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Alluvial fan, braided stream and possible marine shoreface deposits of the Lower Palaeozoic Erquy-Fréhel Group, northern Brittany

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The Lower Palaeozoic Erquy-Fréhel Group comprises the Erquy and Fréhel Formations of c.85m and c. 360m thicknesses respectively. The basal 40m of the Erquy Formation consists of red-brown subangular conglomerate and minor sandstone representing deposition on a stream-dominated alluvial fan. An overlying 3m thick sequence of red sandy mudstone constitutes a fan abandonment facies. In part interbedded with, and then succeeding the fan abandonment facies is 10m of trough cross-stratified, locally pebbly sandstone reflecting braided stream deposition. This association in turn is overlain by 30m of flat bedded and large and small scale cross-stratified, mature quartz arenite interpreted to represent deposition on a marine shoreface.

At the base of the overlying Fréhel Formation is 4 to 12m of red-brown subangular conglomerate recording a return to alluvial fan deposition. This was possibly in response to a base level fall accompanying marine regression. This is succeeded by approximately 50m of interbedded pebble conglomerate and trough crossstratified sandstone grading into 300m of trough cross-stratified red sandstone with minor shale. These latter two sequences were deposited by a major eastwards draining, gravelly to sandy braided river.

The above depositional sequences are modelled as filling an east-west orientated graben with marginal alluvial fans draining laterally into a longitudinal braided river. The interval of marine shoreface sedimentation is thought to reflect a rise in sea level with consequent flooding of the basin axis from the east.

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Introduction and geological setting

The Erquy-Fréhel Group is one of several red-bed sequences of northern France and the Channel Islands believed to have been deposited in response to the final stages of Cadomian uplift and erosion (Renouf 1974; Went and Andrews 1990). This sequence has been the subject of keen debate over the past few years regarding its age, stratigraphic relationship to the underlying Erquy Volcanic Formation and possible Cambro-Ordovician, post-orogenic setting (Cogné 1963; Cogné *et al.* 1980; Shufflebotham and Roach 1985). This paper provides a sedimentological account and depositional model for the Erquy-Fréhel Group which it is hoped will be of some use in constraining future discussion.

The geology of northern Brittany is dominated by Precambrian and Lower Palaeozoic rocks of the Cadomian orogenic cycle. The Precambrian basement of the region comprises local relics of Icartian crust (c.2000Ma) succeeded by a sequence typically consisting of deep water sandstones and mudstones, and both subaqueous and subaerial volcanic rocks named the Brioverian (750-580Ma). These sequences were deformed during the late Precambrian Cadomian Orogeny (590-540Ma), an event accompanied and post-dated by considerable calc-alkaline plutonism. A regional unconformity separates the Precambrian from the Lower Palaeozoic sequences of the region which are commonly of a redbed character. It is generally accepted that the northern Brittany and Normandy areas avoided major reworking during the Hercynian Orogeny and hence, the Precambrian and Lower Palaeozoic rocks of the region are well preserved.

The Erquy-Fréhel Group

The Erquy-Fréhel Group comprises two formations and is exposed in three main outcrops on the Côtes du Nord, northern Brittany (Fig. 1). The Erquy Formation (c.85m thick) rests with uncertain relationship on the underlying Erquy Volcanic Formation (see Cogné *et al.* 1980 and Shufflebotham and Roach 1985 for contrasting interpretations) and is restricted to the westernmost of the outcrops. The Fréhel Formation (c.360m thick) overlaps the Erquy Formation eastwards onto crystalline basement of the Fort de la Latte complex.

The Erquy Formation

The Erquy Formation comprises four facies assemblages or depositional members. These have been named by Went (1989, in part modified from Pruvost and Waterlot 1936) the Erquy Conglomerate (c.40m thick), the Red Mudstone of Pointe de la Trois Pierres (c.3m thick), the Pebbly Sandstone of Pointe de la Trois Pierres (c. 10m thick) and the Erquy Quartzite (c.30m thick) (Figs 1 and 2). A measured section through almost the entire Erquy Formation is shown in Fig. 2.

Erquy Conglomerate

Description

This association consists of conglomerates bedded on a metre scale with minor intercalated sandstones. In detail the conglomerates are typically arranged in beds decimetres to a little over a metre in thickness, or less commonly are thinly bedded on the scale of 5-10cm. The conglomerate beds typically exhibit a crude subhorizontal stratification (Fig. 3a), although locally they may show more massive textures, and less commonly still are planar cross-bedded on a decimetre scale. The conglomerates are clast- to matrix-supported, the clasts angular to subangular, locally imbricated, and set in a red matrix of granular sand. Local source clasts are common and include vein quartz, cherts, siltstones and sandstones, red intraformational mudstones and a few intermediate and basic volcanics.

Intercalated, laterally impersistent sandstones are locally pebbly, occur most commonly in beds a few tens of centimetres in thickness, and are massive, trough cross-stratified, or faintly parallel laminated. The limited number of palaeocurrent readings obtained from the Erquy Conglomerate (Fig. 2) were obtained mainly from the trough cross-stratified sandstones, together with isolated occurrences of clast imbrication and planar cross-bedding in the conglomerates.

Interpretation

The Erquy Conglomerate is believed to represent deposition on a stream-dominated alluvial fan, an interpretation broadly supported by the coarse-grained immature texture of the unit and presence of local source clasts.

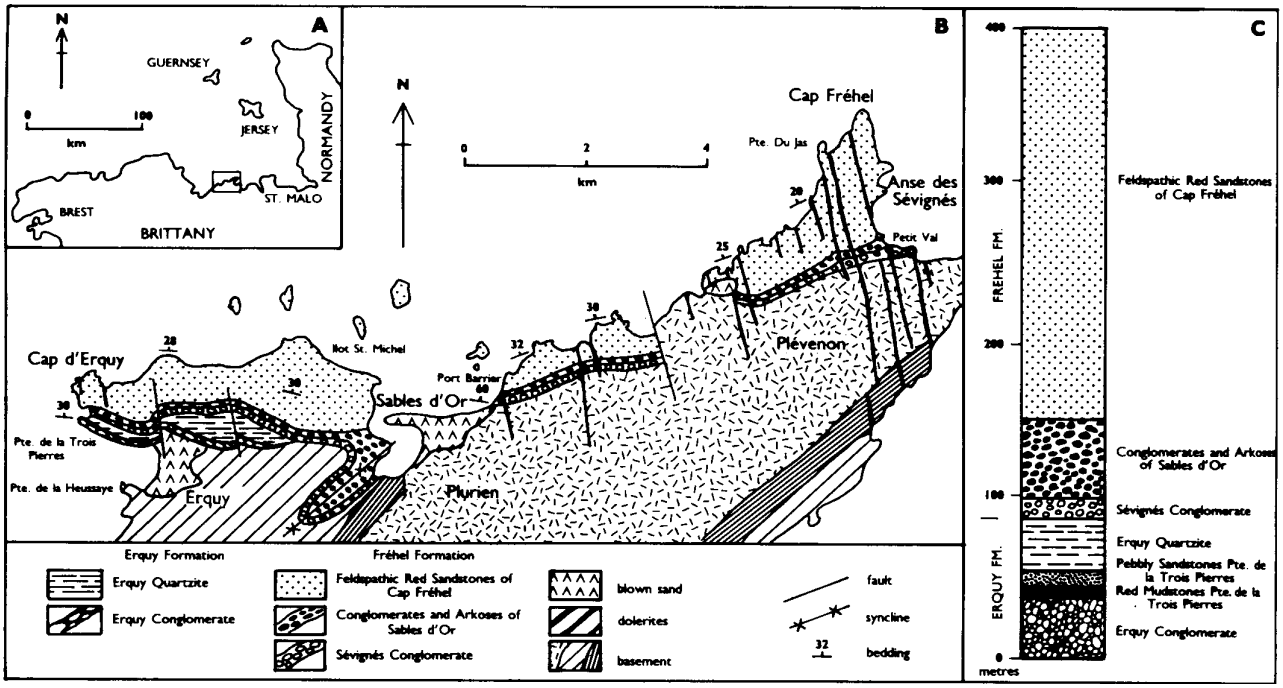

Figure 1. Location, geological map and stratigraphic subdivision of the Erquy-Fréhel Group, modified from Pruvost and Waterlot (1936). Vertical scale on stratigraphic summary is approximate.

The stratified and generally well organised character of the conglomerate beds indicates that they were stream deposited probably reflecting deposition on longitudinal or related gravelly bars (Smith 1974; Hein and Walker 1977). These bars rarely develop slipfaces, hence the limited occurrences of decimetre scale cross-bedding in the conglomerates of this association. The subordinate interbedded sandstones are commonly restricted in their lateral extent and may have been deposited as 'in-channel' dunes, cut-off channel fills and bar sand wedges (Rust 1972; Smith 1974).

Red Mudstone of Pointe de la Trois Pierres

Description

This association abruptly overlies the Erquy Conglomerate (Fig. 2). In its upper part it occurs interbedded with lenticular units of sandstone of the succeeding facies association (Fig. 3b). It consists of a fairly uniform sequence of deep-red coloured, silty, sandy and locally granular mudstones. Sedimentary structures other than a faint crude subhorizontal lamination are rare. The impression fossil *Arumberia* sp. has been found in the deposits of this association (Bland 1984).

Interpretation

These sediments are interpreted to have been deposited from low energy sheet flow (Hogg 1982) and possibly also from suspension in temporarily ponded waters. The replacement of graveliferous with muddy styles of fan sedimentation is thought to record the end to marked source area dissection in this area and hence, to the abandonment of the alluvial fan. The impression fossil *Arumberia* sp. is believed to have been left by an algae which is thought to have lived, at least locally, in low energy, freshwater environments and may have survived in ephemeral pools of water on lower fan segments (B.H. Bland, pers. comm.).

Pebbly Sandstone of Pointe de la Trois Pierres

Description

This association consists of coarse-grained, locally pebbly, trough cross-stratified sandstones that are crudely bedded on a decimetre scale (Fig. 2). The lowermost units of this association are interbedded with the red `fan abandonment' mudstones described above, and exhibit lenticular channel-form geometries (Fig. 3b). The pebble clasts of the upper parts of the sequence are subrounded to rounded but compositionally indistinguishable from those occurring in the Erquy Conglomerate. The limited numbers of palaeocurrents recorded from this association (Fig. 2) were obtained from trough foresets.

Interpretation

These sediments are interpreted to have been deposited in a sandy, braided river. They may be equivalent in terms of sedimentary environment to the cross-stratified sandstones of the Fréhel Formation (i.e. Conglomerates and Arkoses of Sables d'Or and Feldspathic Red Sandstone of Cap Fréhel). A fluvial origin for these sandstones is supported by the preservation of lenticular channel-form geometries and widespread trough crossstratification.

Erquy Quartzite

Description

The Erquy Quartzite is a pinkish-white, coarse- to very coarse-grained, well sorted, mineralogically mature sandstone that is, in general appearance, regularly bedded on a metre scale (Fig. 3c). The sandstones in the lower parts of the sequence are locally pebbly. Flat to gently inclined stratification is the dominant sedimentary structure. Above 59m in Fig. 2, the most common other structure is moderately large scale (0.5-1.1m high) planar asymptotic cross-stratification. Small scale trough cross-stratification (<20cm high) is also locally present. Below 59m, flat stratification is less abundant whilst large and small scale crossstratification and low angle cross-stratification are common. The latter locally occurs in association with smaller scale planar crossstrata. Palaeocurrents obtained from all structures on the line of the measured section are remarkably consistent. A north directed mode is most prominent with subsidiary modes orientated west and possibly also east (Figs 2 and 4).

Interpretation

The Erquy Quartzite is interpreted to reflect deposition on a high energy, wave and storm dominated, marine shoreface. In the absence of fossil evidence, this interpretation is necessarily based on such features as sandstone maturity, grain size, and the association of sedimentary structures and their palaeocurrents. The strandline is thought most likely to have been orientated roughly east-west as this is inferred to be parallel with the basin margin and perpendicular to the local fluvial palaeoslope.

The textural and mineralogical maturity of this association of

sandstones is believed to reflect the marked abrasion and winnowing of the sediment in a coastal setting (cf. Heward 1981). The sequence of structures below 59m in Fig. 2, containing abundant large and small scale cross-strata, low angle cross-stratification and subordinate flat stratification is interpreted to reflect near-shore bar and trough deposition in a wave dominated upper shoreface setting (Hunter *et al.* 1979; Clifton 1981). The flat stratified sandstones which predominate above 59m are interpreted for the most part as storm deposits of the middle to lower shoreface (cf. Kumar and Sanders 1976).

The predominant palaeocurrent mode is to the north and offshore. The large scale planar asymptotic cross-sets were deposited by mainly northwards flowing, strong, unidirectional currents. These structures, which occur throughout the sequence, are interpreted to have been rip-current generated. A significant secondary palaeocurrent mode is directed roughly westwards. This may reflect a significant component of longshore sediment transport. The domination of west over east directed longshore currents would suggest that the dominant wave approach was from the east. This would be from the open sea in the palaeogeographic reconstruction of Went and Andrews (1990).

Fréhel Formation

The Fréhel Formation consists of three facies assemblages or depositional members. These have been named by Pruvost and Waterlot (1936) the Sévignés Conglomerate (4-12m thick), the Conglomerates and Arkoses of Sables d'Or (c.50m thick), and the Feldspathic Red Sandstones of Cap Fréhel (c.300m thick).

Sévignés Conglomerate

Description

The Sévignés Conglomerate is well exposed behind the village of Erquy and at Petit Val in the Anse des Sévignés (Fig. 1, 2 and 3d). At Erquy the Sévignés Conglomerate overlies an erosion surface exhibiting up to 2m of relief cut into the top of the Erquy Quartzite. This is filled with red-brown, clast to matrix supported conglomerate. Similar conglomerates, but which exhibit bedding on a decimetre scale and with perhaps matrix supported textures slightly more prominent succeed these ponded fills (Fig. 2). The bedding in these units is parallel to that of the Erquy Quartzite. Pebble clasts are mainly subangular to angular and include vein quartz, cherts, sandstones, volcanics including a purple porphyritic andesite, and intraformational mudstones.

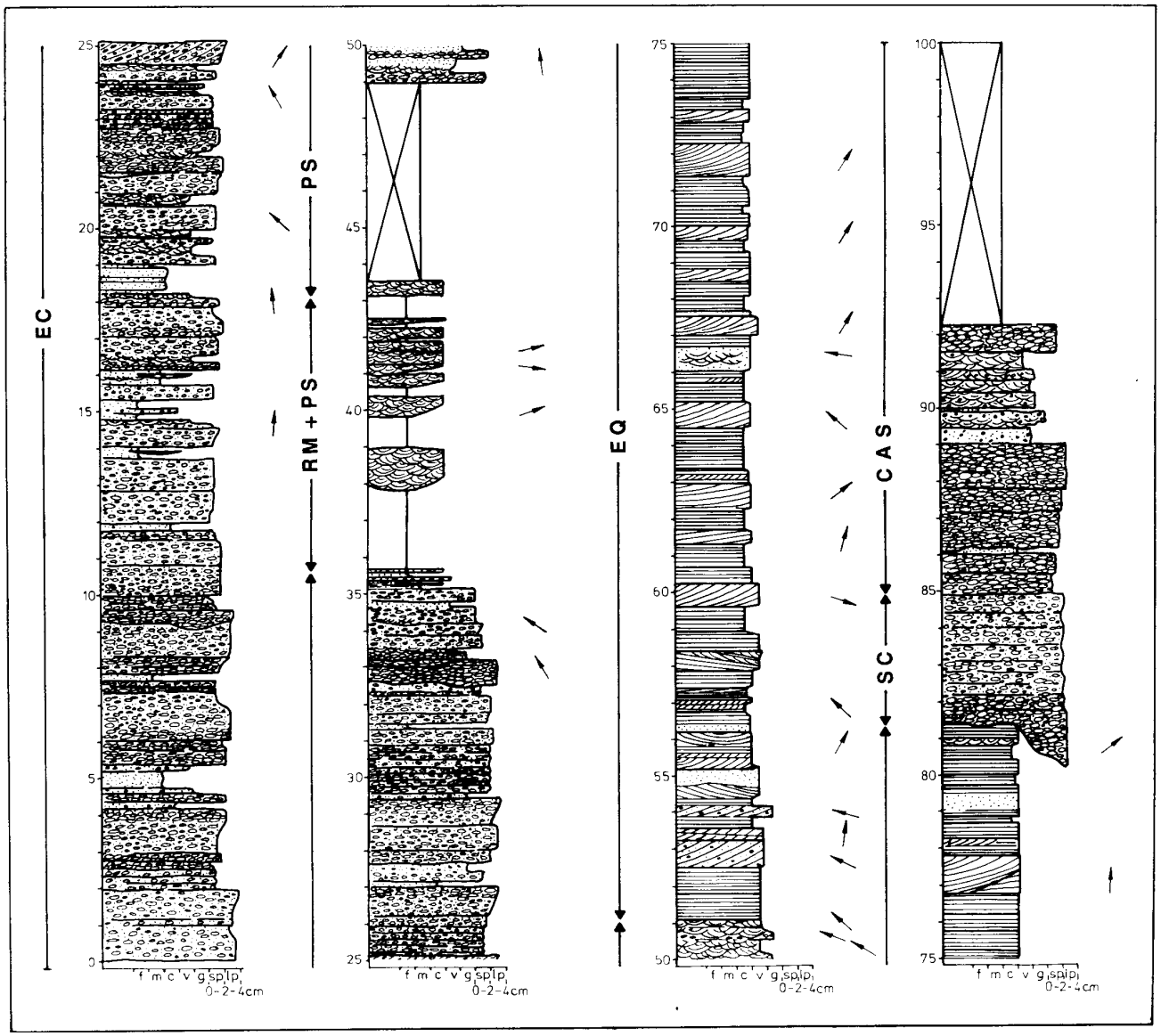

Figure 2. Measured section through the Erquy Formation and lowermost Fréhel Formation at Pointe de la Trois Pierres. Vertical scale is in metres. Stratigraphic subdivisions: EC = Erquy Conglomerate, RM = Red Mudstones of Pointe de la Trois Pierres, PS = Pebbly Sandstone of Pointe de la Trois Pierres, EQ = Erquy Quartzite, SC = Sévignés Conglomerate, CAS = Conglomerates and Arkoses of Sables d'Or. Palaeocurrent arrows: north to top of page.

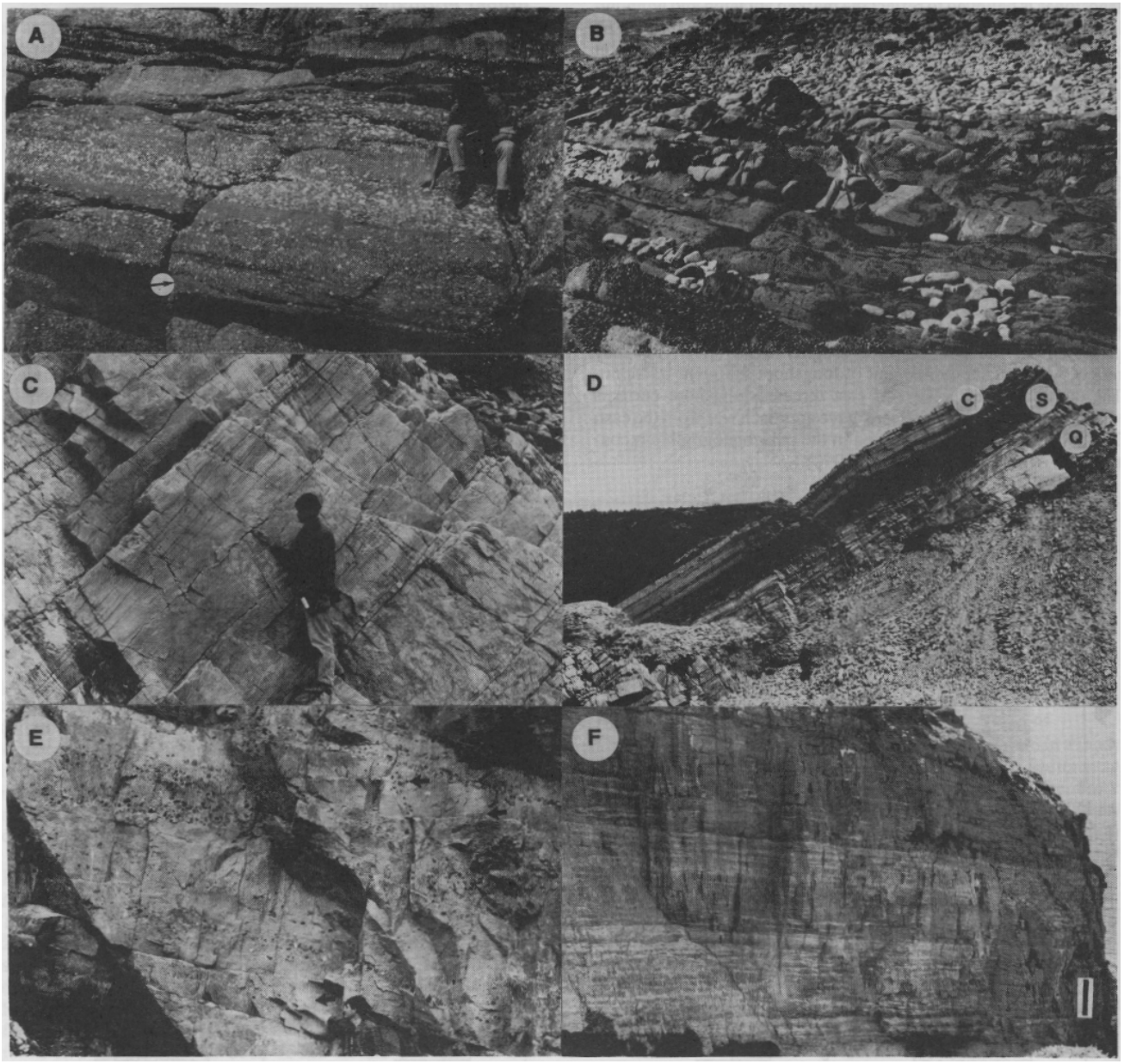

Figure 3. a) Horizontally stratified conglomerate and trough cross-stratified sandstone (arrowed) of the Erquy Conglomerate, Pointe de la Trois Pierres.
b) Lenticular unit of trough cross-stratified sandstone encased in red sandy mudstone, Pointe de la Trois Pierres. Corresponds to 35-40m, Fig 2.
c) Flat bedded and gently inclined stratification in the Erquy Quartzite, Pointe de la Trois Pierres.
d) Erosion surface separating Erquy and Fréhel Formations at the western end of the quarry at Erquy. The Sévignés Conglomerate (S) is c.4m thick at this locality. C = Conglomerates and Arkoses of Sables d'Or, Q = Erquy Quartzite.
e) Pebble conglomerate and trough cross-stratified pebbly sandstone (arrowed), Conglomerates and Arkoses of Sables d'Or, Port Barrier, Sables d'Or.
f) Repetitively stacked, lenticular to sheet-like packages of trough cross-stratified sandstone, Feldspathic Red Sandstones of Cap Fréhel, Pointe du Jaz, Cap Fréhel.

At Petit Val in the Anse des Sévignés, the Sévignés Conglomerate is unconformable on weathered granodiorites of the Fort de la Latte complex. This weathering may have occurred immediately prior to deposition (Went 1991). Overlying an erosion surface cut into the weathered basement is a chaotic-textured boulder conglomerate up to 3m thick. The conglomerate is coarse-grained throughout, clast-supported, unsorted and non-stratified. Gravel sized clasts are mostly subrounded to rounded. Compositionally, sandstone clasts of probable Brioverian affinity predominate. Also present, however, are cherts, vein quartz, and purple coloured porphyritic andesites. Clasts similar to that of the local basement are absent. Succeeding this boulder bed are c.12m of red-brown, pebble conglomerates, bedded on a decimetre scale, and locally intercalated with thin laterally impersistent sandstones. Pebble clasts are mostly subangular and compositionally similar to those occurring in the underlying boulder bed. Imbrication of pebble clasts is locally evident and was used to estimate palaeocurrent flow (Fig. 4a).

Interpretation

The Sévignés Conglomerate represents a return to 'alluvial fan' deposition, an interpretation broadly supported by the coarse-grained immature texture of the unit.

At Erquy, the erosion surface upon which the Sévignés Conglomerate rests is interpreted to record a short period of base level lowering. That this coincides with an end to marine quartzite deposition suggests perhaps, that base level lowering may have resulted from marine regression. The Sévignés Conglomerate itself is believed to represent a distal fan segment or sheet, introduced into the succession as a result of a relatively short lived episode of fan progradation. This areal expansion of the fans may

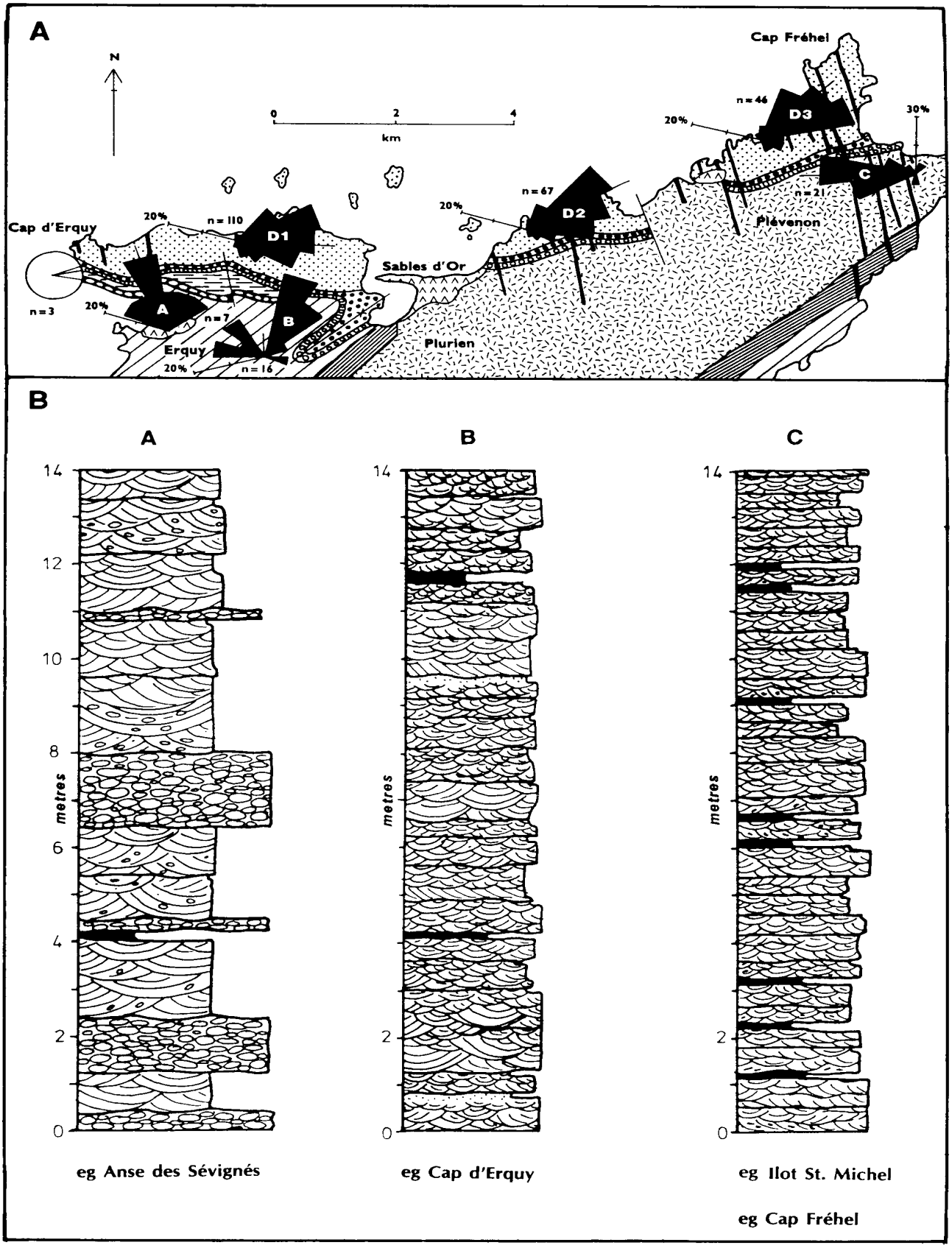

Figure 4. a) Palaeocurrent summary: n = number of palaeocurrent measurements. Rose diagrams: A = Erquy Conglomerate; B = Erquy Quartzite; C = Sévignés Conglomerate; Dl, D2, D3 = Conglomerate and Arkoses of Sables d'Or and Feldspathic Red Sandstones of Cap Fréhel. b) Schematic vertical profiles from the Fréhel Formation: A = Conglomerates and Arkoses of Sables d'Or; B = Feldspathic Red Sandstones of Cap Fréhel (lower); C = Feldspathic Red Sandstones of Cap Fréhel (upper).

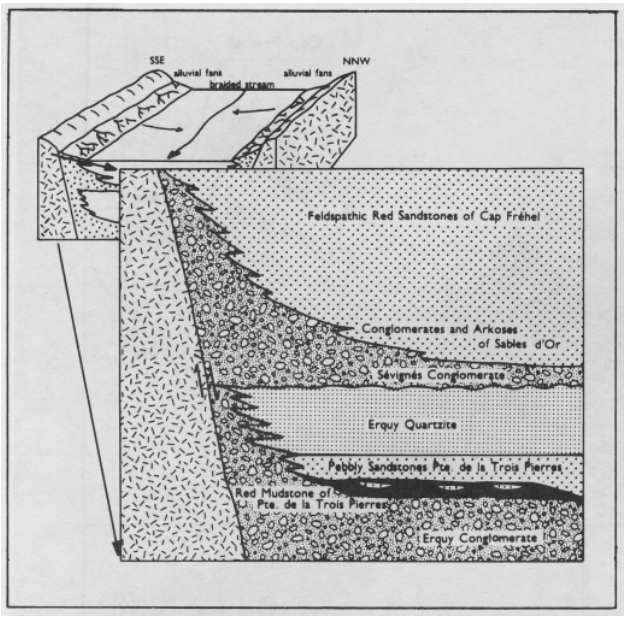

Figure 5. Depositional model accounting for the development of the Erquy Fréhel Group sequence at a fault controlled basin margin.

have resulted from the aforementioned drop in base level, with as a consequence, source area streams dissecting both the hinterland and pre-existing sediments (cf. Heward 1978).

At Petit Val in the Anse des Sévignés the chaotic-textured boulder conglomerate is interpreted to represent deposition in a bedrock stream by a single non-cohesive debris flow (cf. Pierson 1981). The lack of local basement clasts and the presence and rounded character of the exotic sandstone clasts preclude a colluvial origin for this unit. The lack of stratification, poor sorting and dispersal of large boulders throughout the bed, however, do point to transport and deposition *en masse* (Nemec and Steel 1984). In marked contrast, the overlying bedded pebble conglomerates clearly suggest a more selective and discontinuous accretion of the framework clasts. These units, which are very similar to those of the Erquy Conglomerate, represent deposition from pebbly streams.

Conglomerates and Arkoses of Sables d'Or and Feldspathic Red Sandstones of Cap Fréhel

Description

The Conglomerates and Arkoses of Sables d'Or are exposed in each of the three main outcrops (Fig. 1) and consist of interbedded units of conglomerate and (commonly pebbly) feldspathic sandstone (Fig. 4b). In the lowermost parts of the sequence conglomerate beds are up to 1.5m thick, although more typically and throughout occur as thinner units a few decimetres in thickness. The conglomerates are clast- to matrix-supported, moderately to well sorted, and contain well rounded pebble and locally small cobble sized clasts. The conglomerates are gradational into pebbly sandstones. Clast types are similar to those present in the Erquy Conglomerate and Sévignés Conglomerate and include vein quartz, chert, silicified and non-silicified volcanics and minor intraformational mudstones. Interbedded coarse-grained sandstones are commonly pebbly and ubiquitously trough cross-stratified. Cross-stratification is of a large scale with sets attaining a maximum height of around lm (Fig. 3e). The cross-strata occur bounded between erosion surfaces spaced approximately 1-2m apart which define lenticular to sheet-like parcels of sediment.

The Conglomerates and Arkoses of Sables d'Or grade into the Feldspathic Red Sandstones of Cap Fréhel. The latter are well exposed around the coast in each of the three main outcrops and on several small islands which are accessible at low tide (e.g. Ilot St Michel, Fig. 1). Representative sections through the basal and upper parts of the member are shown in Fig. 4b. The sandstones are regularly bedded on a decimetre scale, the bounding erosion (bedding) surfaces defining lenticular to sheet-like sediment bodies (Fig. 3f). Beds typically consist of cosets of trough cross-stratification with set heights ranging from c. 10 to 50cm. The scale of the cross-stratification and bed thickness both decrease up the 300m section (mean cross-set height decreasing from c.40 to 10cm, and bed thickness from c.75 to 35cm) concomitant with a decrease in modal grain size from coarse to medium (feldspathic) sand. Locally, laterally impersistent finer grained, massive to faintly parallel laminated muddy sandstones occur interbedded with the coarser cross-stratified sandstones. These intercalations are rare in the lower and medial parts of the sequence but relatively common in the uppermost sections (e.g. Ilot St Michel).

Palaeocurrents were obtained form numerous coastal exposures of the Conglomerates and Arkoses of Sables d'Or and Feldspathic Red Sandstones of Cap Fréhel members in each of the three main outcrops, principally from bedding plane exposures of trough axes. The re-orientated readings are shown as rose diagrams in Fig. 4a. The data point to current flow to the east and north-east, with low overall dispersion.

Interpretation

These sediments are believed to have been deposited by a major eastwards flowing gravelly to sandy, probably braided river (cf. Miall 1970), an interpretation broadly supported by the textural immaturity of the sandstones and the unidirectional character of the palaeocurrents.

The interbedded conglomerates and sandstones are interpreted to represent deposition in channel-bar environments. Thicker conglomerate beds may represent deposition on the upstream parts of longitudinal bars whilst thinner lenses of conglomerate associated with overlying cosets of trough cross-strata are thought most likely to be of channel lag origins (cf. Williams and Rust 1969). The rounded nature of the gravel clasts when compared with the Erquy and Sévignés Conglomerates, is taken to reflect the longer periods of abrasion suffered by clasts in major rivers when compared with small alluvial fans. The trough cross-stratified sandstones which predominate throughout most of the sequence were deposited as sinuous crested megaripples (Harms *et al.* 1975) most probably in the deeper main channel environments where the flow would have been swift and deep (cf. Cant and Walker 1978).

The repetitive nature of the succession probably reflects at the largest scale (10's of metres), the multi-storey stacking of braided river channel belts, and at a smaller scale (metres), the selective preservation of deep channel deposits during the aggradation of individual channel belts (cf. Bridge and Leeder 1979). The erosion surfaces which bound cosets of cross-strata are thought to reflect repeated episodes of channel migration and avulsion within the (braided) river tract (cf. Coleman 1969; Campbell 1976), with some of the more laterally persistent horizons possibly marking more major channel belt bases (Fig. 3f). High level sediments (e.g. bar-top sediments, overbank fines) were not preserved as a result of repeated reworking by subsequent erosional events. The locally developed, laterally impersistent units of faintly laminated to massive, muddy sandstone are interpreted to have been deposited in abandoned or slough channels (cf. Rust 1972).

Palaeocurrents obtained from this succession indicate flow to the east and north-east. This is at a high angle to the palaeocurrents obtained from the alluvial fan deposits (Erquy Conglomerate, Sévignés Conglomerate) and is parallel to the prevailing (Cadomian) structural grain of the region. These deposits are therefore consistent with, and interpreted to represent, those of a longitudinal trunk river to which the alluvial fans many have been tributaries (cf. Miall 1981). Such an interpretation is further supported by the similarity of the gravel clast types present in the Conglomerates and Arkoses of Sables d'Or and Sévignés Conglomerate members. Feldspar, however, which is absent in the Sévignés Conglomerate (and the Erquy Formation) is abundant in the remainder of the Fréhel Formation pointing to the fact that the longitudinal river system was tapping a more distant source in addition.

Depositional model and tectonic setting

The foregoing accounts on each of the depositional assemblages are integrated into a depositional model for the Erquy-Fréhel Group, illustrated in Fig. 5. The depositional basin is modelled as an E-W to ENE-WSW orientated graben (or half graben), an interpretation consistent with the preliminary results of structural work carried out on the area (Ballard *et al.* 1988).

Alluvial fans are believed to have shed detritus from the basin margin to the south (and possibly also from the north). Episodes of fan growth/progradation are interpreted to have resulted in the deposition of the Erquy and Sévignés Conglomerates. Gravelly to sandy braided rivers are modelled as draining the basin axis towards the (Cambrian) shoreline that lay to the east. Deposition of the Conglomerates and Arkoses of Sables d'Or, Feldspathic Red Sandstones of Cap Fréhel and possibly the Pebbly Sandstone of Pointe de la Trois Pierres is thought to have occurred in this environment. The former two assemblages form part of a finingupwards megasequence beginning with the Sévignés Conglomerate. Such alluvial fan to braided stream type megacycles are commonly ascribed a tectonic control, with episodes of basin margin fault activity resulting in the progradation of alluvial fans and subsequent source area erosion and scarp retreat facilitating fan retrogression and onlap by axially draining river deposits (e.g. Heward 1978). The Erquy Conglomerate to Pebbly Sandstone of Pointe de la Trois Pierres succession of the Erquy Formation might be considered likewise.

The Erquy Quartzite is interpreted to represent an interval of marine shoreface sedimentation in an otherwise alluvial sequence and is thought to have resulted from a relative rise in sea level with flooding of the basin axis from the east. Such rises in sea level and westwards directed episodes of marine transgression have been recorded from the Cambrian of Normandy (Dore 1972). Marine regression may have resulted in base level lowering, alluvial incision and the progradation of marginal fans to produce a sheet of subangular conglomerate over the Erquy Quartzite, thereby initiating deposition of the Fréhel Formation in this area.

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