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THE CISMON APTICORE (SOUTHERN ALPS, ITALY): A "REFERENCE SECTION " FOR THE LOWER CRETACEOUS AT LOW LATITUDES

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Riassunto. Il pozzo APTICORE nella Valle del Cismon (Bacino di Belluno, Alpi Meridionali) ha penetrato 131,8 metri di calcari, marne e "black shales". La sezione carotata corrisponde all'intervallo Aptiano Superiore-Hauteriviano Superiore (circa 117-130 Ma) di cui rappresenta uno standard stratigrafico per le basse latitudini a livello mondiale. È stato eseguito un carotaggio continuo con un recupero pari al 100% di carote di ottima qualità. Il pozzo é stato anche analizzato con metodi geofisici (logging) utilizzando strumenti all'avanguardia. Il materiale recuperato costituisce l'archivio geologico più completo per documentare e ricostruire i cambiamenti globali di paleoambiente, organismi, geochimica e paleotemperatura degli oceani del Cretacico Inferiore. Viene qui presentata la descrizione-base delle operazioni in situ, della litologia e cronostratigrafia della successione recuperata, nonché le specifiche tecniche degli strumenti utilizzati.

Abstract. APTICORE at the Cismon Valley (Belluno Basin, Southern Alps) penetrated 131.8 m of limestones, marlstones and "black shales". The cored interval extends from the Upper Aptian down to the lower Upper Hauterivian (about 117-130 Ma) and can be considered a "reference section" for low latitudes. The hole was continuously cored with essentially 100% recovery of excellent quality material and completely logged with state-of-the art logging tools. Freshly cored material and logs from the Cismon drill site provide the most informative records for documenting and understanding global changes in the paleoenvironment, biota, geochemistry, paleotemperature of Early Cretaceous oceans. The following is a "site report" containing descriptions of the geologic setting, field operations, basic lithology and age information, and the logging tools and techniques.

Introduction.

The coring and logging of the Lower Cretaceous section in the Cismon Valley (Southern Alps, Italy) were done within the context of a study of the Earth's responses to a period of major, global climate change. After a Valanginian "greenhouse" episode (Lini et al., 1992), the mid-Cretaceous was marked by a "greenhouse" climate (Weissert & Lini, 1991), perhaps initiated by a huge pulse of volcanism beginning in the Late Barremian and continuing into Aptian time. This study is part of a larger program called APTICORE (Larson et al., 1993). Primary objectives of this program are (a) the documentation of global oceanic anoxic events, isotopic excursions of carbon and strontium, fluctuations in abundance and diversity of planktonic communities, and paleotemperature in the oceans, and (b) the understanding of the causal linkages among various geological processes that led to the mid-Cretaceous "greenhouse" climate state.

The Cismon APTICORE will represent a "reference section" for this period of global change with coring and logging studies through the climatic transition in an expanded pelagic section that, in particular, contains both a complete carbonate and organic carbon record through the critical black shale intervals. Surface outcrop studies in the Cismon area had resulted in suggestive but incomplete data sets due to covered intervals and degradation by weathering processes, freshly cored material and logs from the Cismon drill site likely provide the most informative records.

Site location and geological setting.

The Cismon drill site is located in the Venetian Prealps, West of Feltre (prov. Belluno) along the Strada del Passo Rolle (State Road 50), at km 52.6, (46°02'43.46"N; 11°45'46.85"E; 398 m altitude) in the valley of the Cismon river (Fig. 1). The Venetian Prealps are part of the Southern Alps, a West-East structural unit delimited by the Insubric Line to the North and by the Po Plain to the South. The Southern Alps represent a portion of the southern margin of the Mesozoic Tethys, characterized by a horst and graben morphology inherited from the rifting associated with the opening of the central North Atlantic and the Ligurian Ocean. In Jurassic-Cretaceous time, the major structures of the Southern Alps are, from West to East, the Lom-

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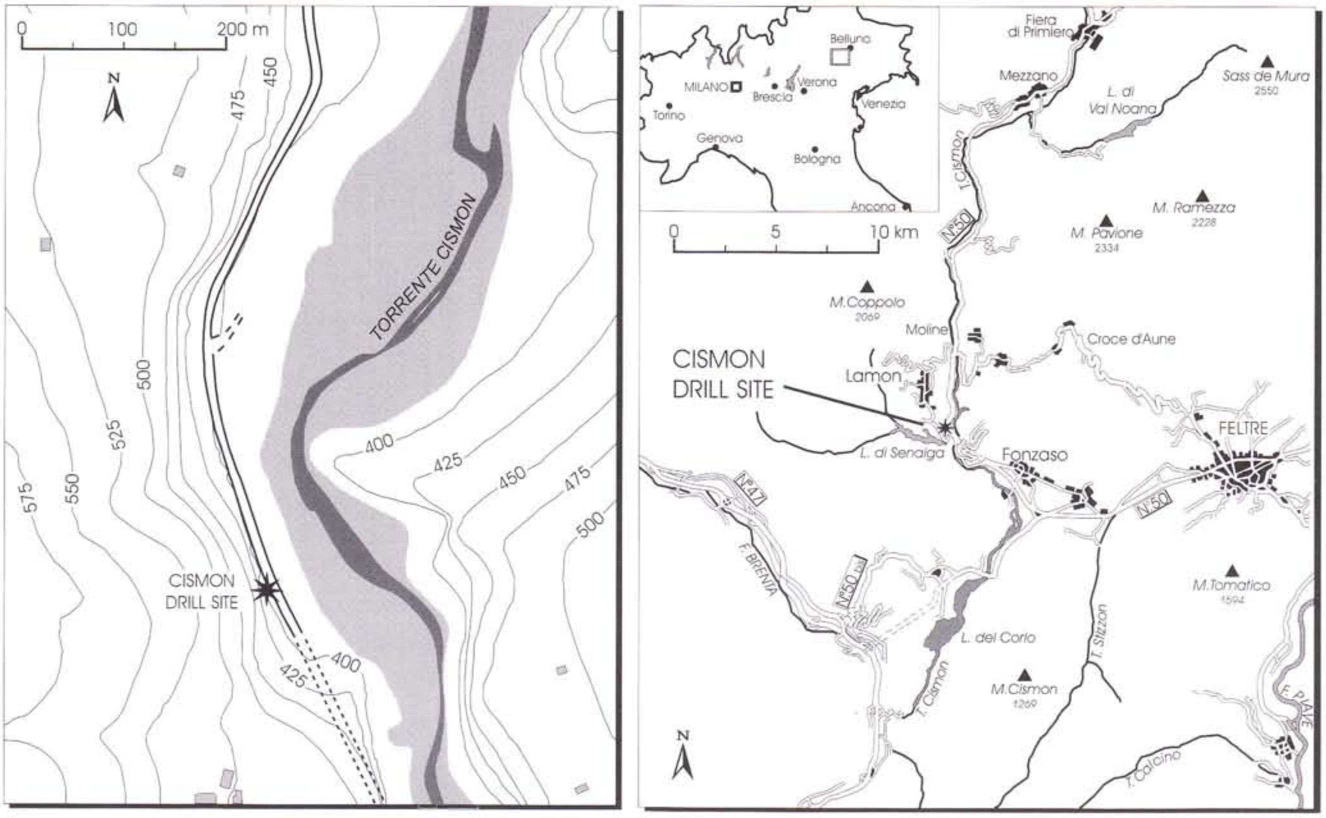


Fig. 1 - Location of the Cismon drill site.

bardy Basin, the Trento Plateau, the Belluno Basin and the Friuli Platform. The Cismon drill site is located on the eastward-deepening slope between the Trento Plateau and the Belluno Basin, at an estimated paleodepth of 1000-1500 m during the Early Cretaceous.

The Lower Cretaceous section at Cismon has been extensively studied for bio-magnetostratigraphy (Channell et al., 1979; Bralower, 1987; Bralower et al., 1994; Erba, 1994), cyclostratigraphy (Herbert, 1992) as well as for organic, inorganic and stable isotope geochemistry (Weissert et al., 1985; Weissert, 1989). The Valanginian-Aptian pelagic carbonates at Cismon were identified as a potential reference section for its regular and relatively high sedimentation rate along with the occurrence of the Lower Aptian Selli Level, the sedimentary expression of the Oceanic Anoxic Event 1a (Arthur et al., 1990).

Field operations.

Coring operations.

The Cismon drill site was located and the hole spudded on 6 November 1995 about 4 m off the paved roadway that runs along the Cismon River (Fig. 1). The "well head" referred to in Table 1 and figures was the top of the casing pipe set level with the top of a steel box used to contain the drilling mud, and was about 30 cm above ground level. Approximately the top 6 meters of the hole were cased with steel pipe and the rest left open. The Atlas Mustang A52 coring machine consisted of a water-well drilling rig mounted on the rear of a tractor similar to one used in farming operations.

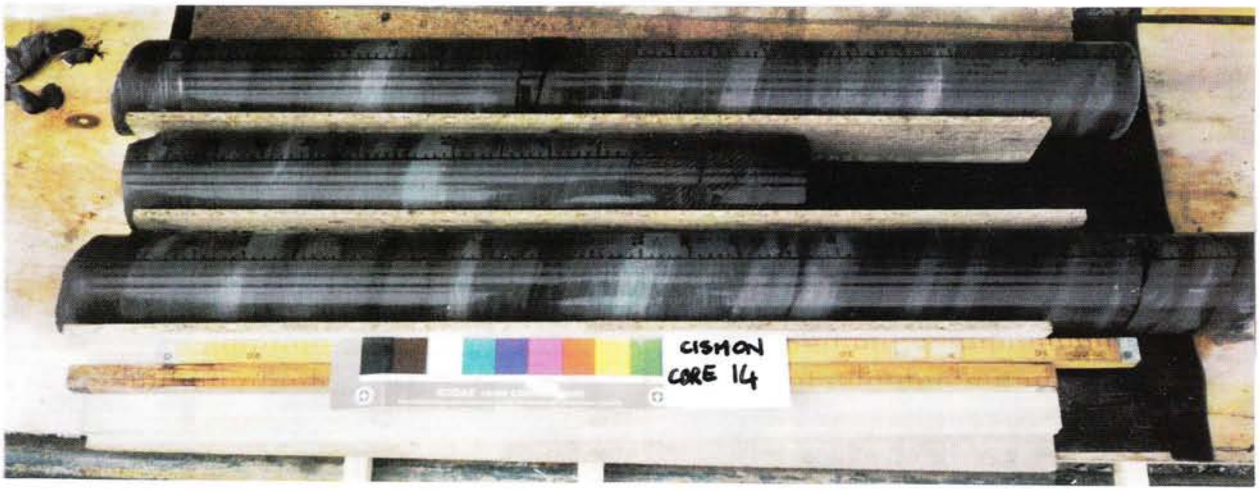
Coring was accomplished with a T2 double corer, using narrow-curf, saw-toothed drill bits that cut a 13.1 cm diameter hole and approximately 11 cm diameter cores. Cores were taken in approximate 3 m lengths using the drillpipe alone to contain the cores. Plastic core liners often utilized to core and to contain soft sediments were not used or necessary in this operation. Coring proceeded at rates that averaged slightly less than one meter per hour, so a full day's coring under optimum conditions resulted in 3 cores or about 9 m of total penetration (Tab. 1). The hole is nearly vertical, deviating linearly from true vertical at 10 meters below well head (mbwh) down to a maximum of 1.4 degrees deviation towards the north at its bottom.

The cores were extruded by hand into a U-shaped steel trough or channel of the same length as the core barrel, taking care not to invert or to lose small fragments. The cores were then moved to an adjacent description table, the fragments assembled to their "in place" configurations and the core marked and measured. As there is significant dip (17 degrees or more) throughout the hole, all depth measurements were made to the middle point of a horizon's outcrop on the surface of the core. Cores 1-8 (0-6.85 mbwh) contain many

Tab. 1 - Coring data set of the Cismon APTICORE.

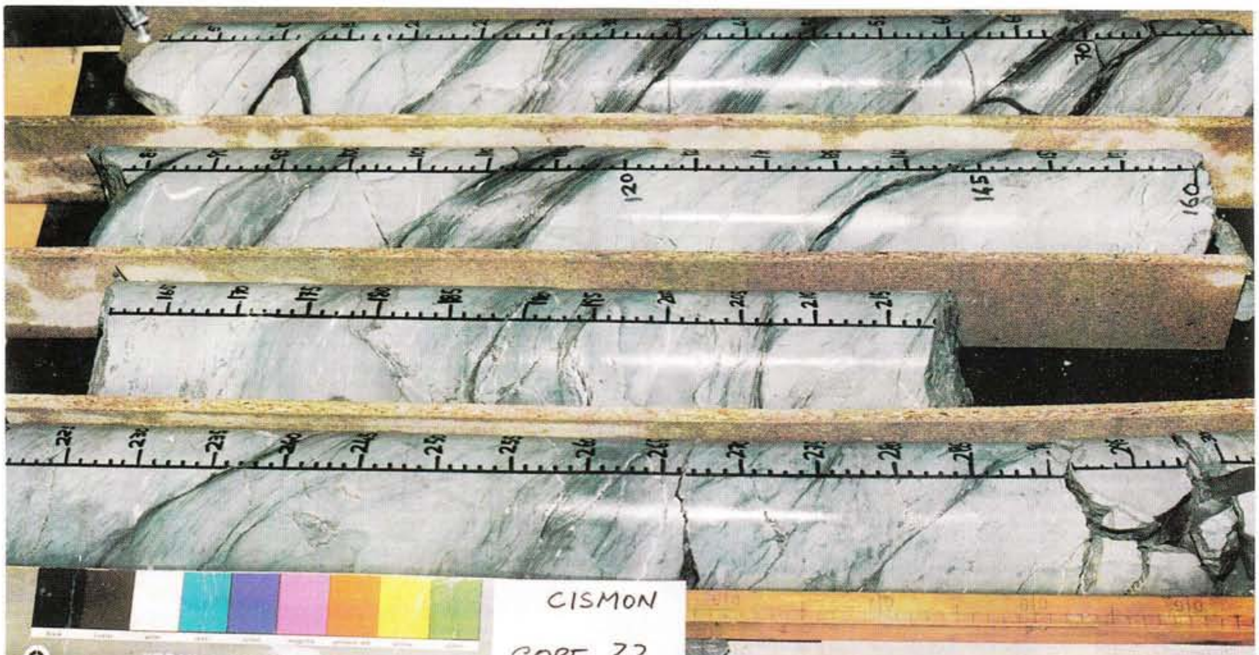
Date	Core #	Hour	Meter Below Well Head	Penetration (m)	Recovery (m)
06/11/95	1	13.30-15.45	1.20-2.00	0.80	9 pieces
	2	16.10-16.30	2.00-2.60	0.60	0.45
07/11/95	3	08.00-08.20	2.60-3.00	0.40	0.185
	4	08.30-09.45	3.00-4.70	1.70	1.915
	5	09.50-10.50	4.70-5.05	0.35	0.31
	6	11.00-12.00	5.05-6.20	1.15	1.19
	7	13.50-14.55	6.20-6.76	0.56	0.58
	8	15.10-16.00	6.76-6.85	0.09	0.09
08/11/95	9	08.40-11.15	6.85-9.20	2.35	2.35
	10	11.30-14.20	9.20-12.20	3.00	3.03
	11	14.35-18.00	12.20-15.20	3.00	2.98
09/11/95	12	0815-11.15	15.20-18.18	2.98	2.98
13/11/95	13	09.40-13.10	18.18-20.98	2.80	2.76
	14	14.42-18.20	20.98-24.02	3.04	3.04
14/11/95	15	07.47-13.50	24.02-27.32	3.30	3.27
	16	14.21-17.14	27.32-30.27	2.95	2.93
	17	17.45-20.22	30.27-33.24	2.97	2.90
15/11/95	18	07.52-11.15	33.24-36.02	2.78	2.89
	19	11.51-14.00	36.02-37.87	1.85	1.72
	20	14.50-21.00	37.87-41.00	3.13	3.13
	21	21.30-01.30	41.00-43.70	2.70	2.74
20/11/95	22	15.30-20.14	43.70-46.70	3.00	3.04
21-11-1195	23	08.30-12.52	46.70-49.70	3.00	2.97
	24	15.00-19.02	49.70-52.70	3.00	3.06
22/11/95	25	08.25-13.25	52.70-55.72	3.02	3.00
	26	14.42-19.15	55.72-58.79	3.03	3.03
	27	21.35-22.35	58.75-59.45	0.70	0.73
23/11/95	28	08.25-13.10	59.45-62.45	3.00	3.08
	29	14.00-17.40	62.45-64.70	2.25	2.17
24/11/95	30	08.42-14.00	64.70-67.67	2.97	3.03
27/11/95	31	11.30-12.00	67.67-68.00	0.33	0.33
	32	14.30-19.45	68.00-71.07	3.07	3.05
28/11/95	33	08.25-11.58	71.07-74.10	3.03	3.05
	34	12.45-18.00	74.10-77.10	3.00	3.02
	35	18.55-21.05	77.10-78.30	1.20	1.18
29/11/95	36	08.05-13.45	78.30-81.20	2.90	2.93
	37	14.30-21.05	81.20-84.20	3.00	2.96
11/12/95	38	12.30-17.00	84.20-86.45	2.25	2.03
12/12/95	39	09.42-10.45	86.45-86.85	0.40	0.62
	40	11.45-18.40	86.85-89.90	3.05	3.03
	41	19.40-01.25	89.90-92.90	3.00	3.04
13/12/95	42	09.00-14.55	92.90-95.95	3.05	3.00
	43	15.10-19.00	95.95-98.95	3.00	3.00
14/12/95	44	09.10-13.55	98.95-102.00	3.05	3.02
	45	15.23-19.10	102.00-103.80	1.80	1.83
15/12/95	46	08.25-12.50	103.80-105.70	1.90	1.89
18/12/95	47	14.30-20.00	105.70-108.70	3.00	3.05
19/12/95	48	09.48-14.35	108.70-111.73	3.03	3.01
	49	15.40-16.20	111.73-112.03	0.30	0.27
	50	17.47-23.05	112.03-114.39	2.36	2.36
20/12/95	51	14.48-20.45	114.39-117.42	3.03	3.03
	52	22.25-05.25	117.42-120.49	3.07	3.06
21/12/95	53	09.28-16.05	120.49-123.49	3.00	3.02
	54	17.25-00.36	123.49-126.54	3.05	3.05
22/12/95	55	07.45-16.05	126.54-129.00	2.46	2.46
	56	17.48-01.50	129.00-131.80	2.80	2.80

SELLI LEVEL (u. Lower Aptian)



Upper Barremian

Lower Barremian



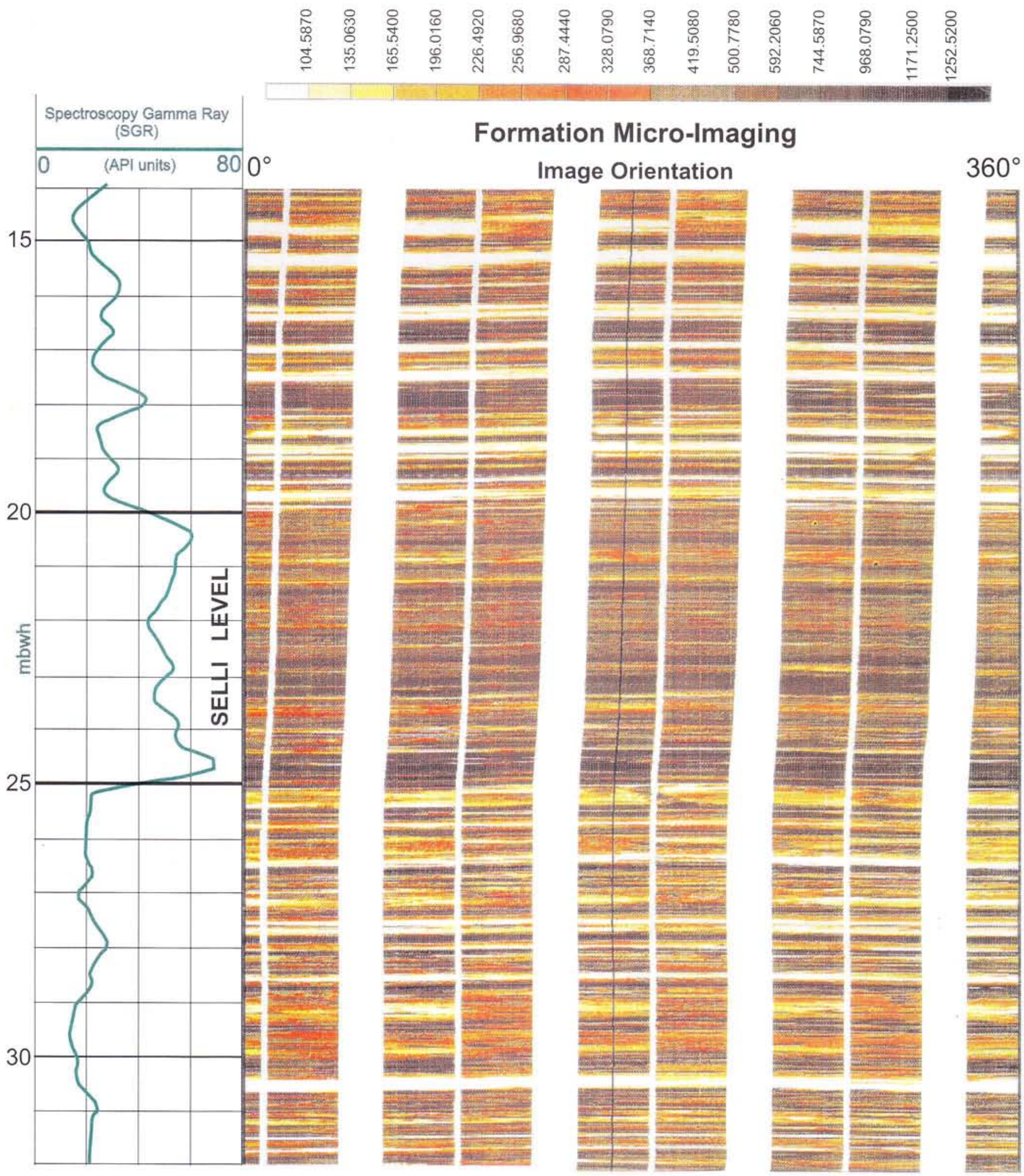


Fig. 3 - FMI (Formation Micro-Imaging) record and SGR (Spectroscopy Gamma Ray) of the upper part of the Cismon borehole (14 through 32 mbwh). The FMI display shows the micro-resistivity of the formation with a relative color scale: darker colors indicate relatively higher resistivities and lighter colors indicate relatively lower resistivities. The Selli Level is marked by higher SGR values and generally higher micro-resistivity. High-frequency fluctuations in the FMI record suggest strong rhythmicity in the Selli Level as well as in the limestones above and below.

Fig. 2 - (facing page) Photographs of selected cores recovered at Cismon. Core 14 (20.98 - 24.02 mbwh) penetrated the Selli Level, Core 18 (33.24 - 36.02 mbwh) recovered Upper Barremian limestones and Core 33 (71.07 - 74.10 mbwh) recovered Lower Barremian limestones.

broken fragments, but the quality of all the cores below that level is generally excellent (Fig. 2).

Recovery was essentially 100% throughout the drilling. A few cm at most were missing in some of the cores. Other cores contained slightly more than 100% recovery (Tab. 1). This is possible because the amount of penetration estimated by the drillers can be slightly in error, and when broken fragments were reassembled on the description table, they sometimes occupied more space than in their original, unfractured state. The cores were described lithologically, photographed, packaged, labled and boxed for shipment by truck to Milano (about 300 km from the drillsite). Coring was completed on 22 December 1995.

Reaming Operations.

It was necessary to enlarge the hole by reaming in order to accomodate the Formation Micro-Imaging logging tool (FMI) that required a minimum 16.5 cm (6.5 in) hole diameter. Consultation with the drilling engineer concluded with the decision to ream the hole open to 20.3 cm (8.0 in) in order to allow for potential swelling of clay-rich stata or for broken, partially-displaced rock fragments protruding from the borehole wall. Two different reaming tools were used. For the upper part of the hole a nested set of three saw-toothed bits expanded the hole from 13.1 cm to 14.0 cm, then to 16.8 cm and finally to 20.3 cm. This tool reamed a very clean, smooth surface, but proceeded even slower than the coring, making about 6 m of penetration per day. Thus, on 14 November 1995 it was decided to design a new reaming tool. This eventually consisted of a tri-cone bit with a one-meter driving pipe (tubo guida) that preceeded the tri-cone cutting surfaces down the hole and maintained the same hole deviation and azimuth as was originally cored. This tool was used to ream the lower part of the hole at about one meter per hour.

Reaming reached 84.2 meters below well head (mbwh) by 22 December 1995 when the job was shut down for the Christmas holiday and resumed on 30 December 1995. It was completed on 16 January 1996. The bottom of the hole was finished in the following manner so that the hole can be re-entered for potential future coring. Coring the hole with a 13.1 cm diameter bit terminated at 131.80 mbwh, while reaming with the 20.0 cm diameter tri-cone bit terminated at 130.95 cm mbwh. Thus, a 0.85 m-deep "rat hole" is present below the maximum reaming depth to guide any potential future coring efforts using 13.1 cm diameter bits.

Logging Operations.

Logging with the Schlumberger MAXIS system was conducted on 17-18 January 1996. The upper logging shive, usually suspended in the upper derrick on normal logging operations, was suspended from a 10-ton crane boom rented seperately for this operation. Three logging runs using different sets of tools were accomplished on 17 January and FMI logging was done on 18 January. The general characteristics of these logging tools are described in a subsequent section.

On 17 January the first tool string consisted of the Phasor Dual Induction-Spherically Focussed Resistivity tool (DITE-SFR) and the Natural Gamma Ray tool (NGT). The second tool string consisted of the Short-Spaced or Array Sonic tool (SDT) and the NGT. The third tool string consisted of the Integrated Porosity-Lithology tool string (IPLT) that combined the Accelerator Porosity Sonde (APS), the Hostile Environment Natural Gamma Ray Sonde (HNGS) and the Litho-Density Sonde (LDS). A full "production" run and a partial repeat run were made with each of the three tool strings.

The Formation Micro-Imaging tool (FMI) failed on 17 January and replacement parts were ordered for overnight delivery by truck. The truck arrived at 0730 on 18 January and the FMI and NGT were assembled into the final tool string. Three full runs were made in the borehole. During the last run, full pressure was applied to the resistivity pads to push through the mud cake on the borehole wall. This was successful and appears to be the best of the three data sets (Fig. 3).

Lithostratigraphy and chronostratigraphy of the Cismon core.

The Cismon core was drilled to a total depth of 131.8 mbwh. The formation dips to the north, with relatively uniform dips of 17-22 degrees from 0 to 60 mbwh, and generally steeper, more variable dips below 60 mbwh. Detailed sedimentological analyses including carbonate content, dominant colors determined with the Munsell Color Chart, occurrence of radiolarian-rich levels, "black shales" and chert allowed us to distinguish 8 units (Fig. 4). From stratigraphic top to bottom the unit sequence, below 2 meters of rubble, is as follows:

Unit 1 (2 to 3.10 mbwh): Light grey limestones with frequent, 2-8 cm thick, dark grey to black clayey marlstones ("black shales"). Common dark grey wispy burrows.

Unit 2 (3.10 to 8.25 mbwh): Variegated pinkish grey, light reddish grey and dark reddish brown limestones, alternating with reddish brown marlstones, 1 to 7 cm thick. Three "black shales", 3 to 6 cm thick, are present in the uppermost part of this unit (3.10 to 3.785 mbwh). Reddish brown chert nodules occur between 6.82 and 6.91 mbwh.

Unit 3: (8.25 to 19.84 mbwh): Light grey limestones with abundant grey to dark grey trace fossils (mainly *Chondrites*, *Planolites* and *Teichichnus*). Frequently interbedded dark grey marlstones, 2 to 6 cm thick. Regularly spaced radiolarian calcarenitic horizons, 2 to 6 cm thick and grey in color. Discrete pyrite crystals at 13.10, 13.30 and 14.75 mbwh. From 15.65 mbwh downwards lithotypes display darker colors and radiolarian horizons become more frequent. "Black shales" occur at 18.35 and 19.52 mbwh.

Unit 4: Selli Level (19.84 to 25.03 mbwh): Marly limestones, grey, dark grey and very dark grey in color with abundant radiolarian calcarenitic horizons, 3 to 7 cm thick, and grey in color. Pyrite replacing radiolarian tests was observed between 21.25 and 22.00 and 24.05 and 24.40 mbwh. "Black shales", 3 to 8 cm thick, are frequent from unit top to 21.55 mbwh and between 23.55 and 25.03 mbwh, but are absent in the middle part of the unit.

Unit 5 (25.03 to 79.09 mbwh): From top to 76.49 mbwh light grey limestones with common grey to dark grey trace fossils (*Chondrites*, *Planolites* and *Teichichnus*). Abundant radiolarian calcarenitic horizons and lenses, 2 to 10 cm thick, grey in color. Frequent, grey to olive grey marlstones, 1 to 3 cm-thick. From 30.50 mbwh downwards, very dark grey chert nodules associated with radiolarian horizons and lenses. Between 53.60 and 55 mbwh chert nodules are pinkish grey in color. Very dark grey chert layers at 55.81-55.95, 59.30-59.34, 60.10-60.13, and 67.67-67.74 mbwh. Two discrete "black shales" at 67.72-67.80 and 70.52-70.60 mbwh.

In the lowermost part of this unit we distinguished the Faraoni Level equivalent: white to light grey pseudonodular limestones with coalescing irregular stylolites (76.49 to 77.12 mbwh) and a "black shale" level (76.12 to 76.16 mbwh).

From 77.16 to 79.09 mbwh light grey to grey limestones with interbedded 1 to 4 cm thick marlstones, dark grey in color. Common radiolarian calcarenitic lenses and horizons, 3 to 5 cm thick and grey in color. Very dark grey chert nodules associated with radiolarian beds. An aptycus occurs at 77.90 mbwh.

Unit 6 (79.09 to 88.91 mbwh): Pale red to reddish grey pseudonodular limestones with common, irregular and coalescing stylolites. Weak red marly seams. Radiolarian calcarenitic nodules and beds, 2 to 5 cm thick, reddish grey in color. Dark reddish grey to reddish brown chert nodules associates with radiolarian horizons. A very nodular facies, similar to the "Ammonitico Rosso" was observed between 86.05 and 86.35 mbwh; whereas limestones in the bottom part of the unit (88 to 88.91 mbwh) do not display a nodular facies.

Unit 7 (88.91 to 111.50 mbwh): Light grey limestones with common dark grey marlstones, 1 to 3 cm thick. Radiolarian calcarenitic nodules and horizons, 2 to 6 cm thick and grey in color. Rare, very dark grey chert nodules associated with radiolarian horizons.

Unit 8 (111.50 to 131.80 mbwh): Light grey limestones with common dark grey marlstones, 1-4 cm thick. Radiolarian calcarenitic nodules and horizons, 2 to 6 cm thick and grey in color. Common, very dark grey chert bands and lenses, 4 to15 cm thick.

The cored sequence is traditionally attributed to the Biancone Formation (Channell et al., 1979). However, the upper 30.5 meters are characterized by a marly facies similar to the Scisti a Fucoidi of the Umbria-Marche Basin and, following Claps & Masetti (1994), are here attributed to the Scaglia Variegata. The underlying units 4 through 8 belong to the typical Biancone, that is the local equivalent of the Maiolica Formation. Although a lithostratigraphic subdivision of these formations has never been formalized, the top of the Biancone is placed at the youngest black chert nodule (30.50 mbwh) following the procedure adopted for the top of the Maiolica in the Umbria-Marche Basin (Coccioni et al., 1987).

The distinctive red unit 2 was attributed to the *Globigerinelloides algerianus* planktonic foraminiferal Zone and *Rhagodiscus angustus* nannofossil Zone in the Cismon outcrop (Erba, 1994) and is Late Aptian in age. The Selli "black shales" are dated as late Early Aptian (see Erba, 1996 for discussion) and the Lower/Upper Aptian boundary is tentatively located above this level in the lower part of unit 3. Following the recommendation of the Aptian working group (Erba, 1996), the Barremian/Aptian boundary is placed at 30.75 where the base of magnetic chron M0 was identified (J.E.T. Channell, pers. comm., 1997).

In addition to the Selli Level, other distinctive lithologic intervals can be used as regional markers. In unit 5, the two prominent "black shales" at 67.72-67.80 and 70.52-70.60 mbwh, respectively, are correlatable to similar lithotypes occurring in the uppermost part of magnetic chron M3 at the Breggia section (Channell et al., 1993) and dated with ammonites to the *Holcodiscus caillaudi* zone (Rieber, 1977; Channell et al., 1995). Therefore, the Lower/Upper Barremian boundary can be drawn slightly above these "black shales".

The white to light grey pseudonodular limestones (76.49 to 77.12 mbwh) and the underlying "black shale" (76.12 to 76.16) in the lowermost part of core 34 and top of core 35, are correlatable with part of the Faraoni Level originally defined in the Umbria-Marche Basin (Cecca et al., 1994a). The Faraoni Level equivalent was recognized in two sections close to the Cismon drill site (Cecca et al., 1996). The pseudonodular limestones in core 34 correspond to the "Guide-bed" and the underlying "black shale" in cores 34 and 35 is equivalent to the "Lower Interval". Rich ammonites faunas found in the "Guide bed" in the Cismon area indicate the uppermost Hauterivian *Pseudothurmannia catulloi* subzone (*Pseudithurmannia angulicostata* zone) and, consequently, the Hauterivian/Barremian boundary is placed just above the Faraoni Level equivalent. Based on bio-magnetostratigraphy of the Faraoni Level, the lowermost part of unit 5 should correspond to magnetic chron M4 and the upper part of *Lithraphidites bollii* nannofossil zone (Cecca et al., 1994b, 1996).

Unit 6 consisting of reddish-pinkish limestones is a peculiar facies recognized in other sections of the Southern Alps (Bosellini et al., 1978; Channell et al., 1979, 1993; Cecca et al., 1996). Where bio-magnetostratigraphy is available, the pink interval limestones are consistently attributed to magnetic chrons M5 and M6 and to the *Lithraphidites bollii* nannofossil zone.

Preliminary paleomagnetic data (J.E.T. Channell, pers. comm., 1997) suggest that the bottom part of the Cismon core is attributable to magnetic chron M9 and therefore the oldest recovered sediments are early Late Hauterivian in age. The cored sequence extends from the Upper Aptian down to the lower Upper Hauterivian (about 117-130 Ma). It appears to be complete and continuous; minor faults are reported on the lithologic log (Fig. 4) where limestones are heavily fractured and contain calcite veins. However, repetition or gaps of sediments are not evident.

The Standard Gamma Ray (SGR) record obtained on one of the Natural Gamma Ray (NGT) tool runs is shown on Figure 4. The SGR is the summed spectral responses from potassium, uranium and thorium. Potassium and thorium are the primary radioactive elements present in clays, while the presence of uranium is commonly associated with organic matter. Carbonates usually display a low gamma ray signature. Thus, this record presents higher SGR values when sensing the black shale intervals, and lower values when sensing the carbonate intervals in the borehole.

Units 1-3 show generally higher SGR values than units 5-8, indicating more clay/organic matter above unit 4 than below it. Unit 4 (the Selli Level) obviously has the largest positive SGR anomaly. It appears that this anomaly is larger at the top and bottom of unit 4 than within it, a signature that appears on all the natural gamma ray logs. Near the base of unit 5 are three shorter-period, lower-amplitude positive anomalies, each associated with a "black shale" interval. The lowest of these is the basal "black shale" of the Faraoni Level equivalent (lowermost unit 5). The remainder of the record is unremarkable, except for a slight, linear increase in the average background level from the bottom of the hole up to the top of unit 5.

Logging tools.

Full descriptions of these tools, including applications, limitations, environmental effects and log presentations can be found at the World Wide Web site of the Lamont Doherty Earth Observatory's Borehole Research Group (http://www.ldeo.columbia.edu/BRG/). The following physical principles and measuring techniques have, in general, been abstracted from those descriptions.

The Phasor Dual Induction-Spherically Focussed Resistivity tool (DITE-SFR) provides measurements of three resistivity values: IDPH (deep induction), IMPH (medium induction) and SFLU (shallow, spherically focussed induction). In most rocks, the solids are orders of magnitude more resistive than the pore fluids, so the resistivity is controlled mainly by the conductivity of the pore fluids and by the porosity of the entire rock. The induction sonde consists of a series of transmitter and receiver coils mounted on the sonde axis. The alternating current of constant intensity sent through the transmitter coil produces an alternating magnetic field which in turn induces currents in the formation around the borehole. Because the transmitted signal is of constant frequency and amplitude, the currents in the formation are directly proportional to the formation conductivity. These currents produce a magnetic field which induces a voltage back into the receiver coil, which is proportional to the currents in the formation, and therefore to its resistivity. In homogeneous formations the average radial depth of investigation is about 1.5 m (5 ft) and 76 cm (2.5 ft) for the deep and medium curves respectively, and 38 cm (1.25 ft) for the SFLU. These are also reasonable estimates of the vertical resolution of these tools.

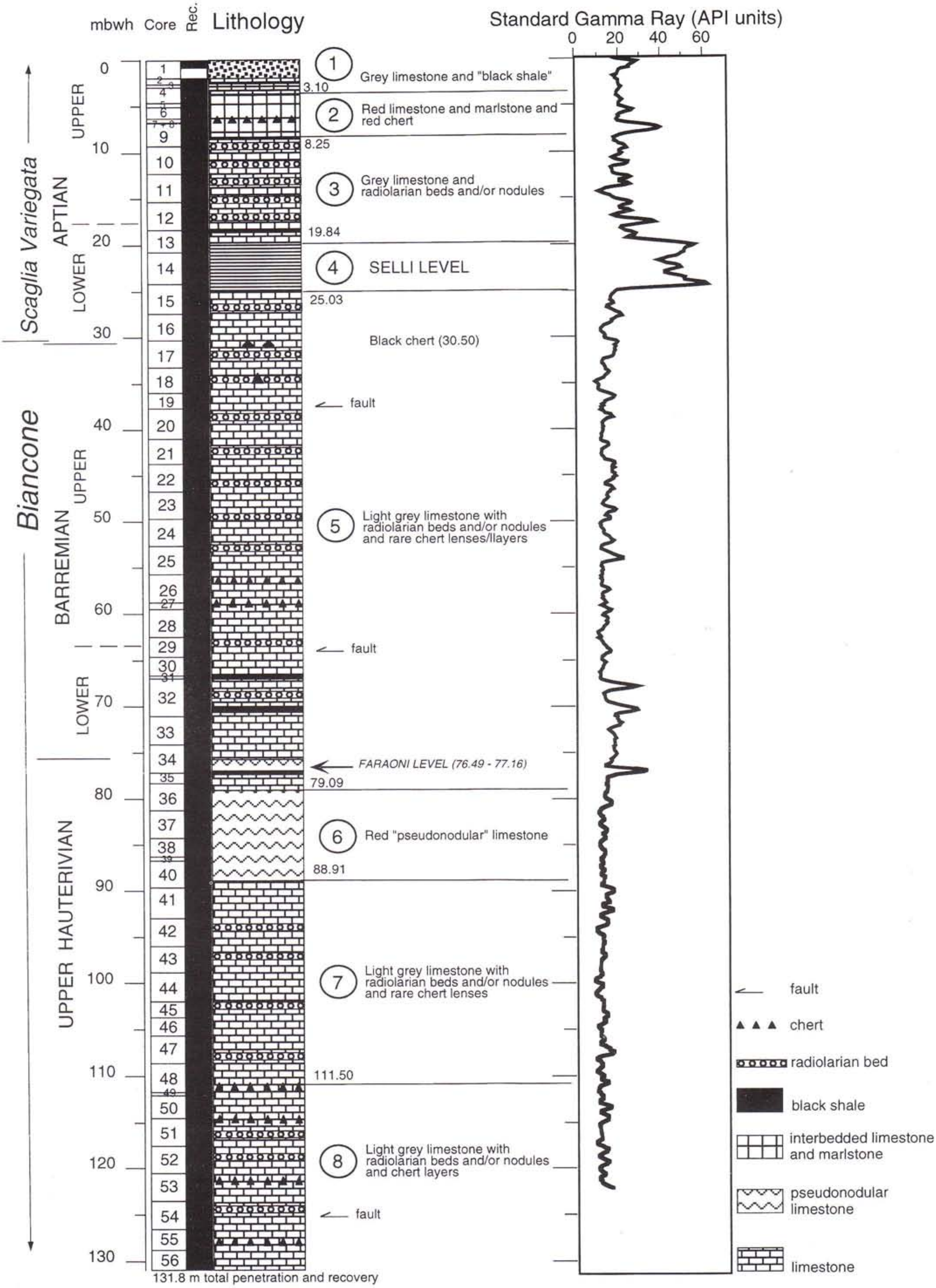
The Natural Gamma Ray tool (NGT) utilizes a sodium-iodide detector to measure the natural gamma ray radiation of the formation and 5-window spectroscopy to resolve the detected spectrum in the three most common natural components. The high-energy part of the spectrum is divided into three energy windows, each covering a characteristic peak of the three radioactivity series. The final outputs are the total gamma ray, a uranium-free measurement, and the concentrations of potassium, thorium, and uranium. The vertical resolution on the log is about 46 cm (1.5 ft).

The Short-Spaced or Array Sonic (SDT) obtains direct measurements for shear, compressional, and Stoneley wave values in fast formations such as those found in the Cismon well. The multireceiver sonic tool, with its linear array of eight receivers, provides more spatial samples of the propagating wavefield for full wave-form analysis than the standard two-receiver tools.

The Integrated Porosity-Lithology Toolstring (IPLT) combines new generation photoelectric density, neutron porosity, and natural gamma ray spectrometry sensors into one modular tool to provide formation porosity and lithology information. The heart of the IPLT is the Accelerator Porosity Sonde (APS) which uses a powerful electronic neutron source (a minitron) instead of a chemical source. The large neutron source yield allows epithermal neutron measurements and detector shielding, resulting in porosity values that are less influenced by environmental conditions. Five detectors provide information for porosity evaluation, gas detection, shale evaluation, improved vertical resolution, and borehole corrections. The vertical resolution on this log is about 30 cm (1 ft).

The Litho-Density Sonde (SDT) measures energy flux at fixed distances from a gamma-ray source. Formation density is extrapolated from this energy flux by assuming the atomic weight of most rock-forming elements is approximately twice the atomic number. A

Fig. 4 - Lithologic log, preliminary chronostratigraphy and Standard Gamma Ray of the Cismon APTICORE.


mbwh
Core
Rec.
Lithology
Standard Gamma Ray (API units)
0 20 40 60
Scaglia Variegata
Biancone
UPPER
APTIAN
LOWER
UPPER
BARREMIAN
LOWER
UPPER HAUTERIVIAN
1 Grey limestone and "black shale"
3.10
2 Red limestone and marlstone and red chert
8.25
3 Grey limestone and radiolarian beds and/or nodules
19.84
4 SELLI LEVEL
25.03
Black chert (30.50)
fault
5 Light grey limestone with radiolarian beds and/or nodules and rare chert lenses/llayers
fault
FARAONI LEVEL (76.49 - 77.16)
79.09
6 Red "pseudonodular" limestone
88.91
7 Light grey limestone with radiolarian beds and/or nodules and rare chert lenses
111.50
8 Light grey limestone with radiolarian beds and/or nodules and chert layers
fault
131.8 m total penetration and recovery
fault
chert
radiolarian bed
black shale
interbedded limestone and marlstone
pseudonodular limestone
limestone

photoelectric-effect index is also provided because photoelectric absorption occurs below 150 keV. This is almost independent of porosity, and can be used directly as an indication of matrix lithology. The vertical resolution on this log is about 38 cm (1.25 ft).

The Formation Micro-Imaging sonde (FMI) consists of four orthogonally-mounted imaging pads. Each contain 32 microelectrodes spaced 2.5 mm apart and arranged in two diagonally-offset rows. These pads are pressed into direct contact with the borehole wall during the recording. The tool works by emitting a focussed current from the 4 pads into the formation. The current intensity variations are sampled at each button every 2.5 mm (0.1 in). The FMI works exactly like the better-known Formation Micro-Scanning sonde (FMS) except that the FMI has twice as many microelectrodes on pads that are twice the angular size of the FMS, so the angular coverage of the FMI is twice the coverage of the FMS. In the 20-cm diameter hole at Cismon, 82% of the borehole wall was imaged on each logging run. In smooth boreholes with very homogeneous bedding, the depth of investigation is about 25 cm (10 in). The vertical resolution on this log is about 0.5 cm (0.2 in).

Conclusions.

Freshly cored material and logs from the Cismon drill site provide the most complete archive of the Hauterivian-Aptian interval at low latitudes. Detailed, multidisciplinary studies are applied to point out high and low frequency changes in the lithologic, paleontologic, geochemical records. The Cismon APTICORE will represent a "reference section" for this period of extreme climate. Integrated stratigraphy of the section will result in the first coherent scheme derived from direct calibration of bio-, magneto-, chemo- and cyclostratigraphy for the Hauterivian-Aptian interval.

Global anoxic events, isotopic excursions of carbon and strontium, fluctuations in abundance and diversity of planktonic communities, palynofacies, distribution of major and minor elements, composition of clay, will be documented for understanding of the causal linkages among various processes that led to the mid-Cretaceous "greenhouse" climate.

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REFERENCES

Arthur M. A., Jenkyns H. C., Brumsack H. J. & Schlanger S. O. (1990) - Stratigraphy, geochemistry, and paleoceanography of organic carbon-rich Cretaceous sequences. In *Cretaceous Resources, Events and Rhythms* edited by R. N. Ginsburg and B. Beaudoin, pp. 75-119, Kluwer Academic Publishers, Dordrecht.

Bosellini A., Broglio Loriga C. & Busetto C. (1978) - I bacini cretacei del Trentino. *Riv. It. Paleont. Strat.*, v. 84, pp. 897-946, Milano.

Bralower T. J. (1987) - Valanginian to Aptian calcareous nannofossil stratigraphy and correlation with the upper M-sequence magnetic anomalies. *Mar. Micropaleontol.*, v. 11, pp. 293-310, Amsterdam.

Bralower T. J., Arthur M.A., Leckie R.M., Sliter W.V., Allard D.J. & Schlanger S.O. (1994) - Timing and paleoceanography of oceanic dysoxia/anoxia in the late Barremian to early Aptian. *Palaios*, v. 9, pp. 335-369, Tulsa.

Cecca F., Marini A., Pallini G., Baudin F. & Bégouen V. (1994a) - A guide-level of the uppermost Hauterivian (Lower Cretaceous) in the pelagic succession of Umbria-Marche Apennines (Central Italy): the Faraoni Level. *Riv. It. Paleont. Strat.*, v. 99, pp. 551-568, Milano.

Cecca F., Pallini G., Erba E., Premoli Silva I. & Coccioni R. (1994b) - Hauterivian-Barremian chronostratigraphy based on ammonites, nannofossils, planktonic foraminifera, and magnetic chrons from the Mediterranean domain. *Cretaceous Res.*, v. 15, pp. 457-467, London.

Cecca F., Galeotti S., Coccioni R. & Erba E. (1996) - The equivalent of the "Faraoni Level" (uppermost Hauterivian, Lower Cretaceous) recorded in the eastern part of the Trento Plateau (Venetian Soutern Alps, Italy). *Riv. It. Paleont. Strat.*, v. 102, pp. 417-424, Milano.

Channell J. E. T., Lowrie W. & Medizza F. (1979) - Middle and Early Cretaceous magnetic stratigraphy from the Cismon section, northern Italy. *Earth Planet. Sci. Lett.*, v. 42, pp. 153-166, Amsterdam.

Channell J. E. T., Erba E. & Lini A. (1993) - Magnetostratigraphic calibration of the late Valanginian carbon isotope event in pelagic limestones from northern Italy and Switzerland. *Earth Planet. Sci. Lett.*, v. 118, pp. 145-166, Amsterdam.

Channell J.E.T., Cecca F. & Erba E. (1995) - Correlations of Hauterivian and Barremian (Early Cretaceous) stage boundaries to polarity chrons. *Earth Planet. Sci. Lett.*, v. 134, pp. 125-140, Amsterdam.

Claps M. & Masetti D. (1994) - Milankovitch periodicities recorded in Cretaceous deep-sea sequences from the Southern Alps (Northern Italy). *Spec. Publs Int. Ass. Sediment.*, v. 19, pp. 99-107, Oxford.

Coccioni R., Nesci O., Tramontana M., Wezel C.F. & Moretti E. (1987) - Descrizione di un livello-guida "Radiolaritico - Bituminoso -Ittiolitico" alla base delle Marne a Fucoidi nell'Appennino Umbro-Marchigiano. *Boll. Soc. Geol. It.*, v. 106, pp. 183-192, Roma.

Erba E. (1994) - Nannofossils and superplumes: the Early Aptian nannoconid crisis. *Paleoceanography*, v. 9, pp. 483-501, Washington D.C.

Erba E. (1996) - The Aptian stage. *Bull. Inst. Royal Sci. Nat. Belgique*, Sc. de la Terre, v. 66 (suppl.), pp. 31-43, Brussels.

Herbert T.D. (1992) - Paleomagnetic calibration of Milankovitch cyclicity in Lower Cretaceous sediments. *Earth Planet. Sci. Lett.*, v. 112, pp. 15-28, Amsterdam.

Larson R.L., Fischer A.G., Erba E. & Premoli Silva I. (1993) - APTICORE-ALBICORE: A workshop Report on Global Events and Rhythms of the mid-Cretaceous. 4-9 October 1992, Perugia, Italy, 56 pp., Washington D.C.

Lini A., Weissert H.& Erba E. (1992) - The Valanginian carbon isotope event: a first episode of greenhouse climate conditions during the Cretaceous. *Terra Nova*, v. 4, pp. 374-384, Oxford.

Rieber H. (1977) - Eine Ammonitenfauna aus der oberen Maiolica der Breggia-Schlucht (Tessin/Schweiz). *Eclogae Geol. Helv.*, v. 70, pp. 777-787, Basel.

Weissert H. (1989) - C-isotope stratigraphy, a monitor of paleoenvironmental changes: A case study from the Early Cretaceous, *Surv. Geophys.*, v. 10, pp. 1-61.

Weissert H. & Lini A. (1991) - Ice Age interludes during the time of Cretaceous greenhouse climate?, in *Controversies in modern geology* (D. W. Muller, J. A. McKenzie, and H. Weissert Eds.), pp. 173-191, Academic Press, London.

Weissert H., McKenzie J. A. & Channell J. E. T. (1985) - Natural variations in the carbon cycle during the Early Cretaceous, in *The Carbon Cycle and Atmospheric CO_2: Natural Variations Archean to Present, Geophys. Monogr. Ser.*, vol. 32, edited by E. T. Sundquist and W. S. Broeker, pp. 531-545, AGU, Washington, D. C.