dubinin 1962

Paraprotacarus hirsti (Hirst 1923); Dubinin 1962

Arachnida?

Unnamed arachnid(?)

Eoarthropleurids

Eoarthropleura sp. Noted in Fayers & Trewin 2004

Chilopods

Crussolum sp. Shear *et al*. 1998; Anderson & Trewin 2003

Unnamed scutigeromorph Fayers & Trewin 2004

Unnamed centipede Fayers & Trewin 2004

Hexapods

Rhyniella praecursor Hirst & Maulik 1926

Rhyniognatba hirsti Hirst & Maulik 1926; Engel & Grimaldi 2004

Leverhulmia mariae Anderson & Trewin 2003; Fayers & Trewin (in press)

Arthropoda *incertae sedis*

Rhynimonstrum dunlopi Anderson & Trewin 2003

In the basin-margin fault zone of the Windyfield Block, the Longcroft Tuffs comprises at least 140 m of intensely altered andesitic lapilli tuffs with subordinate sandstones and minor andesite. The tuffs are up to 1 m thick in normally graded beds with lithic, vesicular and non-vesicular clasts. The sandstones are laminated, in fining-upward beds, with convolute lamination and possible bioturbation. The Windyfield Sandstones and Shales comprise at least 65 m of green sandstone and shale. The sandstone beds have sharp basal erosion surfaces and are parallel- and ripple-laminated. There are a few coarse beds of granitic debris, andesite, sandstone and metamorphic rock. The Windyfield Chert (Fayers and Trewin, 2004) comprises chert lenses up to 1 m across and 0.3 m thick within blue claystones with sandstone and pebble beds. The chert contains freshwater and terrestrial plants and arthropods (Anderson and Trewin, 2003; Fayers and Trewin, 2004) and vent sinter occurs as float (Trewin, 1994).

There is widespread hydrothermal alteration of the Devonian rocks, particularly in the vicinity of the basin-margin faults (Rice *et al.,* 1995, 2002). The altered rocks and the chert sinters contain high (but non-commercial) concentrations of gold and arsenic.

Interpretation

The interpretative model of the Rhynie inlier continues to be refined as more data become available. An earlier structural model invoking a sub-vertical basin-margin fault zone and a gently dipping basal unconformity (Rice *et al.,* 1995) was revised (Rice *et al.,* 2002) in the light of 1997 drilling results. In the 2002 model (Figure 2.74), a zone of extensional faulting along the western basin margin dips 35° eastwards, flattening to a 15° listric basement/cover fault under the basin. The basin-fill succession dips northwestwards, except close to the basin margin, where the strata are folded into a syncline. Further mapping supported by excavation and geophysical (magnetic) survey (Rice and Ashcroft, 2004) has revealed more extensive faulting and folding consistent with a dextral strike-slip origin for the northern part of the basin.

In the Rhynie Block, the Pre-lava Sandstone is interpreted as a small basin-margin alluvial-fan produced by a combination of flash-flood and channel deposition (Trewin and Rice, 1992; Rice *et al.,* 2002). The rare calcrete nodules indicate soil formation in a subaerial, seasonally wet environment and semi-arid climate. The clastic rocks are derived from the local igneous basement and there is no evidence for volcanicity prior to the eruption of the overlying andesitic lava flow. The White Sandstones are interpreted as the deposits of shallow, fluvial channels and sheet-flood events. The Shales with Muddy Sandstones, Lower Shales and Upper Shales are predominantly lacustrine and floodplain deposits. Trewin and Rice (1992) and Rice *et al.* (1995, 2002) interpreted the depositional environment as ephemeral, shallow lakes on an alluvial plain that periodically dried to desiccated mudflats. The fine lamination of the mudstones is attributed to minor seasonal changes in sediment supply, the thin, rippled sandstones representing clastic input to the lakes during flooding events. The tuffaceous sandstones at the base of the Shales with Muddy Sandstones (the Tuffaceous Sandstones of Trewin and Rice, 1992) are largely fine grained and quartzose, but also contain angular, vesicular andesitic clasts. Some of the more tuffaceous beds may be volcanic ashfall deposits, implying contemporaneous volcanicity, but most of the volcanic material was transported by water from a local source. Trewin and Rice (1992) placed these beds stratigraphically immediately above the andesitic lava, but the contact between the units is now interpreted as a fault (Rice *et al.,* 2002). Archer (1978) and Trewin and Rice (1992) interpreted the beds as alluvial-plain deposits, with regional axial current flow from the south (Archer, 1978). Trewin and Rice suggested that a nearby tuff cone undergoing erosion provided the volcanic debris, and that the laminated shales were overbank deposits of small ephemeral pools. The rare calcrete nodules are evidence of carbonate soil formation in a climate that continued to be semiarid and seasonally wet.

The Rhynie Cherts Unit has received much attention on account of its plant-bearing cherts. For a historical summary see Cleal and Thomas (1995). Interpretations are given by Trewin and Rice (1992), Trewin (1994), Rice *et al.* (1995, 2002) and Trewin and Wilson (2004). The revised model (Rice *et al.,* 2002) invokes silica deposition from mineral-rich hydrothermal fluids that emanated from hot (about 100°C) springs along basin-margin faults during the waning of local volcanism. Hot spring activity may have occurred at intervals along at least 2 km of the fault zone as pulses of fluid were released by subsidence movement along the fault zone. The silica-rich fluids permeated an alluvial plain with scattered small ponds, depositing surface sinter. Trewin and Wilson (2004) conclude that sinter deposition took place on a low-angle outwash apron from a hot spring, and that overbank flooding from a river system deposited the sand and mud interbeds (Figure 2.75). The silicification of standing plants and plant debris resulted from flooding of the land surface, but the aquatic arthropods and algae preserved in the chert probably inhabited cooler pools within areas of sinter. The wide range of preservation of the plants is probably due to silicification at different times in the cycle of plant growth and decay, combined with the variable efficiency of the silicification process. An outline model for the chert formation proposed by Rice *et al.* (2002) is shown in (Figure 2.74). The sinter textures in the chert compare with those in modern subaerial and subaqueous sinters in the cooler outwash areas of hot springs in Yellowstone National Park USA, and indicate a depositional temperature below 30°C for the majority of the plant-bearing cherts (Trewin *et al.,* 2003).

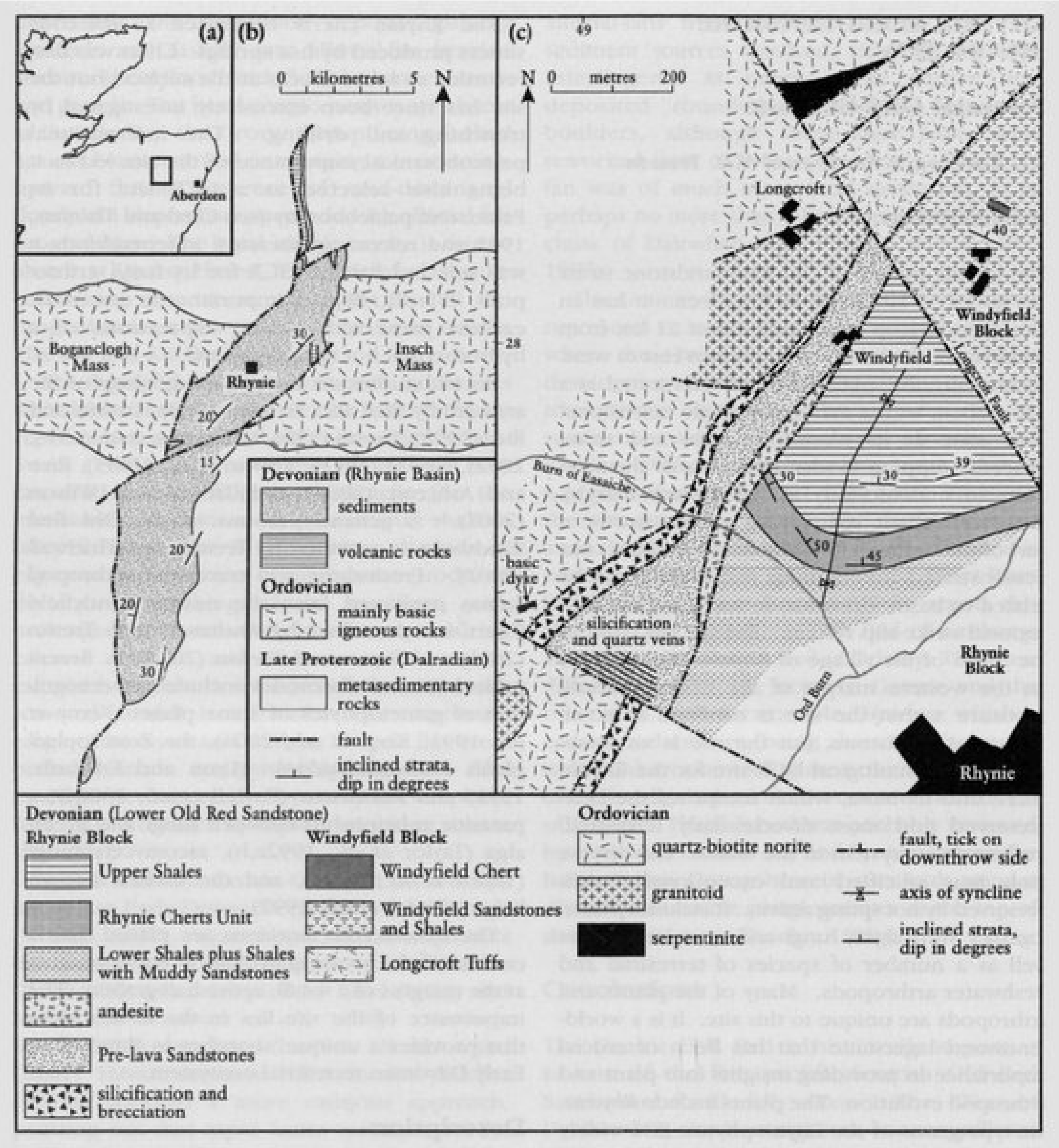
In the Windyfield Block, the Longcroft Tuffs are interpreted by Rice *et al.* (2002) as the product of volcanic activity from a nearby centre, producing lava and airfall tuffs, as well as the product of the erosion of the volcanic source. This introduced coarse debris during flood events into an otherwise low-energy fluvio-lacustrine floodplain. The Windyfield Chert was the product of hydrothermal silicification of the contents of freshwater pools in the vicinity of a hot spring vent.

Rice *et al.* (2002) suggest correlation of the strata in the Rhynie and Windyfield blocks with the succession recognized in the northern part of the Rhynie Basin (Figure 2.73). The Pre-lava Sandstones are correlated with the Tillybrachty Sandstone Formation (British Geological Survey, 1993; Gould, 1997) and the White Sandstones may correlate with the topmost part of the Quarry Hill Sandstone Formation. The succeeding beds of both the Rhynie and Windyfield blocks, including the Rhynie and Windyfield cherts, are correlated as part of the Dryden Flags Formation.

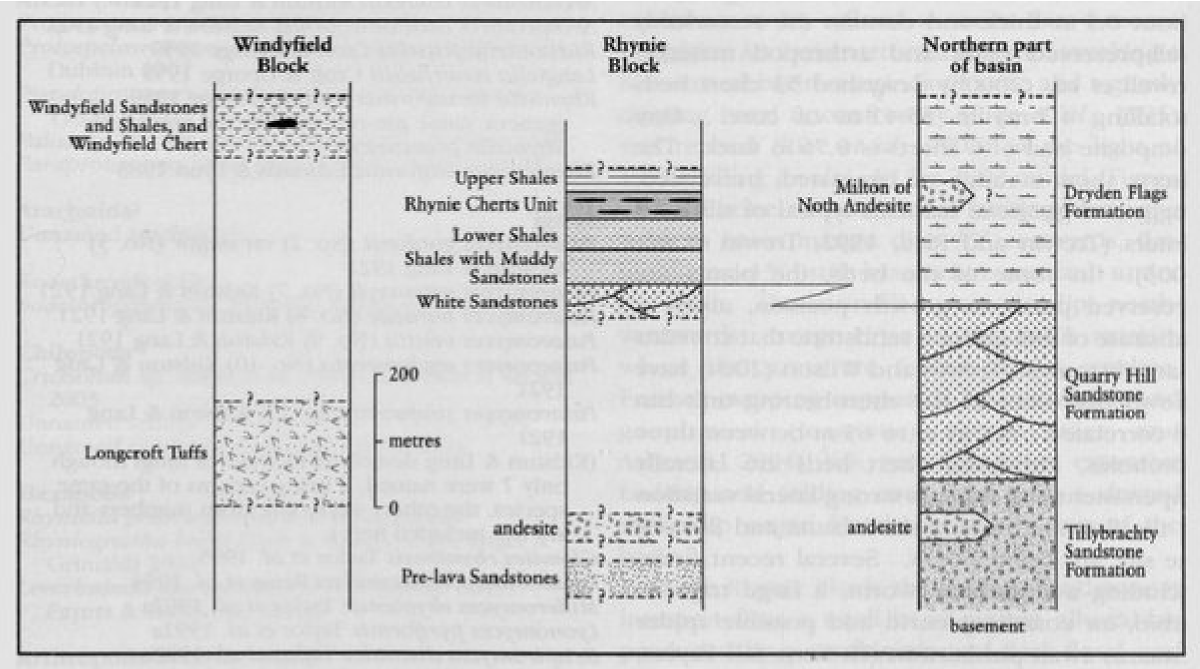
Conclusions

The GCR site at Rhynie is arguably the most important Old Red Sandstone site in Great Britain and one of the most important in the world. In addition to its status as a unique Early Devonian faunal and floral lagerstatte, it is also one of the earliest-known occurrences of the surface expression of a hydrothermal spring system. The strata include cherts that contain an exceptionally well-preserved, silicified, internationally important early land-plant and arthropod assemblage, the whole in-situ biota providing an insight into plant and arthropod evolution and the development of terrestrial ecosystems. The fossiliferous horizons are placed into a context of evolving geological environments at the margins of a small, subsiding basin. Initial alluvial-fan deposition was followed by the eruption of andesitic lavas, marking the local onset of volcanicity. Subsequent sedimentation was on an alluvial plain with ephemeral lakes and ponds. The climate throughout was semi-arid and seasonally wet. As volcanicity waned, the basin-margin faults acted as conduits for silica-rich, mineralized fluids. These emerged on the alluvial plain as hot springs and preserved the biota in siliceous sinters, now represented by the Rhynie and Windyfield cherts.

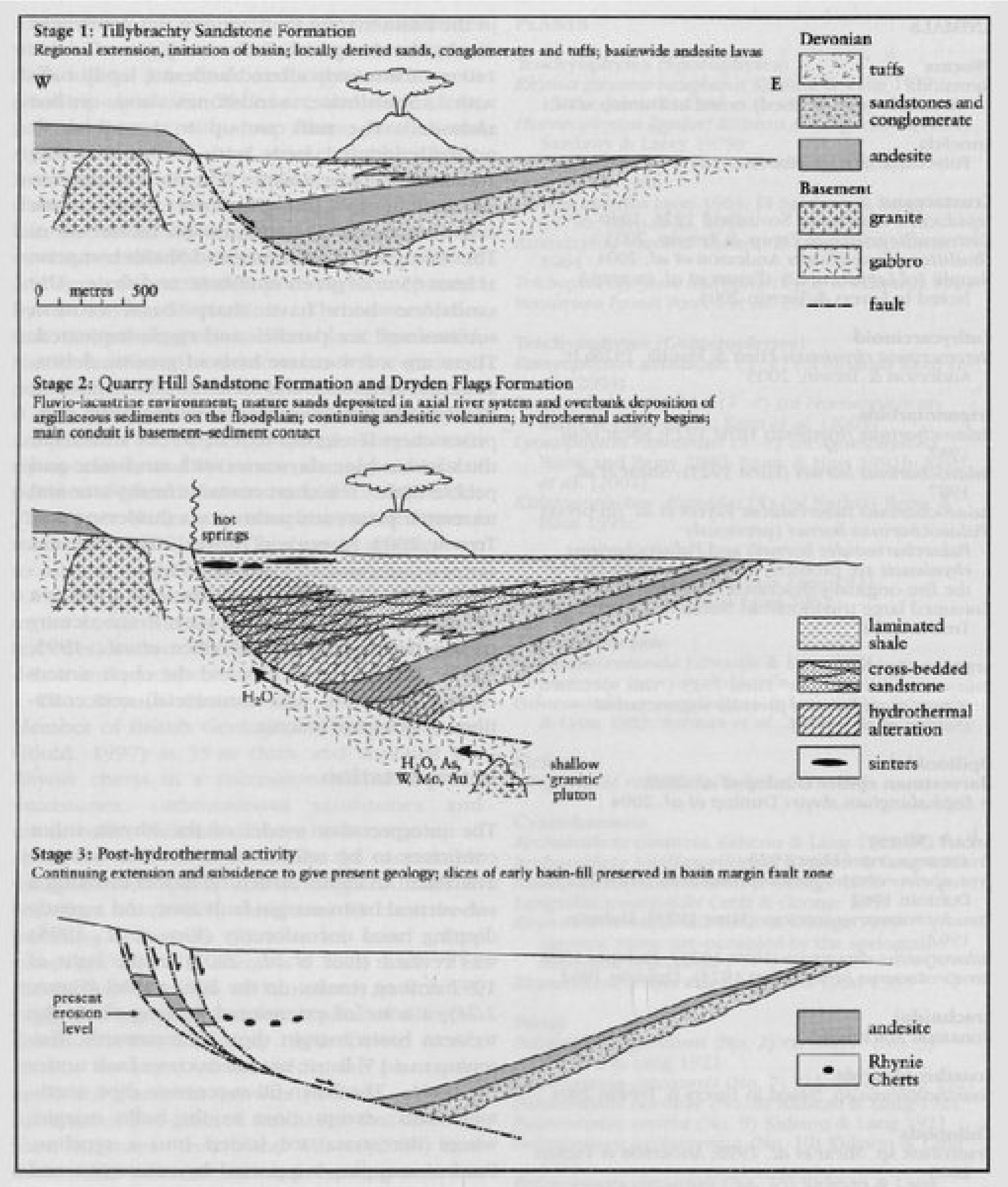
References



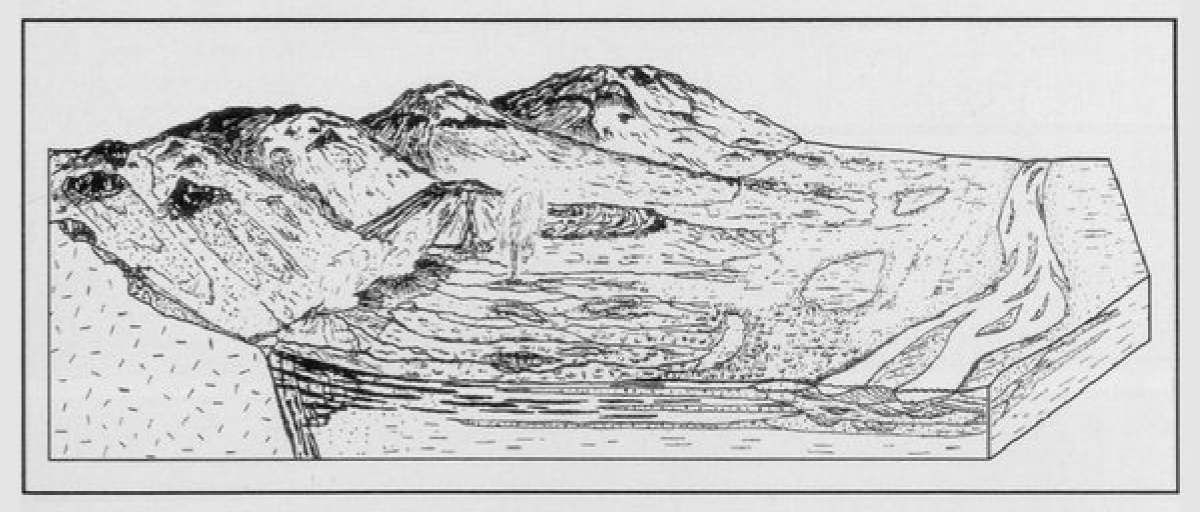
(Figure 2.72) Geological map of the area of the Rhynie GCR site. Inset maps show location of the figure. After Rice et al. (2002). See Rice and Ashcroft (2004) for a new structural interpretation of the northern part of the basin.



(Figure 2.73) *Generalized stratigraphy and basin correlations of the Rhynie Basin. After Rice et al. (2002).*



(Figure 2.74) *Evolution of the Rhynie Basin and hot spring development. After Rice et al. (2002).*



(Figure 2.75) *Cartoon view looking north to illustrate the Rhynie hot spring system and the low-angle sinter apron crossed by streams emanating from hot spring vents. Plants colonized the apron along stream banks and ponds, and on alluvial floodplain areas. The sinter apron was periodically flooded by waters from the axial river system. Some coarse detritus and reworked volcanic ejecta were sourced from the west. After Trewin and Wilson (2004).*